Analysis of the First Rainstorm in the Rainy Season in Dehong under the Influence of the Bay of Bengal Storm

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Abstract Starting from the Bay of Bengal storm, based on conventional meteorological data, FY2G meteorological satellite data, EC fine grid data and ERA5 reanalysis data, the first rainstorm process in Dehong Prefecture in the early summer of 2024 was analyzed. The results show that the strengthening and northeastward movement of the Bay of Bengal storm "Remal" was the main influencing system for the generation of continuous heavy precipitation in Dehong Prefecture from May 25 to 27, 2024. The establishment and strengthening of the low-level southwest jet stream provided better dynamic, water vapor and energy conditions for the generation of this heavy precipitation. The generation and maintenance of rainstorm required the transportation of a steady stream of water vapor to the rainstorm area, and there was strong convergence of water vapor in the rainstorm area. Therefore, in the forecast of summer rainstorm, whether the low-level jet stream is generated or not is very important for the forecast of rainstorm. In addition, there was a good corresponding relationship between the falling area of heavy precipitation, precipitation intensity and duration, and low-level water vapor convergence area. The establishment of southwest monsoon is of great significance to the beginning date of rainy season in Dehong Prefecture. The beginning date of rainy season in Dehong Prefecture was closely related to the first rainstorm process in Dehong Prefecture in early summer. In the future prediction of the beginning date of rainy season in Dehong Prefecture, the first statewide rainstorm process in early summer should be the key point for the prediction.

Key words Bay of Bengal storm; First rainstorm; Heavy precipitation; Beginning date of the rainy season; Southwest monsoon; Low-level jet stream

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Dehong Prefecture is located in the low-latitude plateau area, and has the South Asian tropical monsoon climate. In summer, under the influence of southwest monsoon from the Bay of Bengal, rainfall is abundant, and it has distinct climatic features in dry and wet seasons. In the dry season, there is less natural precipitation, and forest fires occur sometimes; meteorological drought is obvious, which has a great impact on social and economic development and people's life. In the face of extremely severe situation of disaster prevention and reduction, it is of great significance to strengthen the research on the forecasting technology of the beginning of rainy season in Dehong Prefecture. In early summer every year, the first heavy rainfall weather process in the prefecture mostly occurred in the transition period of dry and wet seasons, and its causes have been paid great attention to by forecasters. Whether the first heavy rainfall process in the rainy season in Dehong Prefecture can be accurately predicted in advance is of great significance for alleviating winter and spring drought and agricultural production in the whole prefecture, and relevant departments pay high attention to it, which is also a great responsibility for meteorological departments. Therefore, it is very important to accurately forecast the first heavy rainfall process in the rainy season in Dehong Prefecture. Niu Fabao *et al.* [15] analyzed the weather process of the first provincial heavy precipitation in Yunnan in May 2010, and found that the interaction between the Bay of Bengal storm and the monsoon trough was the main reason for the formation of the first provincial heavy precipitation in Yunnan in 2010. From the analysis of causes of the first heavy rainfall process in Yunnan in 2016 under the influence of MJO, Mi Ruizhi *et al.* [1] found that the activity center of MJO was located in the "wet window" period of Yunnan, and the strengthening and northeastward movement of the Bay of Bengal storm "Roanu" and the southward movement of the Sichuan – Yunnan shear line were the main causes of the heavy rainfall process in Yunnan Province. Zheng Jianmeng *et al.* [7] pointed out that from spring to early summer, the activities of the southern trough generally brought strong convective weather such as thunderstorms, gales, and hail to Yunnan, and it is difficult to form large-scale heavy precipitation, while the Western Pacific subtropical high could only bring relatively large precipitation to southeastern Yunnan during this period. Only when the Bay of Bengal monsoon breaks out and southwest monsoon moves northwards to affect Yunnan, can it cause large-scale heavy precipitation and realize the conversion of dry and wet sections in Yunnan.

