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# Statistical Characteristics Analysis of the Shear Line in the Qinghai-Tibet Plateau from 2000 to 2015

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**Abstract:** To investigate the characteristics of the plateau shear line and its relationship with precipitation in China, the Tibetan Plateau Vortex and Shear Line Yearbook are used to analyze the activity characteristics of the plateau shear line and the precipitation characteristics under the influence of the plateau shear line from 2000 to 2015. The results show that the source region of the plateau shear line mainly concentrates in the central and eastern part of Tibet, and the southwest of Qinghai Province, the high frequency region is located near Nagqu County. From 2000 to 2015, there are a total of 591 plateau shear lines and removed 87 times, the probability of removal is 14.72%. The plateau shear line appeared and removed mostly in the eastern part of the plateau. The activity degree of plateau shear line in the summer half year is much higher than that in winter half year. The period from May to September is the fastigium for the plateau shear line occurrence and the removal times, and it reaches the peak in August. The removal number of the plateau shear line in Sichuan Province is the largest, accounting for 65.52%. 63.45% of the plateau shear line's lifetime is within 12h. For the removing plateau shear line, 78.16% of its lifetime is within 24 ~ 36h. The life history of the removing shear line is generally longer than non-removing shear line. What has the largest influence in the plateau shear line removal in the system is the westerly trough. The eastern removing shear line will lead to a wider range of precipitation and greater precipitation intensity than non-removing.

**Keywords:** meteorology; plateau meteorology; plateau shear line; statistical characteristics; influence system; precipitation

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## 1 Introduction

Shear line of Tibet Plateau is special weather system formed under unique plateau geographical environment. It is also an important weather system affecting rainfall in plateau area<sup>[1]</sup>. The plateau shear line affects not only the climatic change in plateau area, but also the vast area that downstream of the plateau<sup>[2]</sup>. Low vortex and shear line eastward moving from plateau have relatively great impact on rainfall of southwest and eastern China. In summer, rainstorm, flood, mud-rock flow, landslide etc., frequently occur in western China, which to a great extent, is related to plateau low vortex, plateau shear line and plateau weather system<sup>[3]</sup>. In winter and spring, due to activity of

plateau shear line, heavy snow happens in eastern part of plateau and surrounding area, which leads to snow disaster in pasturing area<sup>[4]</sup>. Therefore, analyzing and researching the background circulation field where plateau shear line happens and develops, the interactions as well as impact on weather changes when plateau shear line system interacts with different weather systems, revealing influencing mechanism of plateau shear line system over rainstorm will have profound influence on weather forecast in plateau and neighbouring regions in China<sup>[5]</sup>. Meanwhile, it has played a substantial role in preventing flood disaster in summer and heavy snow in winter and spring. In addition, life and property safety of Chinese have been greatly guaranteed.

Study on Plateau shear line dates back to early 1960s. First of all, Luo Siwei made a comprehensive analysis of the causes of the shear line in the eastern plateau in winter<sup>[6]</sup>, in the following years, the study of plateau shear line has been carried out in a comprehensive way. It

