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The variation and regional differences of precipitation in the Longitudinal Range-Gorge the Region

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This paper examines the regional differences of precipitation in the Longitudinal Range-Gorge Region (LRGR) based on the daily rainfall records during 1960 to 2001 observed at 36 meteorological stations. The regional differences of precipitation in different spatial and temporal scale are analyzed, under the effecting of the special "corridor-barrier" function in LRGR. The results indicate that very close linkages exist between the regional differences and the "corridor-barrier" function: in most areas of the northern LRGR (>26°N), the general features of intra-annual precipitation pattern (IPP) exhibit "multi-peak pattern" with "peach blossom flood period" (PBFP). When latitude is close to 26°N, the PBFP disappears gradually and IPP patterns change from "multi-peak pattern" to "single-peak pattern". From 24°N to 25°N, the "single-peak pattern" appears again; in the southern LRGR, the pattern shows quasi "double-peak pattern" with the characteristic of so-called "autumn rain period", and the larger the longitude is, the more significant the pattern will be. In dry season, the annual variations of precipitation vary similarly because the controlling of atmospheric circulation is relatively single in the LRGR and the influence of the "barrier" function is not significant on precipitation annual variation, but in wet season, the spatial distribution of precipitation annual variations becomes more complicated.

precipitation variation and regional differences, "corridor-barrier" function, the Longitudinal Range-Gorge Region (LRGR), Southwest China

Li[1] indicated that the "corridor-barrier" function has a binary characteristic of the absolute "barrier" function from east to west and the relative "corridor" function from south to north for the hydrothermal factors. Under the influence of the special "corridor-barrier" function in the Longitudinal Range-Gorge Region (LRGR), where most of it is located in Yunnan Province, the complicated ecological efficiency in this region has received significant attention[2−7].

The climate in the region is strongly influenced by both the southwest monsoon and westerly circulation[8]. It can be divided into different monsoon climate areas delimited approximately by the Great Honghe fault: one is the southeast monsoon area caused by warm-humidity air current from North gulf of west Pacific Ocean, and the other is southwest monsoon area caused by warm-humidity air current from the Bengal gulf of Indian Ocean[9−11]. Yan[12], Yang[13], and Cao[14] investigated the relationship between precipitation and summer monsoon, and the influence of thermal and dynamic factors from Tibetan Plateau on precipitation in Yunnan[15]. Guo[16] suggested that the spatial variation of climate factors, such as air temperature, precipitation, and evaporation in the Three-River-Area in Yunnan, showed strong similarities. Cao[17] also studied the spatial distribution of precipitation and temperature in winter and summer over the LRGR. Zhou[18] discovered that the hydro-thermal condition in the LRGR was distributed longitudinally along valleys, and the heat in the valley was higher than the mountainous regions.

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You[19,20] indicated that the precipitation variation from east to west in wet and dry seasons in the LRGR was significant[19], and found the variations of air temperature and annual precipitation in Yunnan Province in the past hundred years through Marr wavelet and Morlet wavelet transforms[20]. These studies, however, mainly focus on the linkage of the features of precipitation variation with the topography in the LRGR.

This paper analyzes the regional differences in precipitation at different spatial and temporal scales in the LRGR. From this, the correlation between the precipitation variations and the special “corridor-barrier” functions are illustrated, and the main influence mechanism of the precipitation variation is also discussed.

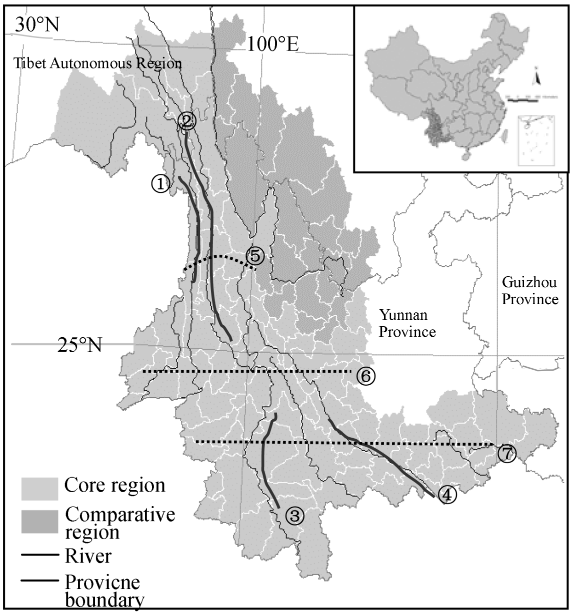

Figure 1 Locations of the selected profiles in the LRGR.

1 Data and methods

The data used in this research include observed daily rainfall records from 1960 to 2001 at 36 meteorological stations in the LRGR. With these data, the mean intra-annual precipitation patterns (IPP) at these stations were analyzed firstly. Seven representative profiles, based on different topography, were selected to discuss the influence of “corridor-barrier” function on the IPP spatial distribution in the LRGR. Furthermore, the variations of precipitation at longitudinal and latitudinal direction in each profile were also analyzed on a monthly and a 5-year moving average time frame to highlight regional differences and determine the physical mechanisms for the differences.

The northern LRGR (28°N－25°N) is typically a range-gorge landscape with high altitude of about 3000－4000 m; in the middle part (25°N－24°N), the landform is relatively fragmented with the altitude between 1500 and 2200 m; in the southwestern (24°N－22°N), the valleys are relatively wider and the mountains lower with the altitude being about 800－1000 m[21].

In the LRGR, the “corridor” function profiles (mainly from the 1st profile to the 4th profile) and the “barrier” function profiles (from the 5th profile to the 7th profile) were selected (Figure 1 and Table 1). These are then analyzed to determine the variation of precipitation in different spatial and temporal scales..

Table 1 The basic information of meteorological stations at the selected profiles

	Station	Latitude (ºN)	Longitude (ºE)	Altitude (m)
The 1st profile	Gongshan	27.45	98.40	1583.3
	Fugong	26.54	98.52	1189.7
	Lushui	25.59	98.49	1804.9
	Liuku	25.52	98.52	910.0
The 2nd profile	Deqin	28.29	98.55	3319.0
	Weixi	27.1	99.17	2325.6
	Lanping	26.25	99.25	2344.9
	Yunlong	25.54	99.22	1658.2
	Yongping	25.28	99.31	1616.4
The 3rd profile	Jingdong	24.28	100.52	1162.3
	Jinggu	23.30	100.42	913.2
	Puer	22.47	100.58	1302.1
	Jinghong	22.00	100.47	1162.3
The 4th profile	Yuanjiang	23.36	101.59	400.9
	Honghe	23.22	102.26	974.5
	Yuanyang	23.13	102.50	257.1
	Hekou	22.30	103.57	136.7
The 5th profile	Lushui	25.59	98.49	1804.9
	Lanping	26.25	99.25	2344.9
	Eryuan	26.07	99.58	2069.5
The 6th profile	Yingjiang	24.42	97.57	826.7
	Shidian	24.44	99.11	1468.2
	Fengqing	24.36	99.54	1587.8
	Shuangbo	24.41	101.36	1968.1
The 7th profile	Cangyuan	23.09	99.16	1278.3
	Shuangjiang	23.28	99.48	1044.1
	Jinggu	23.30	100.42	913.2
	Honghe	23.22	102.26	974.5
	Malipo	23.08	104.42	1094.4

