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LONG-DISTANCE-RELAYED WATER VAPOR TRANSPORT EAST OF TIBETAN PLATEAU AND ITS IMPACTS

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Abstract: This paper attempts to reveal a long-distance-relayed water vapor transport (LRWVT) east of Tibetan Plateau and its impacts. The results show that from August to October, east of Tibetan Plateau, there exists a unique LRWVT, and the water vapor from the South China Sea and the western Pacific can affect the Sichuan Basin, Northwest China and other Chinese regions far from the tropical sea through this way. From August to October, the precipitation of the region east of the Plateau is closely linked both in the intra-annual and inter-annual variations, and the LRWVT from the South China Sea and the western Pacific is an important connection mechanism. The large-scale circulation background of the LRWVT impacting the precipitation of the region east of the Plateau is as follows: At high levels, the South Asian High is generally stronger than normal and significantly enhances with its northward advance and eastward extension over the region east of the Plateau. At mid-level, a broad low pressure trough is over Lake Balkhash and its surroundings, and the Western Pacific Subtropical High (WPSH) is northward and westward located, and the western part of Sichuan Basin and the eastern part of Northwest China are located in the west and northwest edge of WPSH.

Key words: Tibetan Plateau; long-distance-relayed water vapor transport; climate impact
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1 INTRODUCTION

Moisture is a basic factor for the occurrence of precipitation. Previously, a lot of researches related to water vapor transport (referred to as “WVT” hereafter) of China have been given (Xie and Dai[1]; He and Murakami [2]; Huang et al.[3]; Gao and Lu [4]; Ninomiya and Kobayashi[5]; Lu et al.[6]). Xie and Dai[1] pointed out that, to the summer precipitation of China, there are two main water vapor sources: one is brought inland by southerly or southeasterly wind along the southern edge of the Pacific High, and the other is carried into the southwestern part of China by southwesterly along the southeast brink of an Indian low pressure. In recent years, many scholars studied the influence on rainfall by WVT from the viewpoint of monsoon and pointed out that water vapor with monsoon plays an important role in the water vapor balance of monsoon regions. Zhang[7] noted that the southwest wind moisture transport from the Indian monsoon region has important influence on summer rainfall in China; Xie et al. [8] found that the moisture transport from the Bay of Bengal (referred to as “BoB” hereafter) and South China Sea (referred to as “SCS” hereafter) is the main source of the Yangtze River basin precipitation; Ding and Sun [9] pointed out that the warm and humid air with the northward march of the East Asian summer monsoon makes a water vapor source for the start of the rainy season in eastern China; Zhou et al.[12] argued that the northward progress of the moisture coincides with the seasonal march of the monsoon rain belts very well. Shen et al. [14] considered that the anomalous moisture transport of the southeast monsoon directly coming from the south side of the Western Pacific Subtropical High (WPSH) was an important factor of the summer precipitation in the eastern China. Based on the above studies, it is known that the water vapor of summer precipitation in China mainly comes from the SCS, the BoB and the Pacific region, and the moisture along with monsoon from the oceans plays an important role in water vapor balance of the monsoon region.

Tibetan Plateau (the Plateau) and its eastern region occupy an important position in China's regional water cycle (Tao and Yi [15]; Xu et al.[16]; Cai et al.[17]; Shi et al.[18]). The Plateau has a great impact on the distribution and seasonal variability of the water vapor flux over its surrounding areas [15]. The spatial and temporal evolution of the WVT over the Plateau-monsoon region, the so-called “Large Triangle Affecting Region” is a significant scientific issue for studying the abnormal causes of the drought and flood in China, or even in the whole East Asia. A strong westerly water vapor flow from the “transfer platform” of the Plateau during the formation process of a torrential rain in July 1998 is es-

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pecially significant, which may be one of the important abnormal elements of East Asian water vapor cycle that formed the abnormal flood in 1998[16]. The region on the eastern side of the Plateau, such as Sichuan, Yunnan, et al., plays an important role in water vapor balance of its surrounding areas[17-18]. For example, there are two strong WVT belts, one from Sichuan Basin to North China when North China is in a wet summer and the other from Guangdong, Guangxi, and Sichuan Basin to Lanzhou when Northwest China is in a wet summer. For these two places, Sichuan Basin is the important water supply source on the land[17]. Research conclusions above confirmed that the Plateau and its eastern region has a great impact on the water cycle in most parts of China and is the key area of WVT that results in disastrous weather and climate in most of China. However, the current research about WVT in China is mostly concentrated in eastern China with little related to the Plateau and its surroundings (Huang and Shen[19]; Zheng et al.[20]; Miao et al.[21]; Zhou et al.[22]; Shi and Shi[23]; Wang et al.[24]; Li et al.[25]). It is then significant to study deeply the WVT and other related science questions of the Plateau and its surroundings.

In the research about the WVT of the Plateau and its surroundings, Zhou et al.[26] and Zhou[27] found that the warm and humid water vapor mainly comes from the SCS and the western Pacific (referred to as "WP" hereafter) when the western Sichuan Basin is wet in summer, and the WVT by the southerly from the SCS and the WP has an important role in the occurrence and development of extreme precipitation events in the Plateau and its eastern areas. Cai et al.[17] noted that when Northwest China is wet in summer, the anomalous moisture can be traced back to the SCS, East China Sea and other regions. Sichuan Basin and Northwest China east of the Plateau are located in China's inland and far away from the tropical oceans. How is the warm and humid moisture from the SCS and the WP transported to the regions above? When does such transportation route exist? What kind of impact does this way of water transport have on the climate of China and what is the related large-scale circulation background when the water vapor is convergent to form precipitation eventually. These questions have not been discussed in detail. To learn more about the important role of the Plateau and its surrounding areas in water cycle, it is necessary to study the issues mentioned above.

This study is organized as follows. Section 2 discusses the datasets and methods used in this study. Section 3 analyzes the WVT features of the Plateau and surrounding areas and examines the facts of influence by the water vapor from the SCS and the WP region and looks for the corresponding transporting channels. Section 4 discusses the temporal evolution characteristics of the transport path. Section 5 studies the impact on China's climate as a result of this way of transport and shows the related large-scale circulation. Section 6 is the main conclusions and related discussion.

The eastern side of the Plateau (17.5° to 40° N, 97.5° to 110°E) in the study mainly refers to Southwest China and Northwest China east of the main body of the Plateau.