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is generally acknowledged that plateau shear line includes the quasi-east-west and quasi-stationary transverse shear line as well as the quasi-south-north moving vertical shear line; occurrence of plateau transverse shear line doubles that of plateau vertical shear line; while shear line generally happens frequently in June and seems least active in September. Ye Duzheng pointed out that the shear line will develop and move out of the plateau when the shallow system in the plateau boundary layer meets the suitable high altitude conditions in 1979. Hereafter, the first and second Tibet-Plateau Meteorological Science Test have been conducted. The second experiment pays more attention to research on dynamic characteristics of plateau shear line, which becomes one of the major breakthroughs achieved by China in Plateau Meteorology research. In the experiment, Wang Wen, Zhang Xiaoling etc.<sup>[7]</sup> pointed out that instability of two-dimension nonlinear convection well describes role of shear line in process of eastward-stretching and southward-moving as well as the close relationship between formation, development of shear line and generation of plateau local vorticity center and vorticity zone. Meanwhile, Yu Shuhua etc.<sup>[5]</sup> indicate that there is some difference in kinetic energy budget of conditioning tank and shear line during plateau activity. Plateau shear line is one of the main reasons for enhanced sudden rain-storm in west Sichuan Basin. He Guangbi etc.<sup>[8]</sup> pointed out after research that transverse shear line is in relatively warm-wet regions. Its converging ascending motion coincides with positive vorticity zone. Besides, data of 1969–1976<sup>[9]</sup>, 1998–2004, 2000–2007<sup>[5]</sup>, 2007–2010<sup>[10]</sup> are respectively utilized by Tibet-Plateau Meteorology Research Lhasa Group, Li Yueqing, et al.<sup>[11]</sup>, to analyze law of activity of plateau shear line and they point out that compared with the plateau shear line moving eastward from the plateau, the shear line disappears in situ at last is more obvious; it also has an impact on changes of weather in the plateau area when the plateau shear line is mainly maintained on the main area of the plateau, and it mainly affects the weather in the east of the plateau when the plateau shear line moves out of the plateau. In 2013, Yu Shuhua et al.<sup>[4]</sup> summarized impact of Tibet-Plateau shear line on China rainfall in recent 13 years and pointed out that plateau shear line has increasing impact on scope and intensity of rainfall in plateau and other areas of China as activity time grows in summer.

At present, although the meteorologists have made a load of researches on the plateau shear line, the researches on the impact of the occurrence and development of plateau shear line on the precipitation in plateau and the southwestern region are still relatively weak<sup>[12]</sup>. From the above study, it can also be seen that the statistical years of the plateau shear line is not continuous or there is a lack of statistical results of recent years, as well as several questions that need to be solved by statistical analysis, including what areas are mainly influenced by the plateau shear line in our country? What are the characteristics of its life history? What systems affect the plateau shear line and make it move from the plateau? What areas do the move mainly focus on? The paper uses the "Yearbook of Vortex Shear Line in Qinghai-Tibet Plateau" compiled by the Meteorological Research Institute of Chengdu Meteorological Administration to make statistics on the plateau shear line's occurrence and development characteristics, temporal variation characteristics and precipitation characteristics under its influence from 2000 to 2015, and conduct a comparative analysis of two heavy rain cases in July 2010 and August 2012, so as to provide a reference for such a weather system.

## 2 Data and Method

### 2.1 Research data

(1) "Yearbook of Vortex Shear Line in Qinghai-Tibet Plateau" compiled by the Meteorological Research Institute of Chengdu Meteorological Administration (2000–2015), hereinafter referred to as "Yearbook".

(2) China National Surface Meteorological Station's hourly precipitation data, conventional 6 hours upper air observation data from July 2010 to August 2012.

### 2.2 Methods

In order to facilitate the description of the activity characteristics of the plateau shear line in the statistical analysis, the following definitions are given:

Plateau shear line<sup>[13]</sup>: it is reflected in the Qinghai-Tibet Plateau on the 500 hPa isobaric surface, the temperature gradient is small, and the length of convergence line of three stations or two stations with opposite wind direction is more than 5 longitudes / wefts.

Plateau East ( West) shear line: according to the different location of the plateau shear line, the shear located in east ( west)  $92.5^{\circ}\text{E}$  is called the plateau east( west) shear line.

Plateau horizontal and vertical shear lines: according to the different direction of the plateau shear line, it can be divided into quasi-east-west transverse shear line and quasi-north-south ambulant vertical shear line, and the included angle between plateau vertical shear line and longitude is smaller than  $45^{\circ}$ .

Plateau shear line is removed from the plateau: in the movement process of plateau shear line, more than half of the length is removed from the plateau area.

The move probability of plateau shear line: the ratio of the number of plateau shear line moves to the total number of plateau shear lines.