2 The general regional difference feature of IPP in the LRGR

As shown in Figure 2, the general regional difference

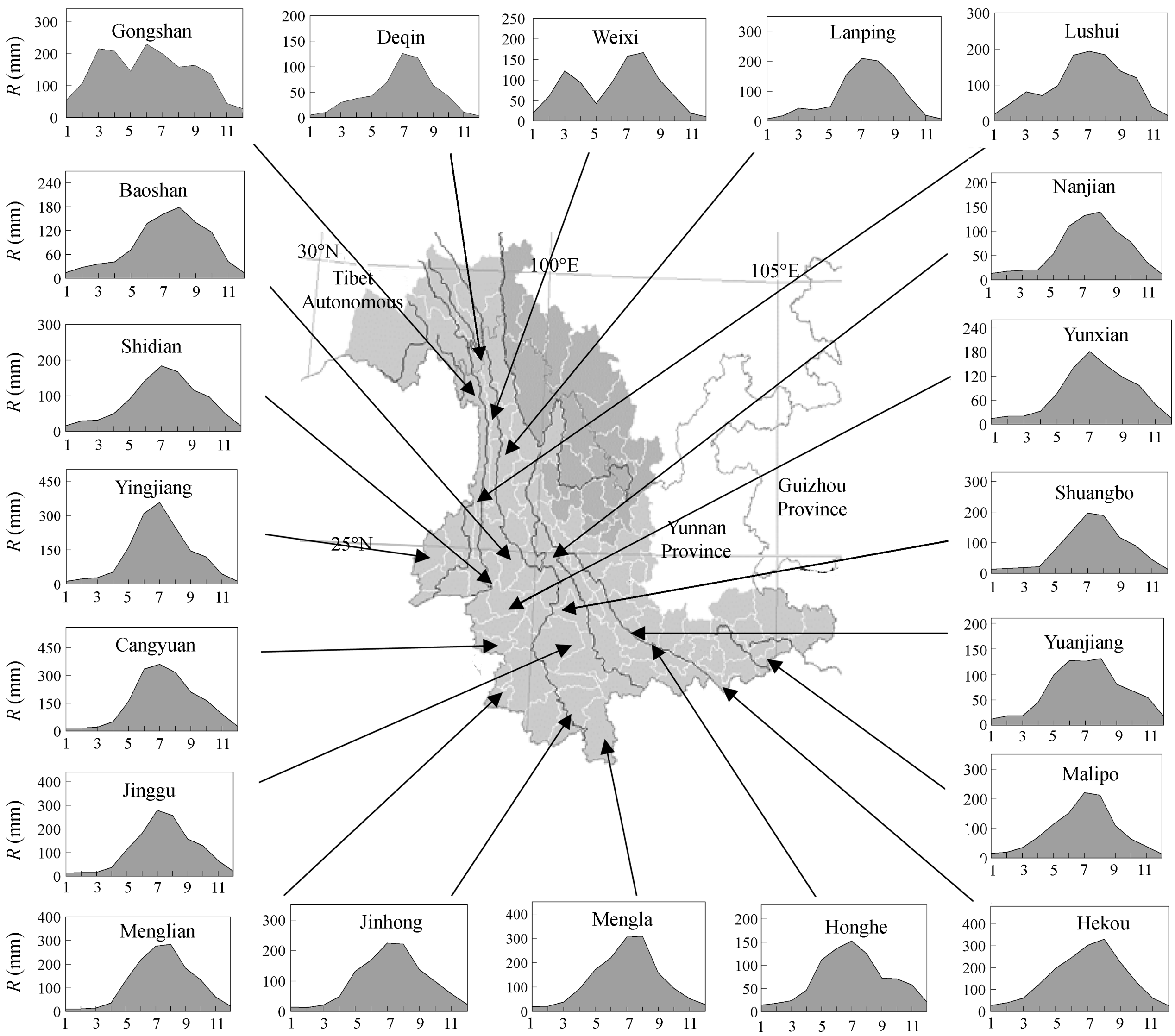

Figure 2 The general feature of IPP in the LRGR. *R*, Precipitation; 1 stands for January; 3 stands for March; 5, May; 7, July; 9, September; 11, November.

law of IPP at 36 stations in the LRGR can be described as: from north to south, IPP changes from a "single-peak pattern" to a "multi-peak pattern", and then gradually turns to a "single-peak pattern" again. In the dry season, there is no significant difference in the spatial distribution of precipitation.

In the wet season, however, the "corridor-barrier" function has a more significant influence on the water vapor brought by southeast monsoon and southeast monsoon, which leads to the spatial variation of precipitation. As a result, more precipitation is found in the southwest and mountainous area compared to the northeast regions and river valleys. A major contributor to this is the warm-humid air from the Bengal gulf which delivers abundant precipitation as it is rapidly uplifted by the "barrier" function of the Gaoligong Mountain. After crossing the Gaoligong Mountain, the water vapor in the warm-humid air current is significantly reduced which results the precipitation in Nu Mountain area being smaller than in the southern Gaoligong Mountain[24].

3 The spatial distribution of precipitation in longitudinal and latitudinal directions in the LRGR

According to the profiles selected in Figure 1, Figure 3 shows the mean IPP based on monthly precipitation records. The results illustrate the characteristics of pre-