2 DATA AND METHODS

Global reanalysis datasets provided by NCEP/NCAR for the period 1951—2011 are used to calculate the atmospheric WVT (Kalnay et al.[28]). The physical variables used in this study include the monthly and daily specific humidity, and the meridional and zonal wind components at eight standard pressure levels, namely, 1000, 850, 700, 600, 500, 400, and 300 hPa. The monthly and daily surface pressures are used to process the impact of topography. The geopotential height provided by NCEP/NCAR is also used to discuss the circulation background.

The data of monthly station precipitation (1951 to 2011) from China Meteorological Administration is used. Widely used in the study of the East Asian climate, this dataset consists of the monthly averaged precipitation of 160 stations in China.

In this study, WVT, a combination of wind and humidity, can show the wind and humidity field, and is essential for summer precipitation. Especially, the vertically integrated WVT is closely related to the precipitation. Therefore, in this paper, the WVT in question is actually the vertically integrated WVT and can be expressed as:

$$Q = Q_\lambda \vec{i} + Q_\varphi \vec{j},\ Q_\lambda = -\frac{1}{g}\int_{p_s}^{p} qu\mathrm{d}p \ ,$$

$$Q_\phi = -\frac{1}{g}\int_{p_s}^{p} qv\mathrm{d}p$$

where Q_λ and Q_φ are the zonal and meridional WVT, vertically integrated (in kg m^{-1} s^{-1}), q is the specific humidity, u and v are the zonal and meridional wind, p is the pressure, p_s is the surface pressure, and g is the acceleration due to gravity. The vertical integration is performed from the surface to 300 hPa. The missing data above 300 hPa has a nearly negligible impact on the result because of the concentration of water vapor in the lower troposphere.

3 ANALYSIS OF THE RESULTS

3.1 *Moisture transport of the Plateau and its surrounding areas*

Under the background of climate average, in the whole winter and March and April, the water vapor of the Plateau and surrounding areas mostly comes from the moisture transport by the westerly over the mid-latitude areas. In May, the WVT over the Plateau and the surroundings is transitional from winter to summer. The BoB transports moisture by a strong southwesterly, which converges with the southern branch of the westerlies over Southwest China and is the main transport flow for most China in May.

In summer, the water vapor for the main body of the Plateau is still from the mid-latitude westerlies. The region east of the main body of the Plateau is affected by various monsoons and the WVT is complicated; it can be from the BoB, SCS and the WP as well as mid-latitude regions. In June and July, to the eastern side of the Plateau, such as Yunnan, Guizhou, Sichuan and other regions, the southwesterly WVT from the BoB is the main WVT flow, but the southerly WVT from the SCS also contributes to the water budget of the region east of 105°E over the above-mentioned areas. The WVT in August is much different to that in June and July. In August (Fig. 1a), with the weakening of South Asian summer monsoon, the WVT from the northern BoB to the Plateau and Southwest China significantly reduces. The ridge of WPSH moves northward to 30°N, and Eastern China is mainly affected by the southeast transport of water vapor from the south side of WPSH, the value of which is relatively small, less than 100 kg m^{-1} s^{-1}. Near 25°N, the southeast WVT of water vapor from the SCS and the WP expands westward to the region east of the Plateau turns into a southwest transport between 100°E and 110°E where it converges with the southerly transport from the northern area of BoB and advances northward.

In September (Fig. 1b), the WVT from the northern region of BoB to the Plateau and Southwest China, as well as the southeast WVT from SCS and the WP, is much stronger than that in August. The southeast WVT turns into a southwest transport over 97.5° to 110°E at the east flank of the Plateau, where it converges with the southerly transport from the northern region of BoB, marches northward, passes the Yunnan-Guizhou plateau, Sichuan Basin, converges in the westerly moisture transport at mid-latitudes, and provides moisture for Northwest and North China. In September, the water vapor of the main Plateau body is still from the mid-latitude westerly moisture transport. The mainland of China east of the Plateau is influenced by the WVT mainly from the SCS, the WP and the BoB.

In October (Fig. 1c), WPSH retreats southward and its ridge is near 25°N. The easterly WVT from the SCS and the WP turns into southwesterly WVT between 17.5°N and 22.5°N over Indochina, and transports water vapor to the region east of 95°E in Asia. In October, the transport from the northern part of BoB decreases and the easterly moisture transport from the SCS and the WP region becomes the most important transporting flow for the areas east of the Plateau. In this month, the moisture of the main body of the Plateau still comes from the mid-latitude westerlies.

In November, the easterly WVT from the Pacific significantly strengthens and advances westwards to the Arabian Sea. A small part of easterly moisture transport changes direction over Indochina and the SCS and transports water vapor to China's mainland, but the strength is very weak.

By analyzing the WVT characteristics of the Plateau and its surrounding areas, it can be found that, from August to October, the easterly moisture transport from the SCS and the WP has a great impact on Sichuan Basin, Northwest China and other regions, which are east of the Plateau. Besides, this effect is achieved through a unique way of long-distance transport. From August to October, the water vapor over the SCS and the WP is firstly transported to the southeast flank of the Plateau (97.5° to 110°E, 17.5° to 25°N), and converges with the moisture from the northern region of BoB. Secondly, the converged water vapor marches northward with the southerly over the region, passes the Yunnan-Guizhou Plateau, Sichuan Basin and the eastern part of Northwest China, finally converges with the westerly moisture transport at midlatitudes, and continues to advance to North China, affecting the precipitation climate of the areas it passes. It can be seen that the eastern side of the Plateau (including Sichuan, Chongqing and other regions), as a relaying station on the WVT path from the SCS and the WP to Northwest and North China, plays a significant role in the water vapor budget of most regions in China.

The following is a discussion of the contribution to the regional water vapor budget by the special long-distance transport route mentioned above. Fig. 2 shows the monthly average water vapor budget of the various regions on the moisture transport channel from August to October. To Region A (mainly including South China, northern part of the SCS and neighboring area of the WP), there are separately 117.1×10^5 kg s^{-1} and 111.8×10^5 kg s^{-1} of water vapor input from its east and south boundary, and there is 82.9×10^5 kg s^{-1} of water vapor output to the middle and lower reaches of the Yangtze River from its north boundary, and 167.4×10^5 kg s^{-1} of water vapor output from its west boundary to Region B (at the southeast flank of the Plateau, mostly including the western Guangxi, southern Yunnan and neighboring areas on Indochina). Averaged from August to October, in general, Region A is a water vapor source and has an output 21.4×10^5 kg s^{-1} of water vapor, which comes from the SCS and the WP.