In recent years, there have been many studies on rainy season in Yunnan, low pressure (storm) in the Bay of Bengal, and southwest monsoon, and many achievements have been made. However, for meteorological departments of Dehong Prefecture, there are few relevant studies on the beginning of rainy season in Dehong Prefecture. Due to the complex topography of Dehong Prefecture, the prediction of heavy rainfall under the influence of complex topography is always a difficult problem for forecasters to overcome, so whether all previous research results are applicable to Dehong Prefecture remains to be tested. In addition, May is the

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transition period of dry and wet seasons in Dehong Prefecture, and the atmospheric circulation is in an obvious adjustment period, which makes it more difficult to predict a heavy precipitation process.

From May 25 to 27, 2024, under the influence of the outer flow of low pressure in the Bay of Bengal, Dehong Prefecture suffered the first statewide heavy precipitation weather process since the flood season, mainly with moderate-to-heavy and local rainstorm and single-point heavy rainstorm. This process has made five counties and cities in the prefecture enter the rainy season one after another, and forecasters have made accurate forecasts of this heavy precipitation process in advance, which has remarkable service effect and has launched the first shot of disaster prevention and reduction. Therefore, it is necessary to conduct detailed analysis and summary of this process. In this paper, starting from the Bay of Bengal storm, based on conventional data and reanalysis data, the influence system and physical mechanism of this heavy precipitation process were analyzed to provide some useful enlightenment for predicting the beginning date of rainy season in Dehong Prefecture in the future.

1 Characteristics of actual situation, disaster situation and social impact

1.1 Precipitation situation From May 25 to 27, 2024, there was an obvious continuous heavy precipitation process in Dehong Prefecture, which mainly distributed in the west of Yingjiang, the north of Longchuan, most part of Lianghe and the east of Mangshi (Fig. 1). Among these regional stations in the prefecture, the cumulative rainfall of 32 stations was above 100 mm, accounting for 25.6%. That of 44 stations was 50 – 100 mm, accounting for 35.2%. In 31 stations, cumulative rainfall was 25 – 50 mm, accounting for 24.8%. The cumulative rainfall of 18 stations was below 25 mm, accounting for 14.4%. The cumulative precipitation of the five big stations in the prefecture is as follows: Mangshi 85.2 mm, Ruili 20.3 mm, Longchuan 55.6 mm, Yingjiang 52.0 mm, and Lianghe 87.1 mm. On May 25, there was mostly heavy rain or rainstorm and locally downpour in Lianghe, mostly moderate or heavy rain and locally rainstorm in Yingjiang, and small or moderate rain in other counties and cities. The maximum rainfall appeared in Guanzhang station of Lianghe County, up to 109.3 mm, and the maximum rainfall intensity was 53.3 mm/h. Among the regional stations, heavy rainstorm happened in 1 station, and rainstorm appeared in 5 stations. On May 26, moderate or heavy rain happened in Ruili, and heavy rain or rainstorm appeared in other counties and cities. The maximum rainfall was 95.5 mm, appearing in Shimiwadi, Sudian, Yingjiang County, and the maximum rainfall intensity was 67.9 mm/h. Rainstorm appeared in 25 stations. On May 27, moderate or heavy rain happened in Mangshi and Ruili, and there was mostly moderate or heavy rain and locally rainstorm in other counties and cities. The maximum rainfall appeared in Anle, Lianghe County, reaching 68.5 mm, and the maximum rainfall intensity was 14.3 mm/h. Rainstorm happened in 4 stations. This precipitation process was the first statewide heavy precipitation since the flood season in 2024, with main characteristics of large precipitation intensity, long duration, large cumulative rainfall, wide influence area, uneven temporal and spatial distribution of precipitation, and it was accompanied by lightning, gale, hail and other strong convection weather.