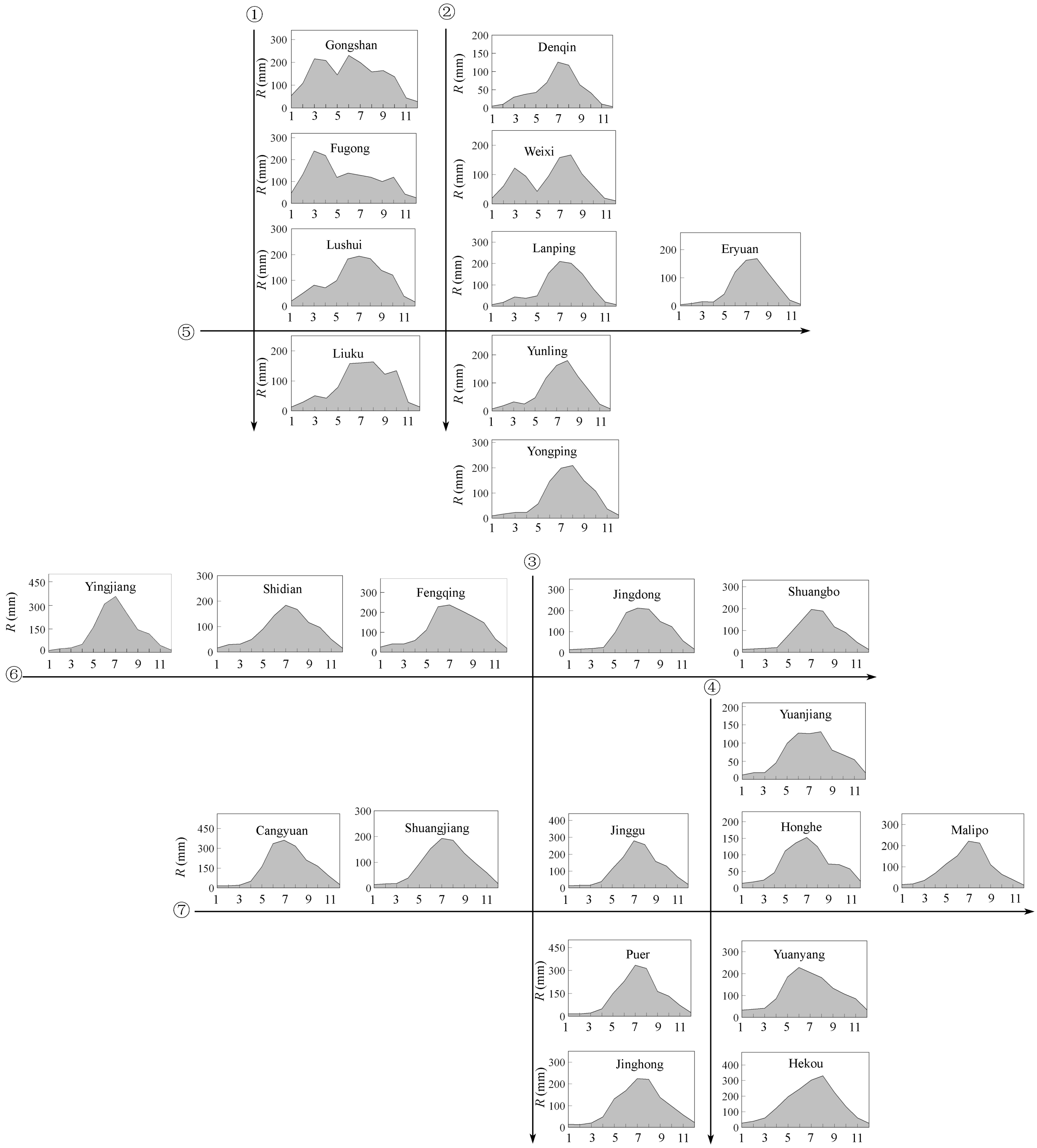

Figure 3 IPP patterns in the seven profiles. *R*, Precipitation; 1 stands for January; 3 stands for March; 5, May; 7, July; 9, September; 11, November.

cipitation variation in longitudinal and latitudinal directions.

3.1 The variation of precipitation in latitudinal direction

3.1.1 The northern part of the LRGR. The 1st profile is located in the upstream region of the Nujiang River basin, where the IPP mainly shows a "multi-peak pattern". The higher the latitude is, the more significant the "multi-peak pattern" is. The rainy season, which starts in March known as "peach blossom flood" period (PBFP), is responsible for the pattern. In the 2nd profile located in the upper and middle section of the Lancang

River basin, the pattern of IPP changes from a "single-peak pattern" to a "multi-peak pattern" from north to south, and then gradually tends to "single-peak pattern" again. It means that rainy seasons start in May in most areas of the 2nd profile, except in the area near 27°N latitude zone (like Weixi station) where rainy seasons start in March (namely PBFP).

3.1.2 The southern part of the LRGR. The 3rd profile lies between Bangma Mountain and Wuliang Mountain, situated mainly in the Lancang River basin. The IPP in this profile exhibits a "single-peak pattern", which means the rainy seasons start in May, and peaks in July or August, and then decreases into the dry season. An- other important point is that the precipitation increases slightly in September, and then decreases gradually after getting another little peak value in October.

The 4th profile is located in the Yuanjiang River valley, which is mainly characterized by the "single-peak" pattern for the IPP. In its northern part, however, (like Yuanjiang and Honghe stations), the precipitation increase obviously between September and October, and the allocation exhibits a quasi "double-peak pattern" with the so-called "autumn rain period". Extending to south Yuanjiang River valley, this quasi "double-peak pattern" weakens gradually, and at the last gauging station (Hekou station) before Yuanjiang River flows out of China, the allocation becomes a complete "single-peak pattern" again.

3.2 The variation of precipitation in longitudinal direction

According to the three profiles (from the 5th profile to the 7th profile) seen in Figure 3, the variation of the IPP in a longitudinal direction and the influence of "barrier" function were further investigated.

In the 5th profile between 25°N—26°N, precipitation on the west side (like Lushui station) exhibits "multi-peak" pattern for the IPP, which shows obvious PBFP in March, and increases significantly between September and October. As longitude being increasing, the PBFP weakens gradually from west to east. On the east side (like Eryuan station), IPP exhibits "single-peak pattern" at last.

In the 6th profile between 25°N—24°N, the IPP exhibits a similar "single-peak" pattern, without the PBFP in March. The precipitation, however, increases slightly again between September and October, then decreases into dry season.

In the 7th profile between 23°N—22°N, the rainy season starts in May and ends in October. As longitudes increases, the increase in precipitation between September and October becomes more and more obvious, and the IPP near 103°E area (like Honghe station) exhibits quasi "double-peak pattern" with the so-called "autumn rain period". As longitude increasing to the west of 103°E, IPP on the east side of profile (like Malipo station) returns to "single-peak pattern" again.

4 The average monthly difference of precipitation in the LRGR

In order to describe quantitatively the spatial variation of the IPP in each profiles, the average monthly difference of precipitation (AMDP) at the stations in each profiles are calculated (Figure 4). Generally, it can be seen from the figure that the intra-annual pattern of the AMDP (ADIPP) can be divided into two general types.

As seen from Figure 4, the ADIPP in the 1st, 2nd and 5th profiles have significant characteristics of "multi-peak pattern". It can be seen that the precipitation increases significantly in March in these profiles (i.e. the monthly difference shows positive value in each profile), especially at Gongshan in the northern part of the 1st profile with a value of 107.1 mm. Then the precipitation in these profiles decreases gradually after April. In May, the reduction in precipitation exhibits the largest value of −99.8 mm at Fugong station. After June, the precipitation increases again which implies that these profiles come into the wet season. The third period of precipitation increase appears between September and October, and decreases gradually into dry season in November at last.

The ADIPP in the 3rd , 4th, 6th and 7th profiles exhibit the characteristics of quasi "double-peakpattern" with "autumn rain period". It indicates that the geomorphological variation has small influence on the spatial and temporal distribution of precipitation in the middle and southern LRGR, which leads to the distribution in this area being homologous.