The easterly WVT from the SCS and the WP passes through the west boundary of Region A and enters Region B, and the input value of this flow is almost 2 times the input value (89.9×10^5 kg s^{-1}) from the south boundary of Region B and three times the input value from the west boundary (58×10^5 kg s^{-1}), and it is the strongest input transport flow, which is very important to the water budget of Region B. Averaged from August to October, there are 155.7×10^5 kg s^{-1} of water vapor entering Region C (mainly including the northern part of Yunnan, Sichuan and other places) from the north boundary of Region B, which is the main input source of water vapor of Region C. To Region D (the eastern

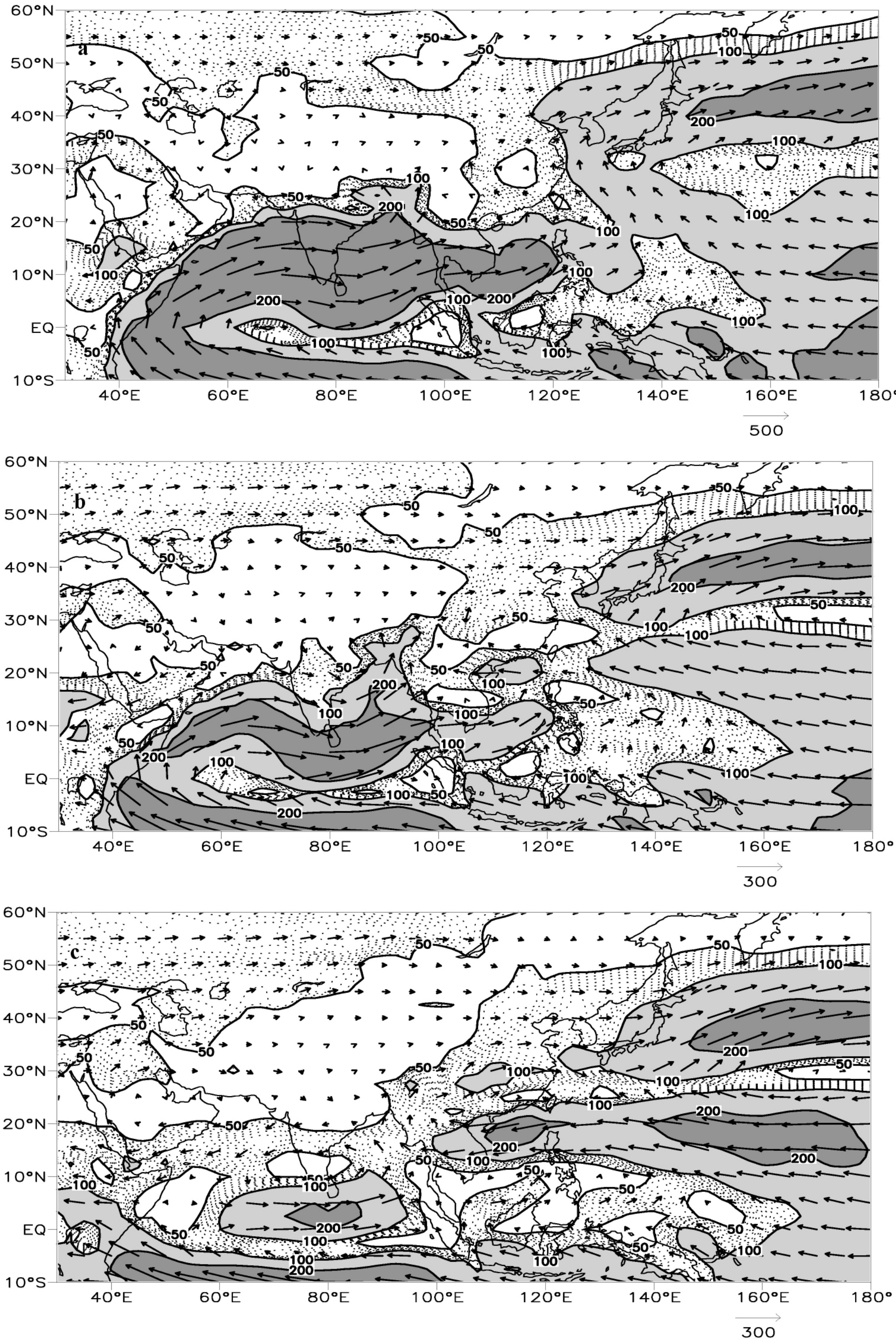

Figure 1. Climatological distribution of vertically integrated water vapor flux vectors averaged from 1971 to 2000. Unit: kg m^{-1} s^{-1}. a: August; b: September; c: October (the dotted-line, light-shaded and heavy-shaded areas denote the transport ≥ 50, 100 and 200, respectively).

part of Northwest China), the WVT from the north boundary of Region C (110.3× 10^5 kg s^{-1}) is the most important source of water vapor. Region D has an output of 178.8× 10^5 kg s^{-1} of water vapor from the east boundary to Region E (North China). For the entire Region E, the WVT from Region D is the primary water vapor input and the value is 2 times more than that from its south boundary. Based on the WVT situation and water vapor budget of the Plateau and its surrounding areas from August to October, it clearly shows how the water vapor of low-latitude oceans, such as the SCS and the WP, is transported to the inland areas east of the Plateau through a special transmission mode, which is like a relay transport. In this paper, it is named as long-distance-relayed WVT (referred to as LRWVT hereafter). For the various regions east of the Plateau,