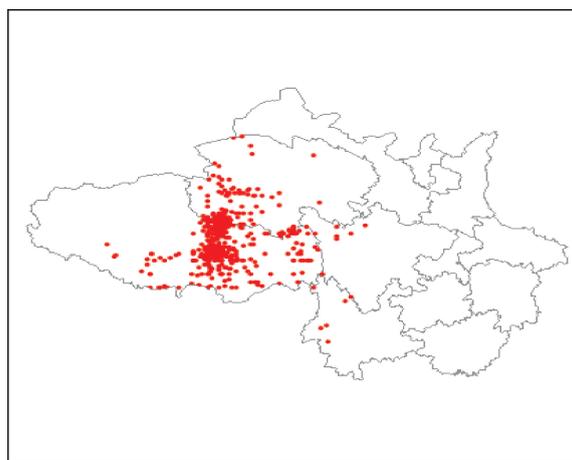
Winter and summer half year: the winter half year refers to the period from November to December of the year, as well as the January to April of the following year; summer half year refers to the period from May to October.

It selects two rainstorm processes in July 2010 and August 2012 affected by the plateau shear line, in which the shear line S1019, which affected the rainstorm in July 2010, was finally moved out of the eastern plateau in south-east direction; S1224 plateau shear line, which affected the rainstorm in August 2012, eventually moved to the south-eastern plateau, but not removed from the plateau. Based on the 1 hour precipitation data of the ground meteorological station and the NCEP reanalysis data, combined with the simultaneous observation data at the same time, it analyzes the differences between the process rainfall and the shear line path in the two rainstorm periods, and further analyzes the influence characteristics of shear line activity on the precipitation occurrence and development.

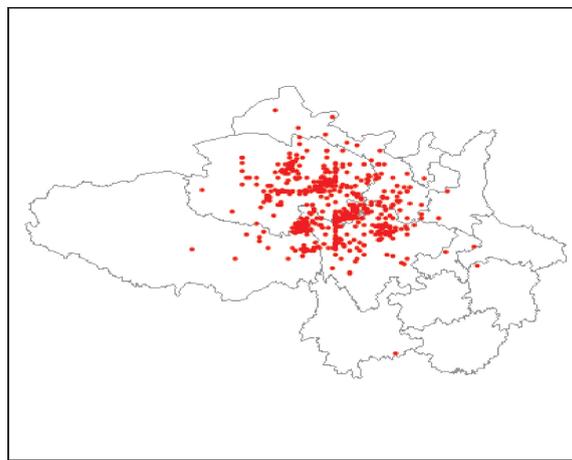
### 3 The activity characteristics of the plateau shear line

From 2000 to 2015, there were a total of 591 plateau shear lines. It can be seen from Fig. 1 (a) that the occurrence of plateau shear lines were concentrated in the central and eastern parts of Tibet and the southwest of Qinghai, where the high frequency region was located near Nagqu County. Figure 1(b) is the shear lines' end position distribution, which shows the end positions of the

plateau shear lines were concentrated in Sichuan Province, and the northernmost position that the shear line can reach was the north of Gansu, the easternmost was the west of Hunan, and the southernmost was the south of Yunnan, then we can see the moving path range of plateau shear line was larger, and the influence range was relatively wide for China, among which Sichuan Province was most affected.



(a) Source region



(b) End position

Figure 1 The distribution map of the plateau shear line from 2000 to 2015

Figure 2(a) indicates that the number of plateau shear lines in the past 16 years showed a slow increase in the number of times, of which a total of 578 plateau east shear lines appeared from 2000 to 2015, the year with the most times was 2009, 59 times; Plateau west shear line appeared a total of 13 times, the average annual occurrence was less than once. The probability of the plateau east shear line reached up to 97.80%, so the plateau shear lines were concentrated in the eastern part of the plateau.