5 The variation of precipitation in wet and dry seasons and its spatial and temporal distribution

Figure 5(a) and (b) show the annual variation of total

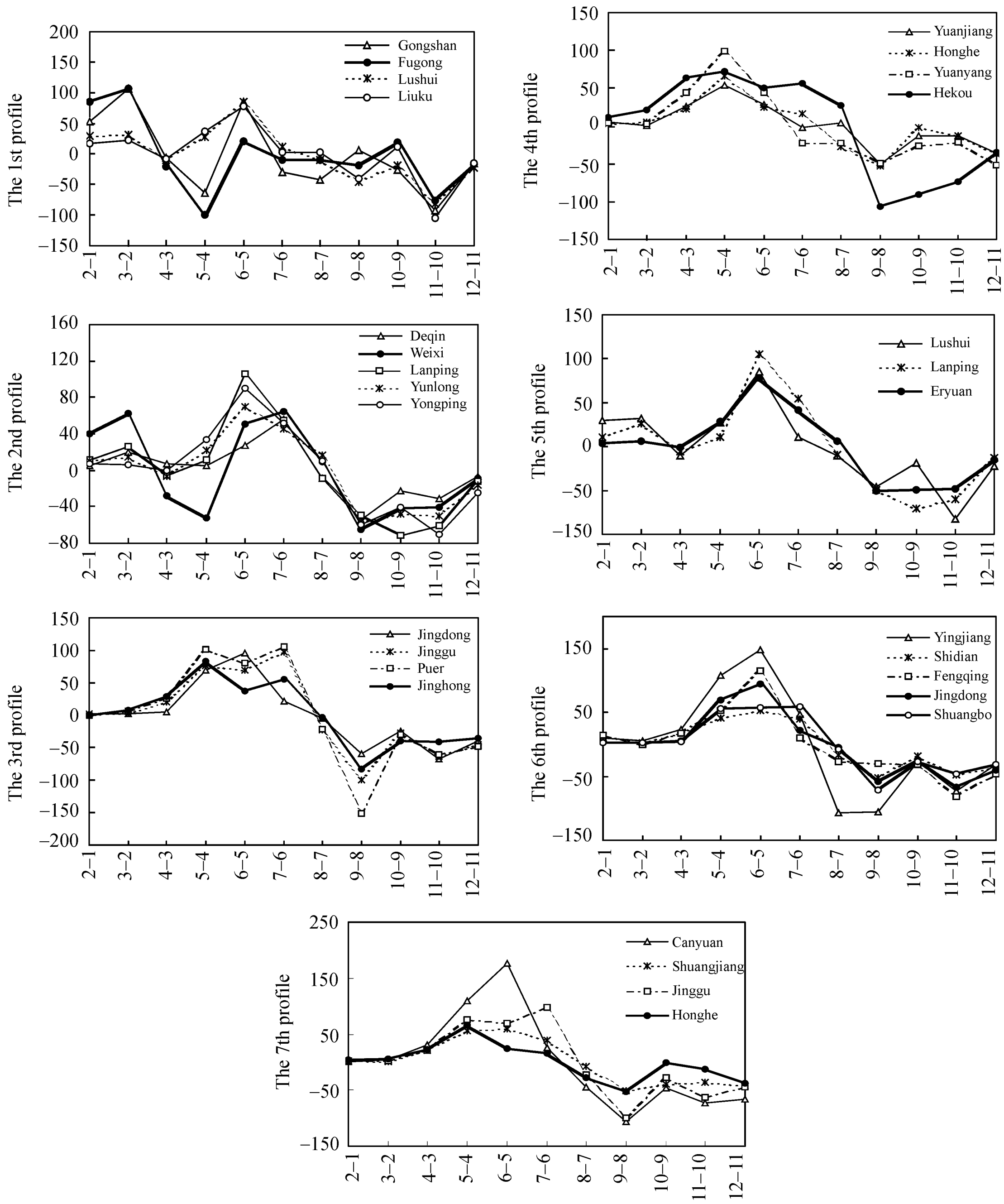

Figure 4 Average monthly differences of precipitation in seven profiles. 2—1, Feb.—Jan.; 3—2, Mar.—Feb.; 4—3, Apr.—Mar.; 5—4, May—Apr.; 6—5, Jun.—May; 7—6, Jul.—Jun.; 8—7, Aug.—Jul.; 9—8, Sep.—Aug.; 10—9, Oct.—Sep.; 11—10, Nov.—Oct.; 12—11, Dec.—Nov.

precipitation in dry season (from November to April) (TPD) and wet season (from May to October) (TPW) in the 1st profile. The results demonstrated that both in the dry season and the wet season, the annual variation of precipitation in the 1st profile could be divided into two different stages delimited by 1993: from 1961 through 1993, TPW and TPD increased gradually, especially for the ascending trends of precipitation variation in the upstream of Nu River basin. But with decreasing latitude (like Fugong and Lushui stations), they did not demonstrate a significant increasing trend. After 1994, the variations turned into a descending trend.

The annual variation of the TPD in the 2nd profile is shown in Figure 6(a). It can be seen that the TPD increased significantly after two apparent jumps in 1970 and 1980, while with a decreasing latitude, the TPD did

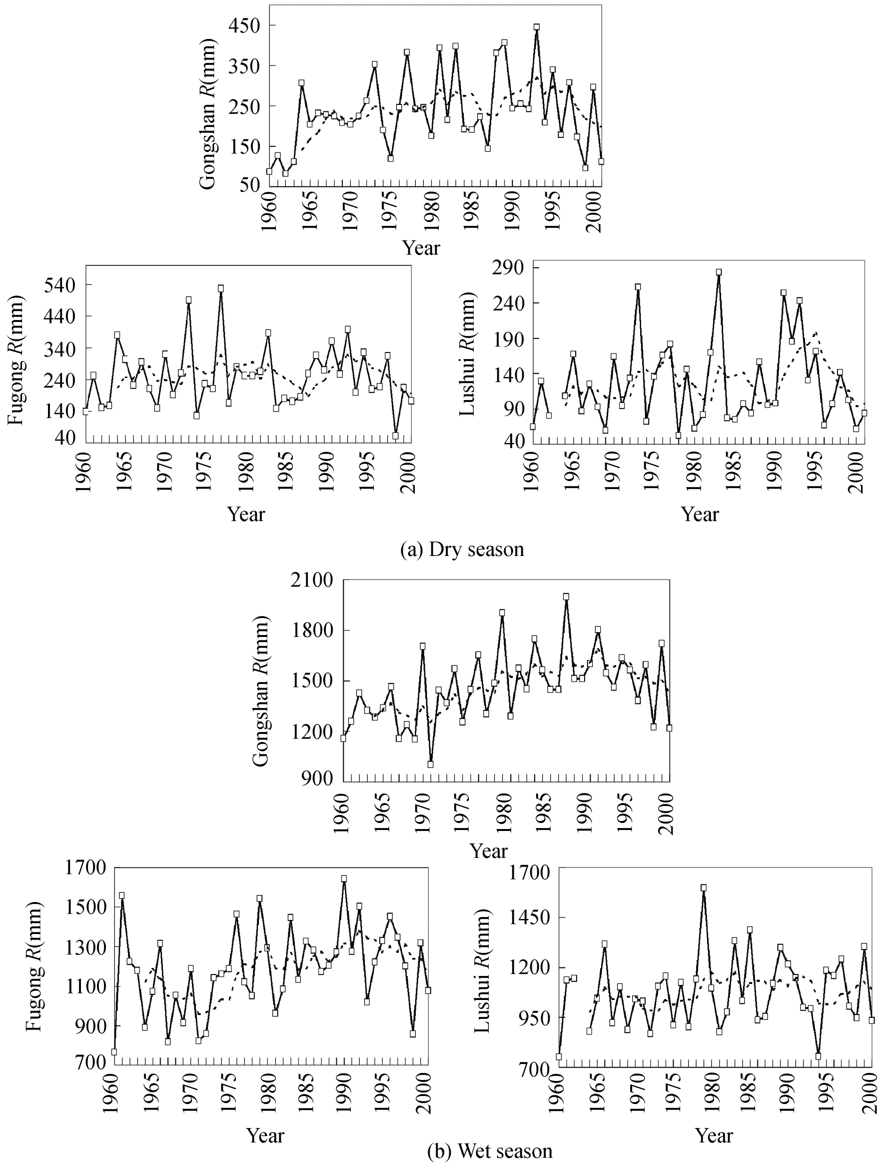

Figure 5 The annual variations of precipitation in wet and dry seasons in the 1st profile. *R*, Precipitation.

not demonstrate an increasing trend. As seen from Figure 6(b), the variation of TPW in the 2nd profile can be divided into two different stages delimited by 1983: they descended prominently from 1960 through 1983, and the lower the latitude was, the more prominent the descending trend would be. From 1984 to 2001, the variations of the TPW turned into an ascending trend.