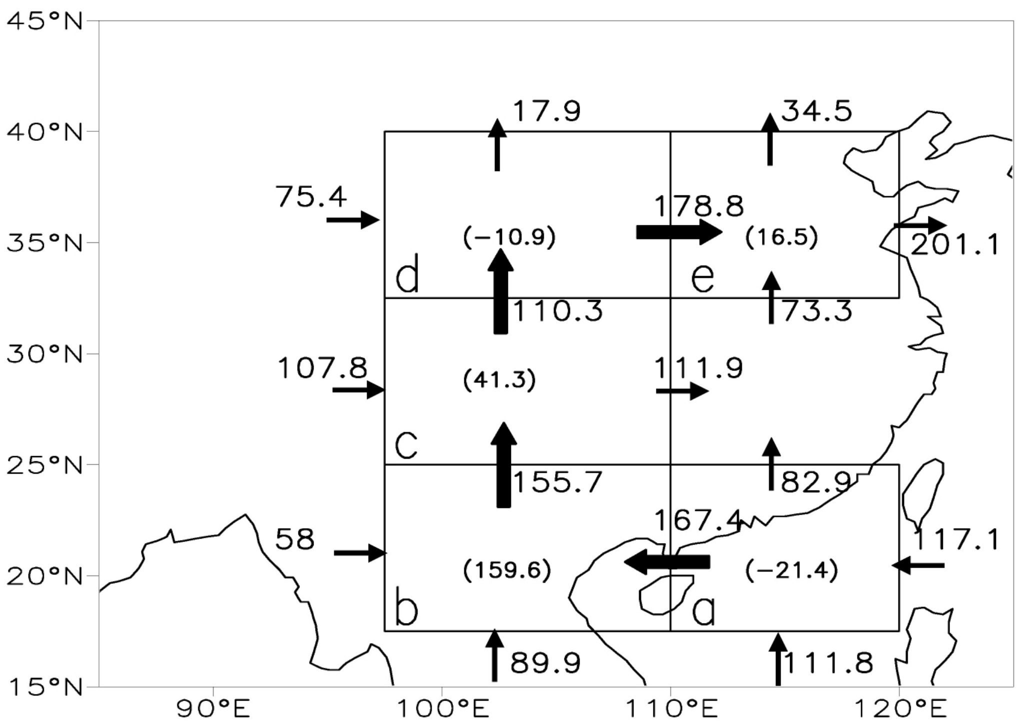

Figure 2. Water vapor budget averaged from August to October in various regions of the LRWVT from the SCS and the WP averaged from 1971 to 2000 (arrows indicate the direction of the water vapor input (output), the value in brackets is the regional water vapor net income, and the positive value shows the moisture convergence). a: (17.5°-25°N, 110°-120°E); b: (17.5°-25°N, 97.5°-110°E); c: (25°-32.5°N, 97.5°-110°E); d: (32.5°-40°N, 97.5°-110°E); e: (32.5°-40°N, 110°-120°E). Unit: 10^5 kg/s.

this special way of transport plays a great role in the regional water vapor budget.

3.2 *Activity characteristics of LRWVT from SCS and WP*

Under the background of climatological mean, the first step of the LRWVT from the SCS and the WP is that the easterly transport of moisture expands westward into the SCS, the WP and South China (Region A in Fig. 2). Firstly, analyze the activity characteristics of the easterly WVT over the latitude zone of 17.5° to 25°N. In Fig. 3, the thick solid line shows the westward expansion of the easterly moisture transport. In early May, the easterly WVT appears near 130°E. In late May, the SCS summer monsoon breaks out, the easterly WVT between 110°E and 140°E enhances significantly, and the easterly WVT obviously retreats eastward. At the beginning of June, the easterly WVT rapidly expands westward again and its forefront gets close to 115°E (South China) in early July. Afterwards, the easterly WVT withdraws slightly eastward. In early August, it goes rapidly westward again and arrives at 97.5°E at the beginning of September. Since then, the forefront of the easterly WVT has stayed near 100°E for a month. It starts withdrawing in late October and retreats westward to 110°E in early November. By analyzing pentad-based distribution of the WVT, it can be found that in Pentad 44, the easterly WVT from the SCS and the WP passes the Guangdong and Guangxi area and expands westward into Yunnan province near 100°E, and then changes its transport direction and marches northward. Afterwards, the water vapor from the SCS and the WP is transported to the region east of the Plateau in such a unique relay way that it affects the precipitation climate of the region it passes. The transport situation mentioned above lasts until the end of October (Pentad 60) before it weakens and disappears. From August to October, there maintains a strong southerly WVT over the region east of the Plateau (especially between September and October, the southerly WVT over this region is even stronger than other areas located at the same latitudes in eastern China.), which is caused by the LRWVT from the SCS and the WP.

3.3 *Impacts of the LRWVT from the SCS and the WP*

3.3.1 IMPACT FACTS

At the climatological mean field of the WVT, the LRWVT from the SCS and the WP mainly affects Southwest China, Northwest China and other places east of the Plateau from August to October. Our analysis reveals that the precipitation of these regions has some common regional features. In these regions (Fig. 4), the precipitation between August and October accounts for more than 30% of annual precipitation, and in most areas, even more than 40%. In addition to it, in most areas on the WVT channel, the precipitation of August is the annual maximum. For example (Fig. 5), In Ya'an, which is located in western Sichuan Basin, the precipitation of August can reach 448 mm, accounting for 26% of the annual total, and its rainfall from August to October amounts to 757 mm, accounting for 44%. In Lanzhou, north of Ya'an, the precipitation of August reaches 75 mm, accounting for 24% of the annual total and the rainfall from August to October amounts to 143 mm, accounting for 46%. In Yan'an (Figure omitted), the precipitation in August is 119 mm, accounting for 22% of the annual total, and the rainfall from August to October amounts to 238 mm, accounting for 45%.

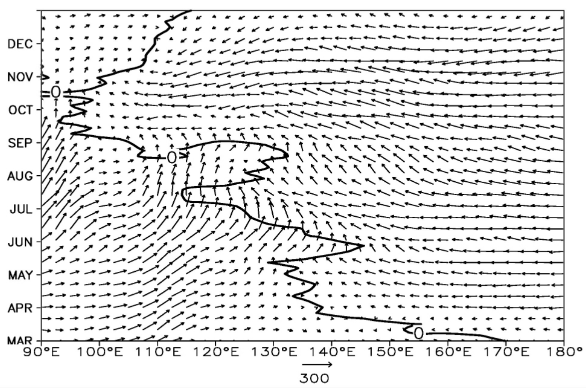

Figure 3. Time-longitude section of pentad-based water vapor flux averaged from 1971 to 2000 along 17.5°-25°N from March to December. Solid lines denote $Q_\lambda=0$. Unit: kg m^{-1} s^{-1}.

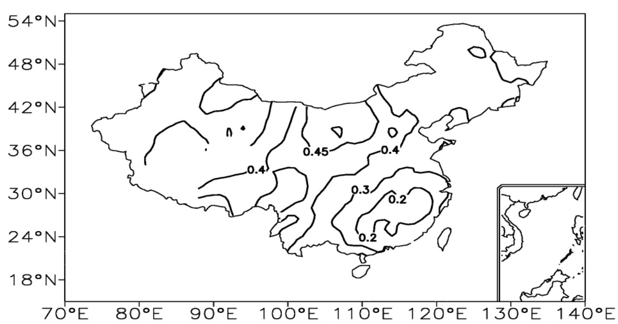

Figure 4. Proportion of the precipitation from August to October to the annual precipitation in China averaged from 1951 to 2011.