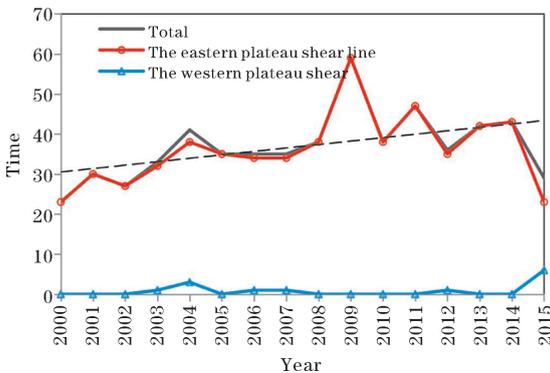
During 2000 to 2015, a total of 449 times plateau shear line in summer half years, accounting for 76.75%,

and 136 times in the winter half years, accounting for 23.25%, plateau shear line more appeared in the summer half year. As shown in Figure 2(b), the monthly variation of the plateau shear line showed the trend of increasing first and then decreasing, and the monthly average is 49.25 times. Plateau shear line in the month mainly concentrated in May to September, a total of 401 times, accounting for 67.85% of the year, among them, August was the most frequent month, which was 98 times. The monthly variation trend of occurrence number of the plateau east shear line was about the same as the total number of shear lines, namely, August was the most frequent month, while the plateau west shear lines did not appear in addition to February, April, November and December, the occurrence number of the rest of the months were more average, stable in 1 to 3 times. It can be concluded that the shear line in the summer half year was much more active than that in the winter half year, and the number of occurrence and development was also higher than that of the winter half year. Therefore, the summer half year, especially May to September, is the best time for studying shear line formation and movement, which is one of the more important reasons for causing summer precipitation in western China and the plateau.

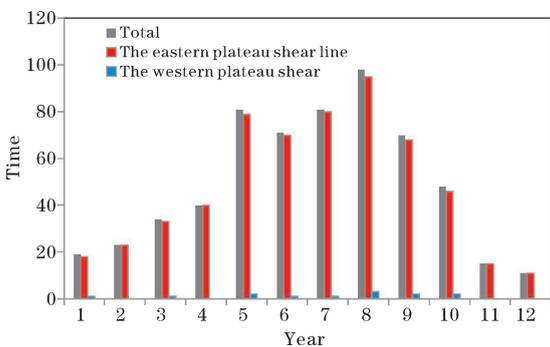
It can be seen from Fig. 1(b) that the activity range of the plateau shear line was wide and its removal was often accompanied by the rainstorm in the downstream area. Then what is the change in the number and probability of removal of the plateau shear line between 2000 and 2015? In the past 16 years, the plateau shear line was removed 87 times, and the probability of removal was 14.72%. Among them, the plateau east shear line was 86 times, accounting for 98.85%; the plateau west shear line was removed only once, which took place in 2003. Hence, the removal of the plateau shear line was also dominated by the east shear line. In terms of monthly removal change, similarly August was the month that had the most plateau shear line removals. Figure 3(a) shows the annual variation of the removal probability of the plateau shear line in different types and different periods. As shown in the figure, the removal probability of the shear line in the plateau east shear line reached the maximum in 2007 and 2009, respectively the removal probability were 44.12%, 45.76%, the removal probabilities of the remaining years were stable between 0% to 20%, of which the minimum value in 2014 was 2.33%; although the removal number of plateau west shear line was not much as that of plateau east shear line, the removal probability of the west shear line in 2003 reached 100%, meaning the plateau west shear line generated within the year had been all removed.

In the past sixteen years, the plateau shear lines were removed for 69 times in the summer half years, removed for 18 times in the winter half years, respectively were 79.31% and 20.69%. The removal probability of the plateau shear line in the summer half years was similar to that of the east plateau, presenting the "M" type changes, and maximum values also appeared in 2007 and 2009. In addition, only in 2000, 2007, 2008 and 2010, there were shear line removals in winter half years, and the removal probabilities were between 20% to 40%.