As for the 3rd profile (Figure 7(a), (b)), it can be shown that near the relative high-middle latitude zone of the profile (like Jingdong, Jinggu and Pure stations), the variation of TPD exhibited an ascending trend at first, and then turned into a descending trend from the 1960s to mid 1980s. After showing a severe fluctuation in 1983, the TPD gradually increased again. As for TPW in the area, they descended gradually from 1960 to 1978 and ascended gradually from 1978 to 2001.

When the latitude descended to Jinghong station, the variation of TPD could be divided into two stages delimited by 1983: during 1960 to 1983, it ascended at first and then descended, while during 1983 to 2001, it turned to descending trend. As for the TPW, it ascended gradually during 1960 to 1972 and then descended gradually.

As seen from Figure 8, in the 4th profile except for the downstream of Yuanjiang River basin (like Yuanyang station), the variation of the TPD in most areas could also be divided into two stages delimited by 1983: during 1960 to 1983, they ascended at first and descended afterwards, but after 1983, they turned to de-

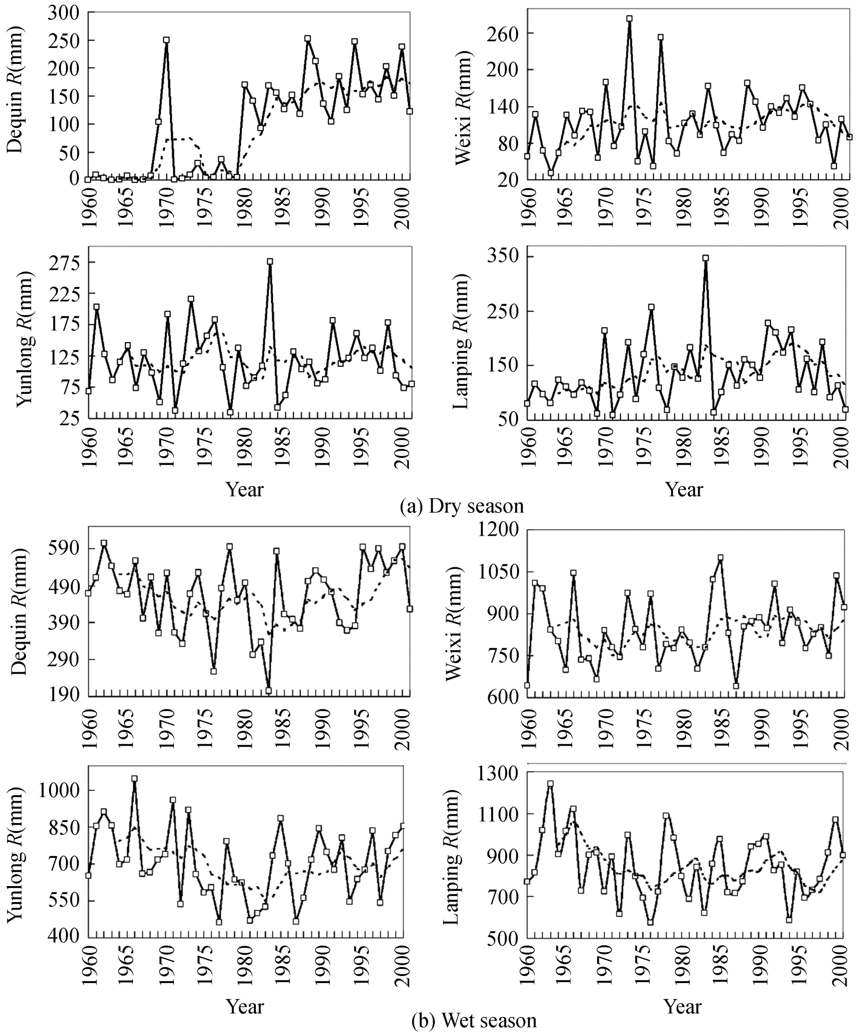

Figure 6 The annual variations of precipitation in wet and dry seasons in the 2nd profile. *R*, Precipitation.

scending trend. The TPW descended gradually during 1960 to 1990 and then ascended gradually.

When it comes to the downstream of Yuanjiang River (like Yuanyang station), the TPW in the area exhibited a significant descending trend over the past 40 years, while the TPD decreased gradually after 1983.

Figure 9(a) and (b) show the TPW and TPD annual variations in the 5th profile. It can be seen that the larger the longitude is, the more significant the ascending trend of TPD will be. Three severe fluctuations can be seen in 1973, 1983 and 1993. This indicates that the proposed 10—11-year evolution cycle of the TPD variation exists at this profile. This periodic oscillation pattern is exactly consistent with the solar spot activity, which implies that the TPD in the 5th profile may be directly related to the supply of solar energy. As far as TPW were concerned, as the longitude increased, the variation trends gradually changed into two different stages delimited by 1983: during 1960 to 1983, they showed significant descending trends, but during 1984 to 2001, they turned to ascending trends.

As shown in Figure 10(a), the variations of TPD in the 6th profile could be divided into two different stages delimited by 1983: the variation trend of precipitation ascends, then descends from 1960 to 1982, and show relatively small fluctuation from 1983 to middle 1990s. The patterns of TPW annual variations are displayed in Figure 10(b). It could be found that in the western profile (like Yingjiang and Shidian stations), the TPW showed ascending trends gradually within the past 40 years. And in the middle of the 6th profile which is located in the eastern Bangma Mountain, the variations of TPW descended gradually during 1960 to 1988, and turned into ascending trends during 1989 to 2001.