Further analysis discovers that, from August to October, the precipitation of the most areas of Southwest China and Northwest China on the transport channel east of the Plateau not only has some common regional features in monthly distribution, but also has significant regional relevance in interannual variability. In Fig. 6, the western Sichuan Basin, South China, most areas of Yunnan, Gansu, Shaanxi, Shanxi, and Hebei are regions of obviously positive correlation, and positive correlation is very significant in inland regions far from the sea (shown by the shaded areas in Fig. 6). Such correlation distribution of the regions east of the Plateau indicates that, from August to October, when the precipitation of the western Sichuan Basin is more than normal, the precipitation of South China, the eastern part of Northwest China and North China is also above normal. Conversely, when the rainfall of the western Sichuan Basin is less than average, the precipitation of South China, the eastern part of Northwest China and North China is also below average. Based on all the analyses above, it shows that, from August and October, the precipitation of Yunnan, Sichuan, Gansu and other areas east of the Plateau is closely linked both in the intra-annual and inter-annual variation.

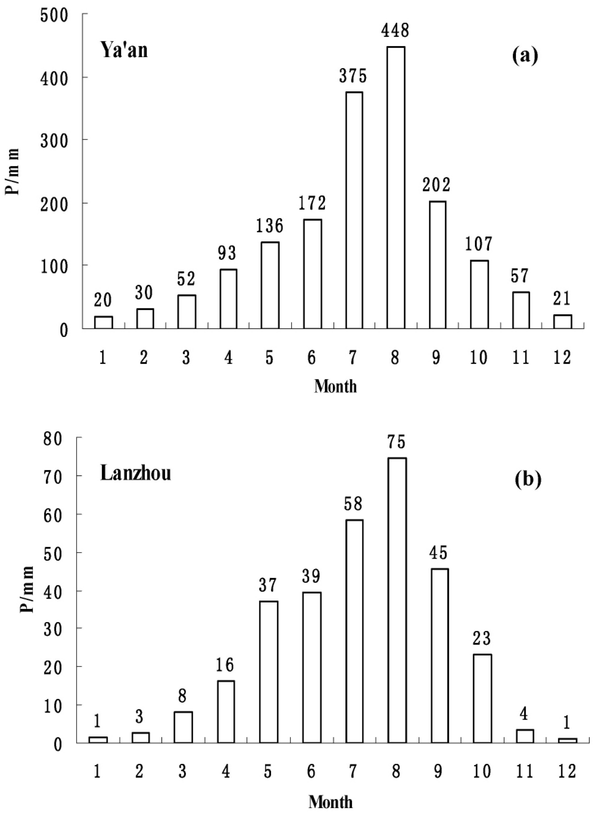

Figure 5. Monthly precipitation variation of Ya'an (a) and Lanzhou (b) averaged in 1951-2011. Unit: mm.

Figure 7 gives the simultaneous correlation between the precipitation of the region east of the Plateau averaged from August to October and the WVT flux. It is known from the figure that, from August to October, the amount of the precipitation of the region east of the Plateau is closely related to the strength of two WVT flows, one being from the SCS and the WP and the other being in the mid-latitudes. The former passes South China and expends westward into the inland of China, changes its transport direction over the areas southeast of the Plateau, and then marches northward and converges with the latter over the regions of the western Sichuan Basin and the eastern part of Northwest China. Obviously, the first significantly related flow is the LR WVT flow from the SCS and the WP. The positive relationship shows that, from August to October, the stronger this southerly WVT is, the more water vapor from the SCS and the WP is being transported to the eastern side of the Plateau, and the more precipitation of the region east of the Plateau is. The analysis shows that the water vapor transport from the SCS and the WP is a main influencing factor that affects the amount of regional precipitation east of the Plateau, and it can be further stated that this special way of WVT is an important contacting mechanism closely related to the regional precipitation changes east of the Plateau from August to October.

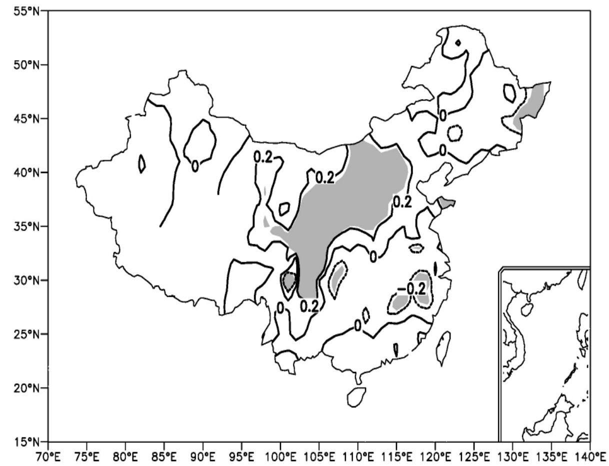

Figure 6. Correlation between the precipitation in the western Sichuan Basin averaged from August to October and the simultaneous precipitation of 160 stations in China from 1951 to 2011 (The precipitation of the western Sichuan Basin is represented by the averaged value of Mianyang, Chengdu and Ya'an, and the shaded area is over the 95% significance level).

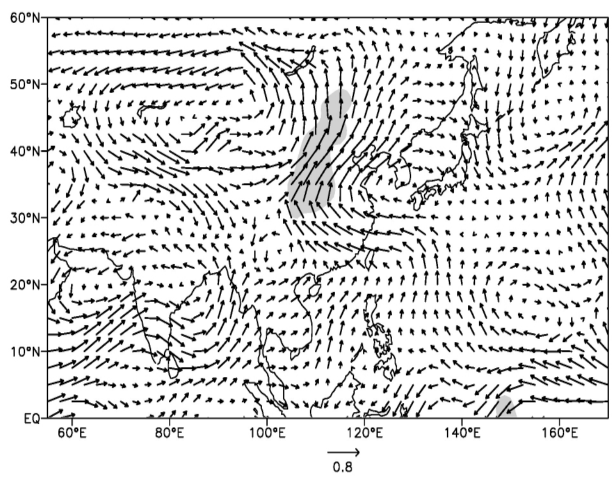

Figure 7. Correlation between the regional precipitation east of the Plateau averaged from August to October and the simultaneous WVT flux in 1951-2011 (shaded area is over the 99% significance level).

3.3.2 INFLUENCE MECHANISM

On the climatological mean field of the WVT in August (summer) and September and October (autumn), the LRWVT can be found to come from the SCS and the WP. In some cases, however, this LRWVT may establish without appropriate coordination of the atmospheric circulation in the mid- and higher-latitudes, which results in large amount of water vapor just passing by and being unable to converge and form precipitation over regions east of the Plateau. Then, what kind of atmospheric circulation background will facilitate the occurrence of regional precipitation?