Figure 3(b) shows the change of the removal number of the plateau shear line in different regions, among which the removals of the plateau shear line in Sichuan Province was the largest, namely 57 times, accounting for 65.52% of the total number of times. In addition, in Gansu, Shanxi and Yunnan, there were 8 times, 7 times and 7 times removals, accounting for 25.29%; respectively there were 3 times in Hunan and Chongqing, and one time in Guizhou and Ningxia.

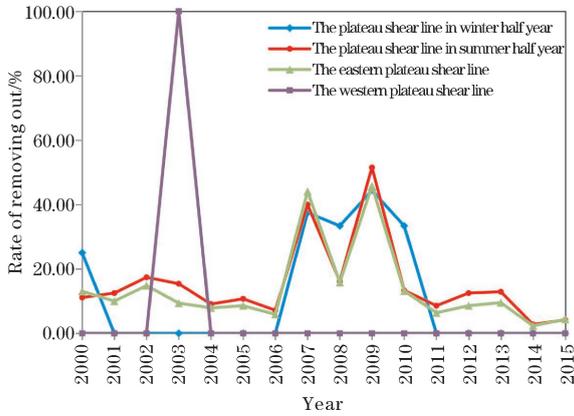


(a) Interannual change

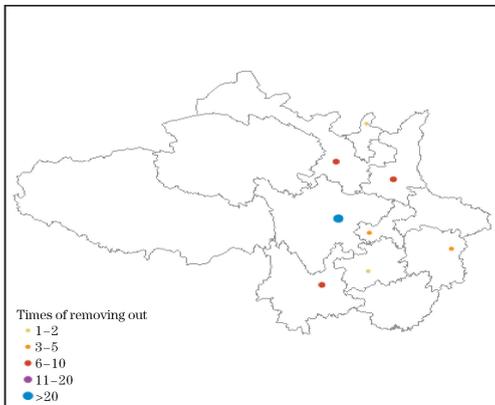


(b) Monthly change

Figure 2 The occurrence of the plateau shear line from 2000 to 2015



(a) The change of moving out rate



(b) The distribution of removal regions

Figure 3 The plateau shear line from 2000 to 2015

Table 1 is the main systems that impact the removal of the plateau shear line based on the Yearbook statistics, as shown in the table that there are a total of 10 categories in the main systems, of which the most influential system was westerly trough, influence rate reaches 28.74%, followed by Qinghai-Tibet high pressure and subtropical high, were 19.54% and 18.39% respectively.

Table 1 The major system influencing the moving out of Qinghai-Tibet Plateau shear lines from 2000 to 2015

The major influencing system	Times of plateau shear line removing out
Qinghai-Tibet high pressure	7
Subtropical high	16
North channel	4
River bend highpressure	3
Qinghai-Tibet high pressure	17
Westerly trough	25
Central Asia high pressure	3
Qinghai high pressure	3
Tibet high pressure	8
Iran high pressure	1
Total	87

The duration of the various types of shear lines is different. As shown in Fig. 4, when the life history was 12 h, the number of shear lines was the largest, a total of 375 times, accounting for 63.45%, while when the life history was 24 hours, a total of 149 times, accounting for 25.21%. With the gradual extension of the life history, the number of plateau shear line shows a decreasing trend, in which the longest duration of the plateau shear line was 72 h, only appeared one time, and the shear line was finally removed from the eastern part of the plateau. For the plateau east shear line which was not removed, its life history was similar to that of the plateau shear line. For the plateau east shear line which was removed, its life history was concentrated in the range of 24 ~ 36 h, a total of 68 removals in the eastern part of the plateau, accounting for 78.16%; plateau west only has one shear line removal, the duration was 60 h. It can be seen that the life history of the plateau shear line which was removed was generally longer than that of the plateau shear line which was not removed.