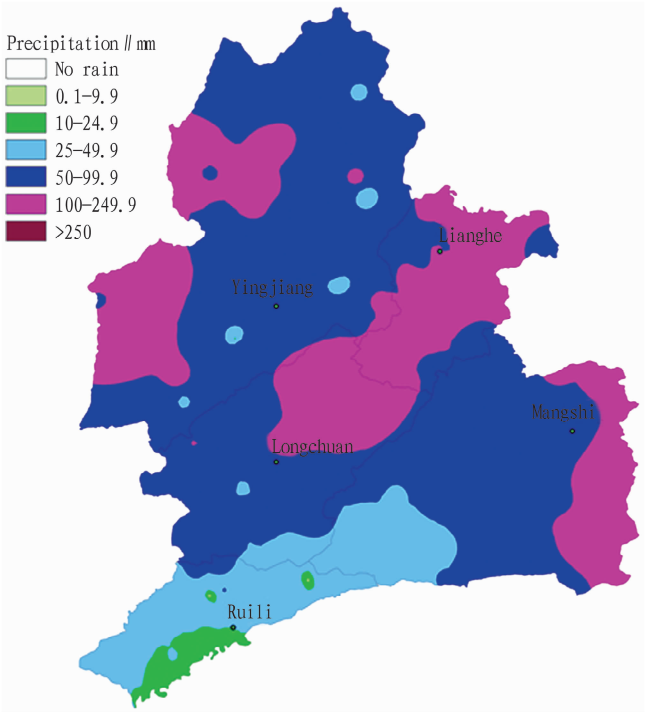


Fig. 1 Distribution of cumulative precipitation in Dehong Prefecture from May 25 to 27, 2024

1.2 Disaster situation and social impact Due to the large rainfall intensity, long duration, large accumulated rainfall, wide range of impact, the heavy rainfall weather caused different degrees of rainstorm, flood and hail disasters in Lianghe County, Mangshi, Longchuan County and other places, resulting in damage to houses, crops, and infrastructure, affecting more than 5 000 people, and leading to serious economic losses. Among them, Lianghe County suffered the most severe damage, involving more than 1 300 households in 31 villages of 5 townships, with direct economic losses of more than 7 million yuan.

For Dehong, the dry season is from the end of the rainy season in October to the beginning of the rainy season in next May. In the dry season, there is less natural precipitation and obvious meteorological drought, which has a great impact on people's production and life, and even leads to forest fires. In the face of the severe drought-relief situation, relevant departments at all levels in the prefecture are facing enormous pressure, so the emergence of the first statewide heavy rainfall process is of great significance. The strong precipitation process appeared at the end of May when Dehong Prefecture was in the transition period of dry and wet season. In the early stage, there were different degrees of meteorological drought in the whole prefecture, which affected people's production and life, so the obvious precipitation weather attracted wide attention from all walks of life. In addition, because of the heavy rainfall weather process, 5 counties and cities in Dehong Prefecture entered the rainy season one after another, so the first statewide heavy rainfall (rainstorm) process in Dehong Prefecture in early summer was closely related to the beginning of the rainy season in Dehong Prefecture.

2 Causes of heavy precipitation

2.1 Atmospheric circulation background Cyclonic storm "Renal", a tropical cyclone generated in the northern Indian Ocean, formed on the evening of May 25, 2024 over the northern surface of the Bay of Bengal (89.3° E, 19.8° N), and moved northwards at a speed of 10 – 15 km/h, gradually increasing in intensity. It landed from central Bangladesh to northeastern India from the night of May 26 to the morning of May 27, with winds of force 9 (23 m/s) near the center and a minimum pressure of 990 hPa in the center. After landing, it gradually moved towards north by east. Xu Meiling *et al.* [9] found that when moved to the east, the Bengal Bay storm had a great impact on Myanmar, Indo – China Peninsula and southwest China, and was one of the main weather systems causing heavy precipitation in southwest China. It can be seen that since landing, "Remal" began to move northeastwards to significantly affect Yunnan.