In order to determine the atmospheric circulation background facilitating the occurrence regional precipitation over areas east of the Plateau, 11 years for which the regional precipitation is above normal and 10 years for which it is less than normal are selected from the annual rainfall variation series of the region east of the Plateau averaged from August and October. It can be seen that, in the years of more precipitation (Fig. 8a), the easterly moisture transport flow anomalously stronger than the climatological mean from the SCS and the WP shifts northward over the eastern side of the Plateau, and converges with the WVT going down southward from Lake Balkhash over the western Basin, the Great Bend of Yellow River area and North China (Fig. 8b). Obviously, the significantly anomalous flow is the LRWVT flow from SCS and the WP mentioned above. This special WVT channel is an important influencing factor that affects the amount of regional precipitation east of the Plateau from August to October, which is consistent with the correlation results above.

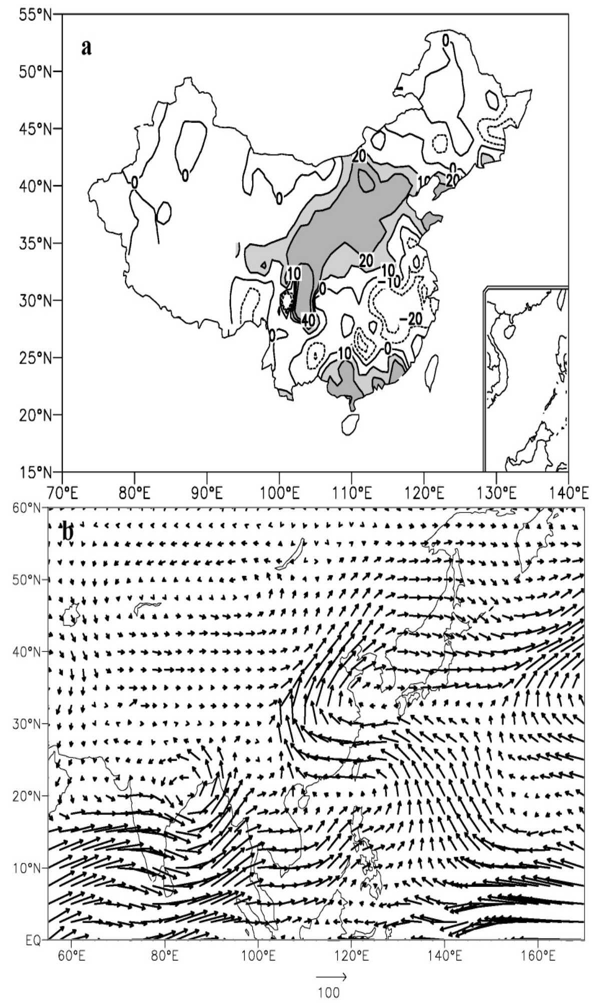

Figure 8. Precipitation anomaly (a, mm) in China and WVT flux difference field (b, kg m^{-1} s^{-1}) between more and less rainfall years for the region east of the Plateau averaged from August to October in 1951-2011 (with the more rainfall years minus the less rainfall years).

Figure 9 is the difference of 100-hPa geopotential height field averaged from August to October between the more and less rainy years selected above. In Fig. 9, the region from 20°N to 40°N, which is covered by the main body of the South Asian high (SAH) from August to October, is a zone that is all positively anomalous, and the positive anomaly in the regions east of 90°E, including Sichuan, Changjiang-huaihe region, North China, Yellow Sea and Sea of Japan is particularly significant (as indicated by shades in Fig. 9). The region south of 20°N is in negative anomaly. Based on the distribution pattern of 100-hPa geopotential height field from August to October, the difference shows that, when the region east of the Plateau is in the more rainy years, SAH is generally stronger than normal and significantly enhances, lifting northward and extending eastward over the Sichuan Basin, the eastern part of northwest, North China and other areas east of the Plateau, which is favorable for lower-level WPSH to maintain in a northward and westward position.

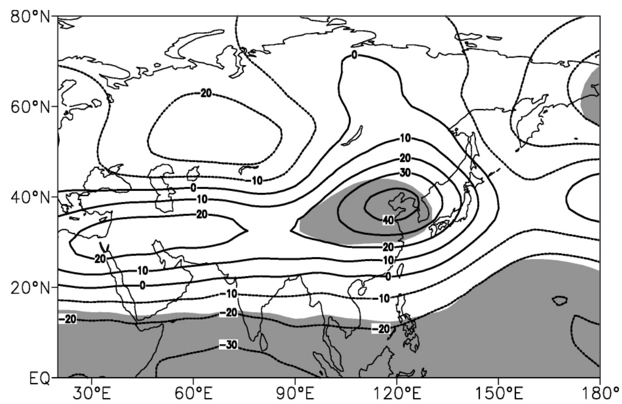

Figure 9. Difference of 100-hPa geopotential height field between more and less rainfall years of the region east of the Plateau averaged from August to October in 1951-2011 (with more rainfall years minus less rainfall years, and the shaded areas are at the 95% confidence level of *t*-test). Unit: gpm.

Figure 10d is the difference of 500-hPa geopotential height field averaged from August to October between the more and less rainfall years. In Fig. 10d, from west to east, the mid- and higher-latitude region of Eurasian continent (40° to 60°N) exhibits a distribution pattern that is positively, negatively and then again positively anomalous. The area west of 40°E is in positive anomaly while Lake Balkhash and the adjacent region are in significantly negative anomaly (passing the 95% confidence level of the *t*-test), and the area east of Lake Baikal in eastern Asia is in positive anomaly. Negative anomaly is found south of 30°N of the WP and significantly negative anomaly exists south of 20°N from 20°E to 120°E. Based on the climatologically averaged distribution of the 500-hPa geopotential height field from August to October, the difference pattern like this shows that, when the region east of the Plateau is in more rainfall years, there is a wide low-pressure trough over Lake Balkhash and its surroundings. Under the circulation like this, the shortwave troughs over the area of Lake Balkhash easily guide northern cold air to go down southward, which is conducive to the development of weather systems over the eastern side of the Plateau and eventually leads to the occurrence of rainstorm. Besides, the difference pattern over the WP shows that, in more rainfall years of the region east of the Plateau, WPSH has a more northward location than the climatological average, and the western part of Sichuan Basin and the eastern part of Northwest China are located near its west and northwest edge. In addition, the India-Burma trough over the Indian Peninsula is stronger than normal. This kind of pattern of WPSH and India-Burma trough is conducive for the water vapor from the SCS and the WP along the edge of WPSH to arrive in Sichuan and its northern region through the relay transport.