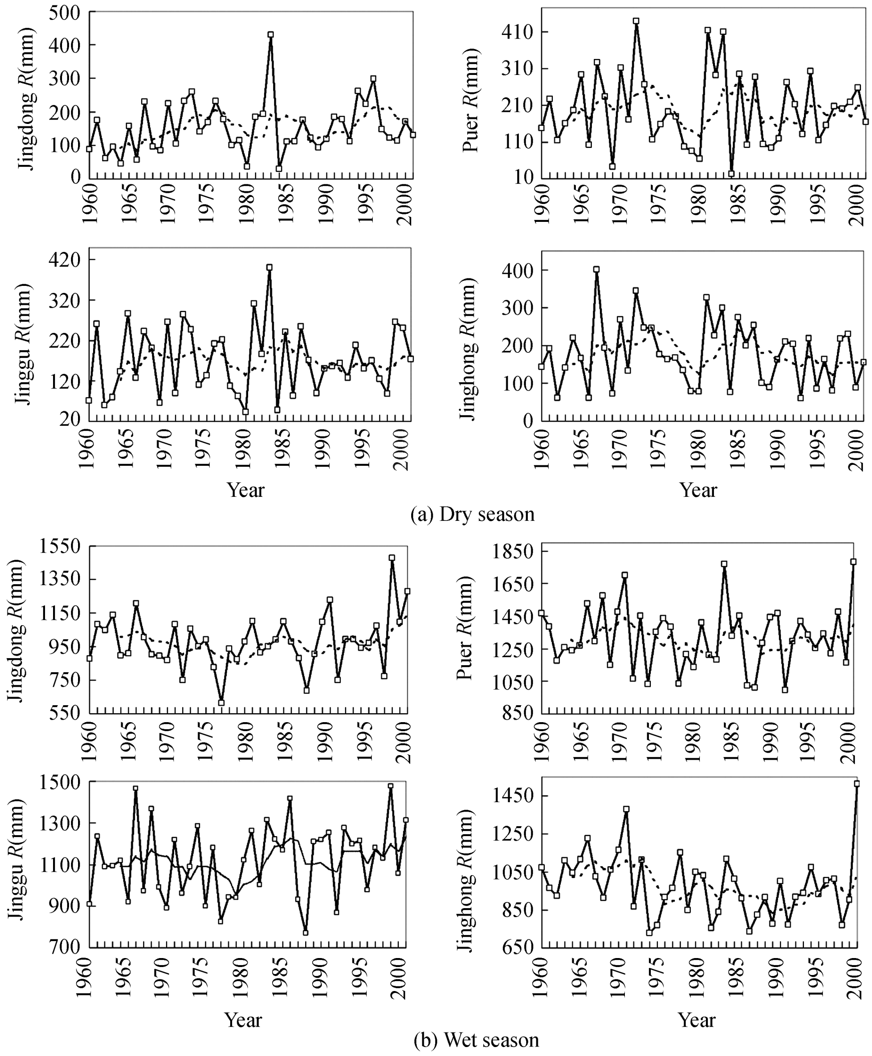

Figure 7 The annual variations of precipitation in wet and dry seasons in the 3rd profile. *R*, Precipitation.

Towards the 7th profile (Figure 11(a), (b)), it can be seen that the variation patterns of the TPD also exhibited two different stages delimited by 1983 within the past 40 years: they ascended firstly and descended afterwards during 1960 to 1983, and gradually ascended again after 1984. As for the TPW, their annual variations exhibited descending trends before 1975, and turned to ascending trends with the longitude increasing after 1975 in most areas of the 7th profile.

According to the above analysis, because the atmospheric circulation controlling the LRGR is relatively simple and the effect of the "barrier" function is not significant on the spatial variation of cold air brought by northeast monsoon, the annual variations of the TPD seem to be similar in most areas, except for local parts (like the lower area in Lancang River basin and Yuanjiang River basin). Even in the local parts, the differences can be found mainly on smaller time scales, which further confirms the research results of You[19], Cao[17] and Tao[22].

In the wet season, the causes of precipitation are complex. According to other researches[27,28], during the early stages of the wet season (February to May), the precipitation is affected by the westwards movement of The Long-Wave Trough-Ridge of the westerly zone. Thus, the interdecadal oscillation of TPW probably has an intimate relationship with the interdecadal evolution of the high-middle latitude atmosphere circulation and Eastern Pacific subtropical high. This results in a greater variation of TPW than TPD, between the sites.

Despite the complex causes, the spatial distribution of long term precipitation trends in the wet season is simple.

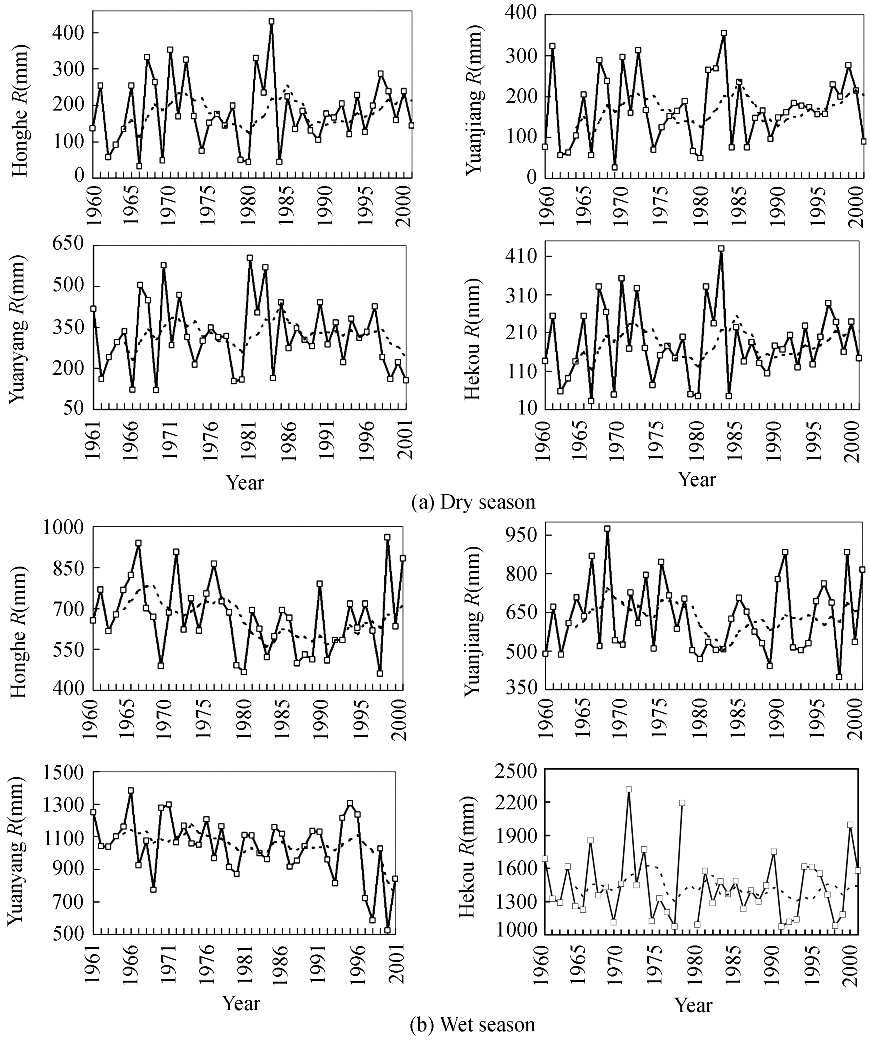

Figure 8 The annual variations of precipitation in the wet and dry seasons in the 4th profile. *R*, Precipitation.

There are large regions within the study area where the long term precipitation trends are increasing and large regions where the trends are descending. This further confirms the results of Miao and Xiao[23]. One suggestion for this trend is that there is a relationship between the TPW and the high-middle latitude atmosphere circulation of 500hPa and latitudinal wind field in the subtropical zone of 200hPa during the early stages of the wet season[29]. This relationship will be discussed in detail in future work.

6 Discussion on the influence mechanism of the spatial and temporal distribution of precipitation in the LRGR

In general, the influence of "corridor-barrier" function in the LRGR on the water vapor transportation can be described as follows: Warm and humid airflow from tropical oceans moves against the longitudinal range gorge, and moisture and heat extend along valleys from south to north, which is called the "Vapor Corridor". At the same time, the longitudinal aerial mountain system obstructs vapor transportation from the west to the east. This influence of unique underlying topography leads to the spatial and temporal variation of precipitation.