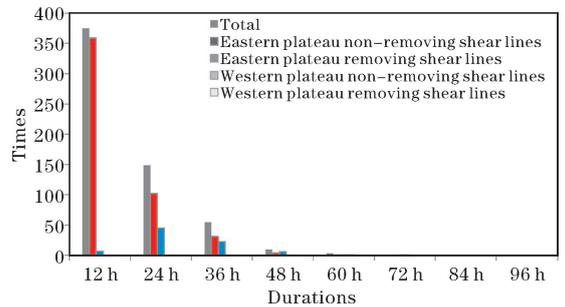


Figure 4 The distribution map of the plateau shear line's lifetime from 2000 to 2015

## 4 Influence of the plateau shear line on precipitation in China

The plateau shear line is inextricably linked to the causes of summer rainstorms in the plateau and its downstream areas. The plateau shear line provides heavy rainfall with sufficient water vapor conditions, flow field convergence, positive vorticity and ascending motion make precipitation can keep on developing and continuing. Figure 5 is the statistics on the number of precipitation extremes in different provinces from 2000 to 2015, in nearly 16 years, a total of 574 plateau shear line led to precipitation development, accounting for 97.12%, which can be seen the probability of precipitation process affected by

Plateau shear line was extremely high, cannot be ignored. As shown in Figure 5, the plateau shear line caused a wide range of precipitation, the northernmost position it can reach was Inner Mongolia, the southernmost was Yunnan, westernmost was Tibet, and easternmost was Anhui; the precipitation extremes are most appeared in Sichuan under the influence of shear line precipitation, a total of 195 times; followed by Tibet, a total of 149 times; in Qinghai, Yunnan, Gansu and Chongqing, the numbers of precipitation extremes were also more, respectively, 78, 53, 26 and 19 times; among them, precipitation extremes occurred in Tibet and Qinghai maintained in the range of 0.1 ~ 30 mm, which was related to its plateau climate characteristics. In Sichuan Province, the number of precipitation extreme above 300 mm under the influence of the plateau shear line was 3 times and the number above 200 mm was 14 times. During the 14 times precipitation above 200 mm, plateau shear line was removed out of the plateau for 9 times, accounting for 64.29%, of which the precipitation under the influence of S1019 plateau shear line which finally was removed in the southeast direction was largest, up to 315 mm. In combination with Fig. 5, it can be concluded that the precipitation in Sichuan Province was most affected by the plateau shear line. The shear line removed from plateau in eastward direction caused a wider range of precipitation and greater precipitation intensity.

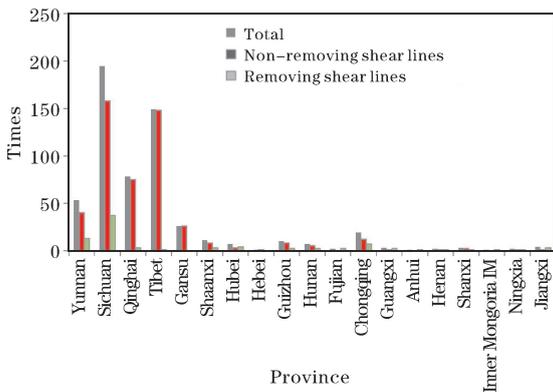


Figure 5 The distribution map of the precipitation extreme under the influence of plateau shear line from 2000 to 2015

In the following, the conclusions obtained from Fig. 5 are further illustrated by two heavy rain processes affected by the plateau shear line. From July 16 to 18, 2010, there was a heavy rainstorm in the eastern and east parts of the plateau. Precipitation mainly concentrated at 6 am on 17th to 6 am on 18th<sup>[15]</sup>, Fig. 6(a) is the rainfall during this

rainstorm, as shown the main areas affected by the heavy rainfall process were the eastern part of Tibet, the central and eastern parts of Sichuan, the southern part of Shanxi and the northwestern part of Yunnan, where the extreme precipitation appeared in junction between the northeastern part of Sichuan and the southern part of Shanxi, the rainfall had exceeded 300 mm. The shear line with stronger influence on the plateau precipitation was S1019, and its moving path is shown in Fig. 6(c). At 6 am on 16th, the plateau vertical shear line was generated in the south of Qinghai Province to the east of the plateau, and it gradually moved to the south; until 16 pm on 18th, it gradually turned to east-west shear line to continue move southward, and finally moved out of the plateau on the 18th.