Taking into account the difference of the atmospheric circulation between August, September and October, we separately selected the years of more and less precipitation in the region east of the Plateau on a monthly basis, and carried out composite analysis. The difference field of the WVT flux between the years of more and less rainfall of every single month is similar to that of Fig. 8b, and the most significantly anomalous transport flow is the LRWVT flow from the SCS and the WP, whose strength plays a great role in the precipitation amount of the region east of the Plateau (figure omitted). Take the monthly difference pattern of 500-hPa geopotential height for example. In Fig. 10a, 10b and 10c, it is can be found that the anomalous distribution pattern in different month is close to each other, particularly for Lake Balkhash, the Yellow Sea, the Bohai Sea, the Indian Subcontinent and other regions. Combine the climatologically averaged atmospheric circulation with the corresponding monthly difference distributions of 500-hPa geopotential height from August to October, we found that, in more rainfall years, there is a wide low-pressure trough over Lake Balkhash and its surroundings, the WP subtropical high has a northward displacement than the climatological average, and the western part of Sichuan Basin and the eastern part of Northwest China are located near its west and northwest edge, and the India-Burma trough over the Indian Peninsula is stronger than normal. These conclusions are consistent with the previous analysis of the average over August to October as well as the related analysis results about 100 hPa.

In order to verify the results above, we picked a heavy rainstorm that occurred in the region east of the Plateau from August to October for analysis. On August 15-17, 1981, a heavy rainstorm took place in Sichuan, Gansu, Shanxi, Hebei and other regions east of the Plateau. The LRWVT from the SCS and the WP pro vides sufficient water vapor for the development of this rainstorm, which is one of the important conditions for

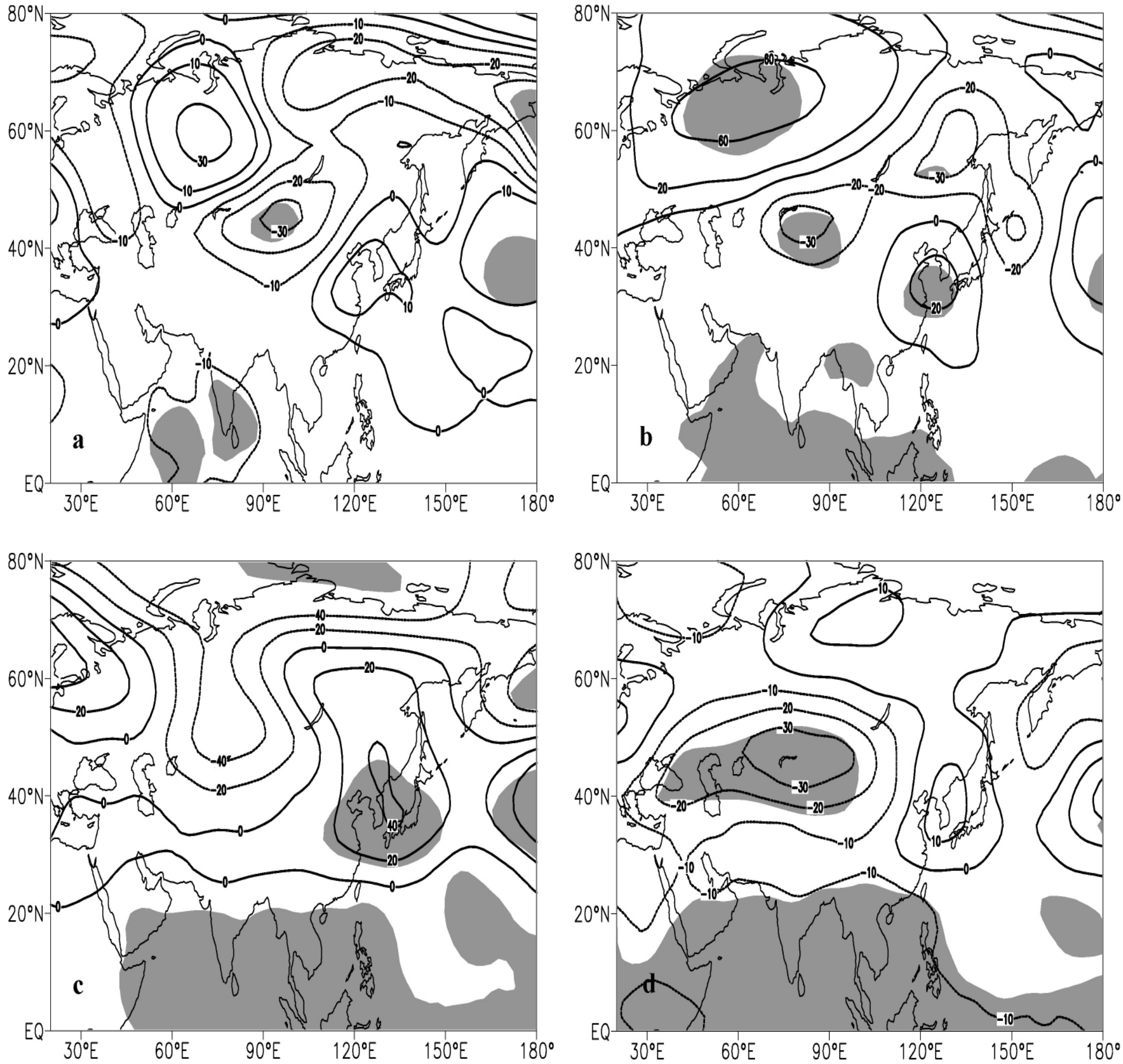

Figure 10. Difference of 500-hPa geopotential height field between more and less rainfall years of the region east of the Plateau in August (a), September (b), October (c) and averages from August to October (d) in 1951-2011 (with the more rainfall years minus the less rainfall years, and the shaded areas are at the 95% confidence level of *t*-test). unit: gpm.

the rainstorm formation and development (Fig. 11a). In the process of this heavy rainstorm, SAH in the 100-hPa geopotential height field is generally stronger than normal and significantly enhances with its northward advance and eastward extension over the region east of the Plateau (figure omitted). In the 500-hPa geopotential height field, from August 15 (Fig.11b) to August 17, there is always a broad low-pressure trough over Lake Balkhash and Lake Baikal, shortwave troughs over the area of Lake Balkhash steer northern cold air to go down southward, which at last leads to the generation and development of the Southwest Vortex over the eastern side of the Plateau (The rainstorm of August 15-17, 1981 is the product of the interaction between the Southwest Vortex, the westerly disturbances along the broad low-pressure trough over Lake Balkhash and Plateau Vortex moving eastward in the westerly belt). The western frontier of WPSH is near 105° E and its ridge (105° to 110°E) lies between 27.5°N and 30°N, and the western part of Sichuan Basin and the eastern part of Northwest China are located in the west and northwest edge of WPSH. This conclusion drawn from of the case is consistent with that determined through the composite analysis above.