The 1st, 2nd, 3rd profiles are typically the range-gorges landscapes of the northern LRGR, which have significantly complex geo-morphological variation. In these areas, the huge mountains (including Gaoligong Mountain, Biluo Mountain (viz. the northern Nu Mountain), and Yunling Mountain) impose a "barrier" in the east-west direction on southwest warm and humidity air currents which come from the Indian Ocean[25]. The deep valleys of the Lancang River and the Nujiang River,

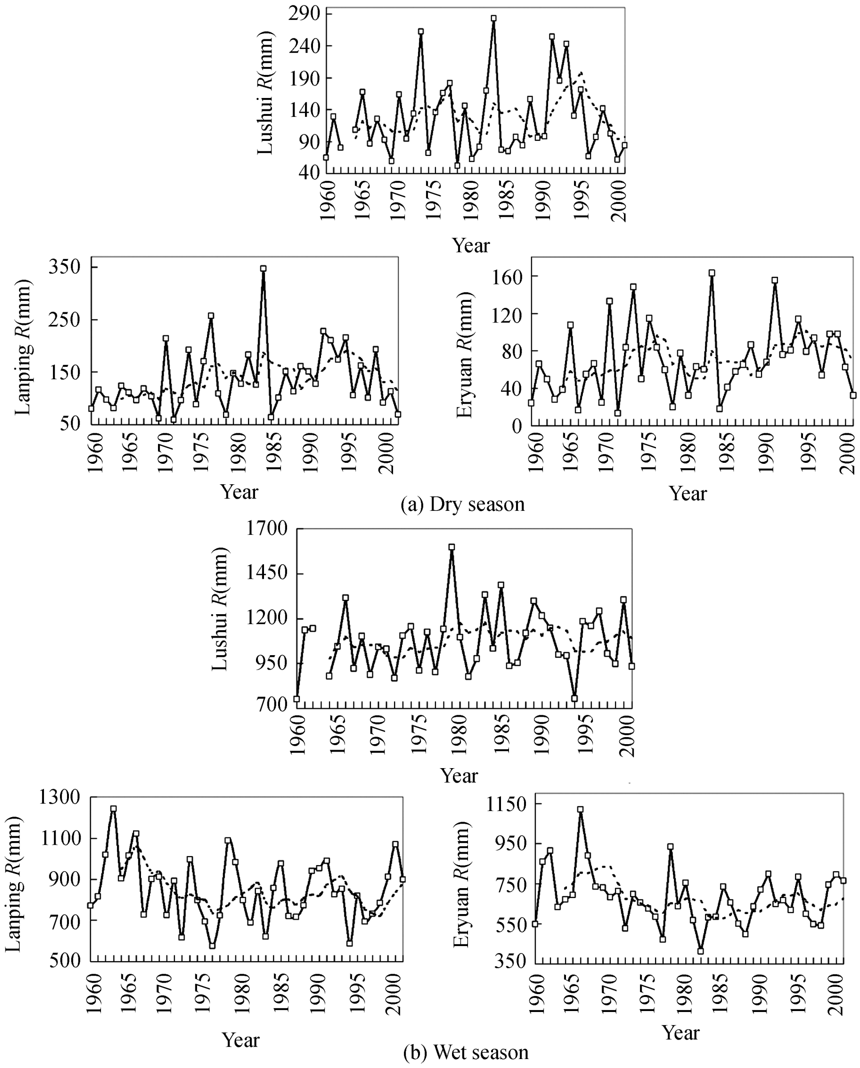

Figure 9 The annual variations of precipitation in the wet and dry seasons in the 5th profile. *R*, Precipitation.

however, provide a “corridor” function, which results in the transportation and diffusion of moisture and heat along the south-north direction. Especially, at Deqin station located in the highest latitude in the LRGR, the “corridor” function of valleys and “barrier” function of mountains have relatively little influence on this area because of its high elevation. As a result, IPP at this station is affected by the atmospheric circulation and exhibits the simple “single-peak pattern”.

As latitude decreases to 27°N, the influence of “corridor-barrier” function in the LRGR on the spatial distribution of moisture and heat condition strengthens gradually. Affected by the terrain of Qinghai-Tibet Plateau, southern westerlies trough is active near 80°—90°E in winter and spring seasons. The northern part of the 1st profile (like Gongshan and Fugong stations) and the middle part of the 2nd profile (like Weixi station) is located under southern westerlies trough (90°E). Therefore, under the strong “corridor-barrier” function in these areas, warm and humid southwest flow rises along the longitudinal range-gorge region toward the tableland in low latitude and the cold advection comes with southern westerlies trough. As a result, precipitation occurs in the west slope of Gaoligong Mountain[26]. The combination of these two flows induces the onset of rainy season in March (PBFP) in this area.

At lower latitudes, the influence of the “corridor” function in the LRGR on the spatial distribution of precipitation, temperature, and humidity weakens gradually. When the latitude decreases to 26ºN, the “barrier” function becomes more significant[16], which weakens the north flow of the Tibet subsidized. This air flow com-

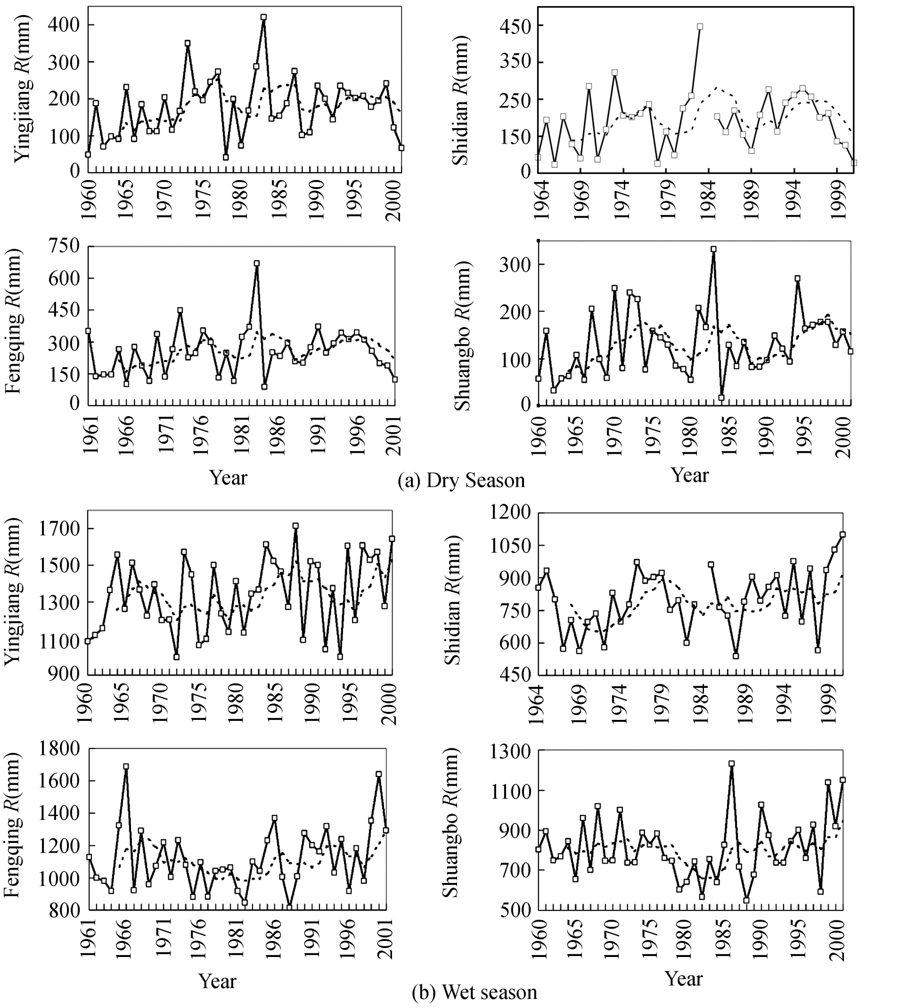

Figure 10 The annual variations of precipitation in the wet and dry seasons in the 6th profile. *R*, Precipitation.

bines with the warm and humid southwest current in the area, which also becomes weaker. Moreover, water vapor in the current is continuously consumed by the high mountains (like Nu Mountain and Yunlin Mountain) and deep gorges (like Nujiang River Gorge and Lancang River Gorge). As a result, precipitation in the PBFP in the 1st and 2nd profiles (both from north to south), and the 5th profile (from west to east) decreases gradually, and the IPP changes to "single-peak pattern" with the wet season starting in May.