Figure 6(b) shows the rainfall during the rainstorm process from August 17 to 19, 2012, showing the precipitation process in the south of Gansu, central Shanxi, central and northern Sichuan and southern Yunnan and southwestern Guangxi. The precipitation extreme area was located in central Sichuan and Guangxi southwest, rainfall reached 210 mm or more. It is worth mentioning that, during 21:00 17th to 18:00 18th, August, 2012, No. 1213 Typhoon Kaitak landed in China's Guangxi Dongxing, with constant west moving of Typhoon Kai-tak, western pacific subtropical high moved westward<sup>[16]</sup>, which caused large-scale high-intensity precipitation in the south of Guangxi to the south of Yunnan. Therefore, the extreme precipitation area was mainly caused by typhoon, which was not considered in this paper. So, the shear line, which has great influence on the heavy rainfall in Sichuan, Gansu and Shanxi, is the S1224 plateau shear line. At 20:00 on the evening of August 17th, it was generated from Gonghe to Nagqu in the eastern part of the plateau, plateau transection in east-west direction. At 19:00 on 19th, the plateau transection had the trend of turning to vertical, during 19:00 to 18:00, it had been completely turned to the north-south direction, and it disappeared in the eastern part of the plateau in on 20th, but did not move out of the plateau (Fig. 6d).

By comparing the similarities and differences between the two rainstorms, the two processes have caused more than 200 mm precipitation in Sichuan Province, and the precipitation extreme value in July 2010 have exceeded 300 mm. In addition, the influence of the heavy rain process in July 2010 was broader than the impact in August 2012, which is in line with the previous statistical conclusion.