Therefore it can be concluded that the large-scale circulation background of the LRWVT route from the SCS and the WP impacting the precipitation of the eastern side of the Plateau are as follows: At the high level, SAH is generally stronger than normal and significantly enhances with its northward advance and eastward extension over the region east of the Plateau. At the mid-level, a broad low-pressure trough is over Lake Balkhash and its surroundings, WPSH has a more northern and western location than normal, and the western part of Sichuan Basin and the eastern part of Northwest China are located in the west and northwest edge of

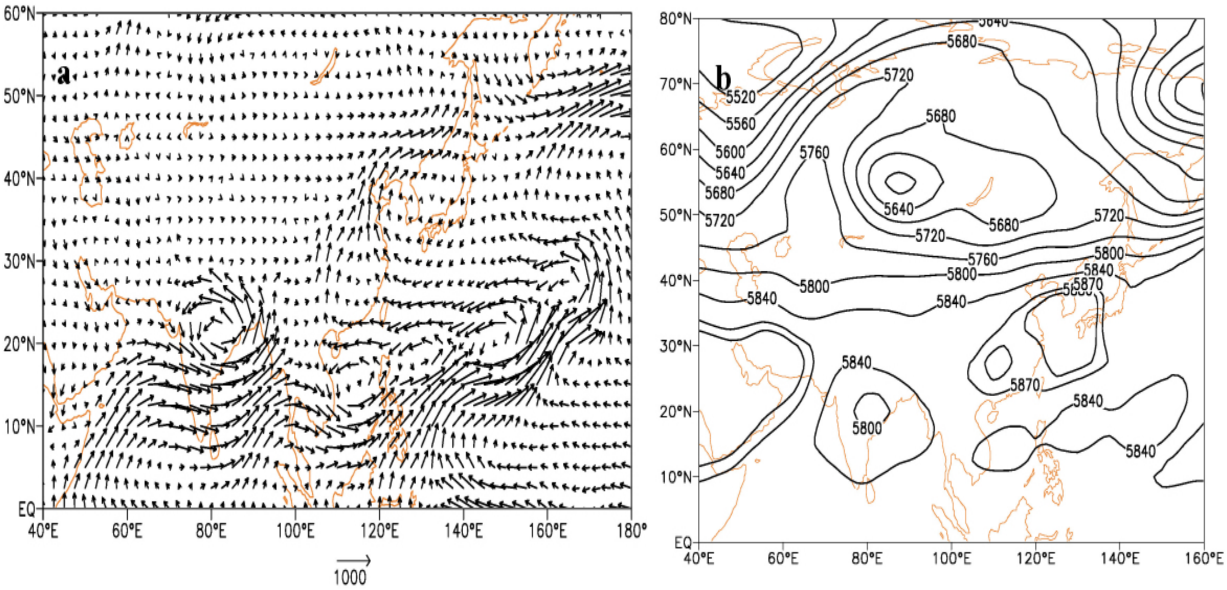

Figure 11. Water vapor flux (a, kg m^{-1} s^{-1}) and 500-hPa geopotential height field (b, gpm) on August 15, 1981.

WPSH.

4 CONCLUSIONS AND DISCUSSION

The present paper reveals that from August to October, over the eastern side of Plateau, there exists a unique LRWVT route, and the water vapor from the SCS and the WP can affect the Sichuan Basin, Northwest and other regions far from the sea in low latitudes through this way. At the climatological mean field of the WVT, the LRWVT route from the SCS and the WP establishes in Pentad 44 in early August and disappears at the end of October (Pentad 60). From August to October, the precipitation of the region east of the Plateau is closely linked both in the intra-annual and inter-annual variation, and the LRWVT from the SCS and the WP is an important contacting mechanism closely related to the regional precipitation changes east of the Plateau from August to October. The large-scale circulation background of the LRWVT from the SCS and the WP impacting the precipitation of the region east of the Plateau are as follows: At the high level, SAH is generally stronger than normal and significantly enhances with its northward advance and eastward extension over the region east of the Plateau. At the mid-level, a broad low-pressure trough is over Lake Balkhash and its surroundings, WPSH has a more northward and westward location than normal, and the western part of Sichuan Basin and the eastern part of Northwest China are located in the west and northwest edge of WPSH.

In autumn, as the summer monsoon retreats southward, the rainy season comes to an end in most parts of China. However, West China, such as Sichuan, Chongqing, Guizhou, Gansu, Shaanxi and other places, often have continuous rain with wide coverage and long duration (Xu and Lin[29]; Bai and Dong[30]; Yuan and Liu[31]; Luo et al.[32]). This continuous rain is called the Autumn Rain of West China (ARWC), which is a special weather phenomenon in China. ARWC is characterized by continuous drizzle and rain days. Therefore, the intensity is always weak and the rainfall amount is not very large. The main rainfall period of ARWC is in September and October[31-32]. Combined with the climatological characteristics of the WVT pattern of these two months (Fig. 1b and 1c), it can be found that, in addition to the southwesterly WVT from the BoB, the LRWVT from the SCS and the WP has a great role in the precipitation of West China. Some studies about ARWC have found the LRWVT is special because it is an important influencing factor that affects the strength of ARWC (Bao and Li[33]; Li et al.[34]).

In addition, this article mostly discusses the features of the LRWVT from the SCS and the WP and its impacts. Yang et al.[35] pointed out that the water vapor from the SCS and the WP changes direction over the southeast side of the Plateau, marches northward, passes Sichuan Basin, and changes transport direction for the second time over the eastern part of Northwest China on the northeast side of the Plateau, transports westward and arrives in Xinjiang, providing moisture for the regional rainstorm. Such a WVT way is also a LRWVT from the tropical low-latitude oceans to inland areas. As the analysis reveals that these special WVT channels occur almost around the large terrain of the Plateau, therefore, are there any impacts on their establishment and maintaining because of the Plateau? And if so, what kind of impact it is and what are the influence mechanisms and processes? These issues are unclear at present. In order to further understand the facts of impact and mechanisms by the Plateau on the climate in China, these issues need to be studied further in the future.

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