Near the southern 25°N latitude zone, the longitudinal geo-morphological variation is smaller than in the 5th profile, which is mainly composed of a series of approximate parallel high or middle mountains including Bangma Mountain, Wuliang Mountain and Ailao Mountain. This region is influenced by the two summer monsoon systems alternately. Under the controlling of southwest monsoon, the wet seasons start in May and weaken in August. But with the western Pacific subtropical high retreating southward to 25°N in the first ten days of September, the coming warm-humidity air current brought by southeast monsoon is affect by the "barrier" function of low latitude parallel mountains in the LRGR, the precipitation will occur in the eastern slope (i.e. the windward slope) of Wuliang Mountain, which results in the increase of precipitation between September and October.

Especially in west slope of Wuliang Mountain, due to the interception of the warm-humidity air current brought by southwest monsoon and the barrier function on the cold air, the TPW at the 3rd profile in western Wuliang Mountain is much more abundance than other profiles of southern 25°N latitude zone. In the 4th profile located in the eastern Great Honghe fault and eastern Ailao Mountain, because of the weaker influence of southwest monsoon and the stronger controlling func-

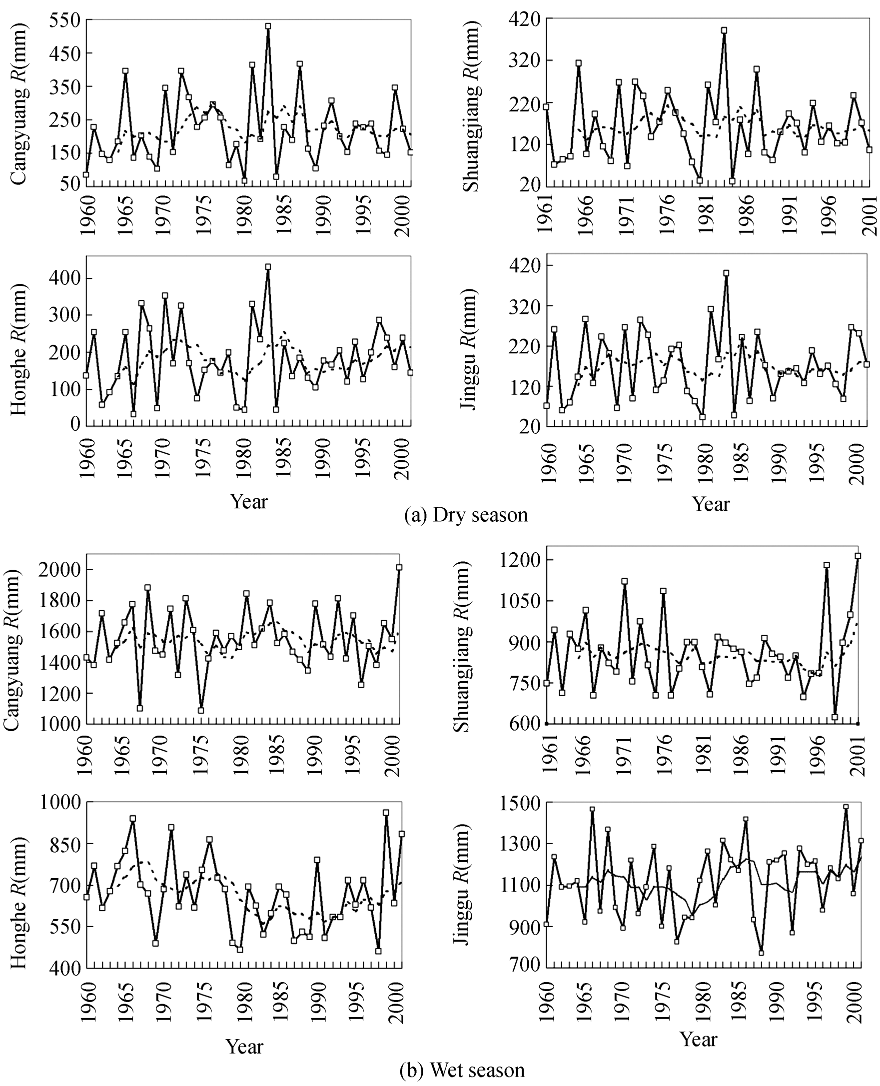

Figure 11 The annual variations of precipitation in the wet and dry seasons in the 7th profile. *R*, Precipitation.

tion of southeast monsoon, the warm-humid air current brought by southeast monsoon is intercepted and obstructed from eastern Ailao Mountain (i.e. the windward slope). This brings abundant precipitation and leads to a more prominent increase of precipitation between September and October. As far as the 6th profile (25°N—24°N) is concerned, since its geo-morphological variation is smaller than the 5th profile, it is significantly affected by the "corridor" function in the LRGR. This means that heat can be more easily distributed and ultimately diffused homogeneously, which results in the IPP exhibiting similar pattern in the 6th profile. Due to the lower latitude, the geo-morphological variation in the 7th profile becomes smaller than the 5th profile and larger than the 6th profile, and the influence of southeast monsoon strengthens gradually from west to east. The water vapor is obstructed (i.e. the "barrier" function) from the parallel mountains in this profile and creates precipitation at the eastern slope (i.e. the windward slope), which makes precipitation near 102°E increase significantly between September and October. As longitude increases to the west of 103°E, however, the topography variation become smaller and the effect of "barrier" function in the LRGR on precipitation is no longer significant. Therefore, the IPP at Malipo station which lies in the eastern 7th profile returns to the simple "single-peak pattern".

7 Conclusions

(1) In most areas of the northern LRGR (>26°N), under the significant "corridor-barrier" function on the

moisture and heat condition, the most important features of precipitation are the intra-annual precipitation pattern (IPP) which exhibits a "multi-peak pattern" with the "peach blossom flood period" (PBFP). When the latitude is close to 26°N, the influence of "corridor" function on the spatial distribution of hydrothermal factors weakens gradually but the "barrier" function strengthens, which results in the PBFB disappearing gradually and the IPP changing from "multi-peak pattern" to "single-peak pattern". In the region from 24°N to 25°N latitude zone, the precipitation is significantly affected by "corridor" function, and the moisture and heat condition distribute and diffuse homogeneously, therefore, the IPP in this area exhibit similar "single-peak pattern" again. In the southern LRGR with relatively low latitude, the "corridor-barrier" functions affect alternately the precipitation and the IPP displays quasi "double-peak pattern" with the so-called "autumn rain period", and the larger the longitude is, the more significant the characters of the pattern will be.

(2) During the last 40 years, the trends of the TPD annual variation are similar in the LRGR: during 1961 to 1993, they ascended at first and descended afterwards in most areas except for that in the 2nd profile, while in the late 1990s, they showed descending trend in all the profiles.

(3) The spatial distribution of the TPW annual variation is more complex than that of TPD. But there are large regions within the study area where the long term precipitation trends are increasing and large regions where the trends are descending.

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