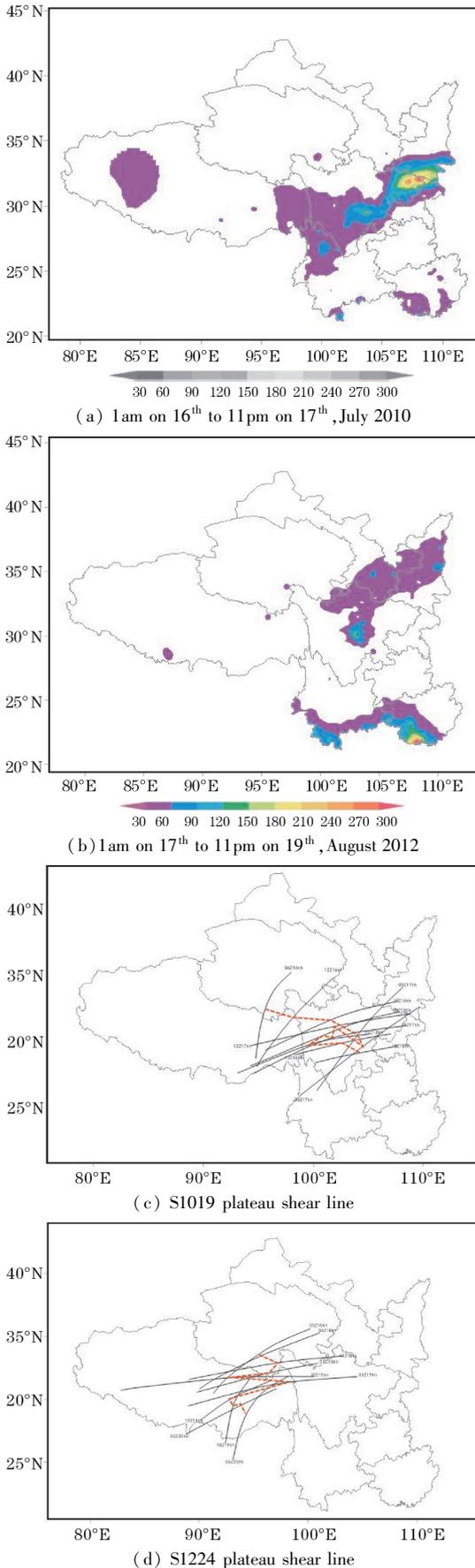


Figure 6 The distribution map of rainfall (Figure a to b, unit mm) and the moving path of shear lines (Figure c to d, red dashed line is the midpoint linking of the plateau shear lines at different times, which demonstrate the moving of the shear lines)

## 5 Summary

Based on the analysis of the occurrence and development characteristics, the time variation characteristics and the precipitation characteristics under the influence of the plateau shear line from 2000 to 2015, and combined with the analyses of the two heavy rainstorms in July 2010 and August 2012, the following conclusions are obtained:

(1) The source region of the plateau shear line was mainly concentrated in the central and eastern part of Tibet, and the southwest of Qinghai Province. Among them, the high frequency region was located near Nagqu County. The end point of the plateau shear line mainly appears in Sichuan Province, the northernmost position it can reach was the north of Gansu, easternmost was the west of Hunan, southernmost was the south of Yunnan.

(2) In the period from 2000 to 2015, there were a total of 591 times of plateau shear lines that showed a slow increase trend, and 578 times appeared in the eastern part of the plateau, 13 times in the west, and the plateau shear line appeared mostly in the eastern part of the plateau. A total of 87 times removals, including 86 times eastern removals and one time western removals, and most removals of the plateau shear line were east shear lines.

(3) The activity degree of plateau shear line in the summer half year was much higher than that in winter half year. In addition, the occurrence, development and removal times were also more than that in winter half year, and the period from May to September was the fastigium for the plateau shear line occurrence and the removal times, it reached the peak in August; plateau shear line removals were most happened in Sichuan Province, followed by Gansu, Shanxi, Yunnan.

(4) The life history of the shear line removed from the plateau was generally longer than the shear line that was not removed. The life history of the shear line removed from the plateau was mainly maintained in the range of 24 ~ 36 h.

(5) In the systems that affect the plateau shear line removal, westerly trough had the largest influence, followed by the Qinghai-Tibet high pressure and subtropical high.

(6) For the precipitation process due to the plateau shear line, the probability was high and the precipitation range was wide; the northernmost position it can reach was Inner Mongolia, the southernmost was Yunnan, westernmost was Tibet, and easternmost was Anhui. Among them, precipitation in Sichuan Province was affected

most. The shear line removed from the plateau eastward will lead to a wider range of precipitation and greater precipitation intensity.

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# 2000-2015年青藏高原切变线统计特征分析

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**摘要:**为探讨高原切变线系统的变化特点及与中国降水的关系, 利用青藏高原低涡切变线年鉴统计分析2000-2015年高原切变线的活动特征及其影响下的降水特征。结果表明, 高原切变线发生源地主要集中在西藏中部及东部、青海西南部地区, 高频地区位于那曲县附近。2000-2015年高原切变线共生成591次, 移出87次, 移出几率为14.72%; 高原切变线的出现和移出均以高原东部切变线为主。夏半年高原切变线活跃程度远高于冬半年, 在夏季5-9月切变线出现及移出次数较多; 8月达到峰值。高原切变线在四川省内移出次数最多, 占65.52%。63.45%的高原切变线生命史在12 h内; 对于移出高原的切变线, 78.16%生命史在24~36 h内; 移出高原的切变线生命史普遍长于未移出高原的切变线。影响高原切变线移出的系统中, 西风槽的影响率最高。东移出高原的切变线影响下的降水范围更广, 降水强度更大。

**关键词:**气象学; 高原气象; 高原切变线; 统计特征; 影响系统; 降水