As can be seen from the evolution of FY2G meteorological satellite infrared cloud images (Fig.2), the convective cloud system was active in the Bay of Bengal after May 22, 2024, but the main location of the cloud system was southward, and the low-pressure spiral cloud system was not obvious. The low-pressure spiral cloud system formed at around 08:00 on May 24, and then continued to increase. The outer cloud system began to move to the north and east to affect Dehong. The low pressure in the Bay of Bengal continued to develop and strengthen, and reached storm level from the evening of May 25 to the early morning of May 26. From the cloud images, it can be seen that at 01:00 on May 26, a rainstorm cloud with strong central intensity formed in the north of the Bay of Bengal, and its outer spiral band cloud system was also strong, forming a huge storm cloud system on a planetary scale. Before the landing of "Remal", the center of the storm was stable and less moving, and continued to strengthen. The outer spiral cloud system continued to separate and cast convective clouds to affect Dehong, leading to precipitation weather in Dehong. The intensity of cloud system in the storm center reached its maximum for the first time at around 08:00 on May 26. It weakened slightly during the day on May 26, and strengthened again at around 16:00. Afterwards, it continued to strengthen as it moved northwards on a west-north track, and landed in the north-by-west direction of the Bay of Bengal (to west of 90° E) in the small hours of May 27. At the time of landing, the storm cloud system gradually spread out, and the track turned to the north-by-east direction. Moreover, it remained to the west of Dehong for a long time. The spread precipitation cloud system continued to move eastwards to form a "train effect", bringing continuous heavy precipitation weather to Dehong. In this process, the center of the Bengal Bay storm did not directly enter Yunnan, but precipitation weather appeared in most areas of Yunnan under the influence of the outer cloud system of "Remal". Especially in western and southwestern Yunnan, there was a relatively strong precipitation process, and precipitation was the strongest in western Yunnan. After the landing of "Remal", the weakened cyclonic circulation stayed on the north bank of the Bay of Bengal for a long time, which provided sufficient water vapor and energy conditions for the heavy precipitation process in western and southwestern Yunnan. Dehong is located in western Yunnan and is the window for southwest air flow from the Bay of Bengal to enter Yunnan. Therefore, when southwest air flow from the Bay of Bengal affected Yunnan along the westward path, it brought a large amount of water vapor to affect Dehong. Due to the special complex mountainous terrain in Dehong, relatively heavy precipitation was often produced under the influence of forced uplift of topography.

2.2 Atmospheric circulation pattern May is the transition period of dry and wet seasons in Yunnan Province, and the atmospheric circulation is in the transition period from winter circulation pattern to summer circulation pattern in the northern hemisphere, so it is very difficult to predict the heavy precipitation process[13]. Yan Huasheng *et al.* [11] studied the weather origin and atmospheric circulation background related to the precipitation in Yunnan in May, and pointed out that the equatorial convergence zone, the South Asian High, the West Pacific subtropical high and the seasonal transformation of atmospheric circulation were important factors affecting the precipitation. Zheng Jianmeng *et al.* [7] believed that there was a significant difference in the relationship between precipitation in different regions of Yunnan in May and sea surface temperature (SST) in different regions of the world. Zhang Jinwen *et al.* analyzed the influence of the atmospheric circulation in the southern hemisphere on the precipitation in May in Yunnan from the perspective of atmospheric circulation, and pointed out that the westerly potential anomaly in the Southern Hemisphere was related to the precipitation in May in Yunnan. He Yuan *et al.* discussed the phase characteristics of the Arctic oscillation and the snow cover in the Northern Hemisphere by using the wavelet condensation spectrum method, as well as the relationship between the changes of the two and the precipitation in Yunnan in May. Li Ting *et al.* studied the difference of rainfall in Yunnan in May under different phases of tropical intraseasonal oscillation, and pointed out that the eastward transmission of tropical intraseasonal oscillation led to the northward transmission of tropical convection, thus affecting the precipitation in Yunnan in May. It can be seen that the factors affecting the precipitation in Yunnan in May are very complicated. On the one hand, May is the transition period of dry and wet seasons in Yunnan. In the dry season, it is mainly affected by the westerly air flow. In the wet season, the westerly air flow weakens to disappear, and the southwest monsoon breaks out to bring a lot of water vapor. This seasonal change of atmospheric circulation directly or indirectly affects the evolution of various circulation systems. On the other hand, the interaction of different factors on different time scales causes the complexity of precipitation in Yunnan in May.

In this process, before the formation of the Bay of Bengal storm "Remal", there were "two troughs and one ridge" over

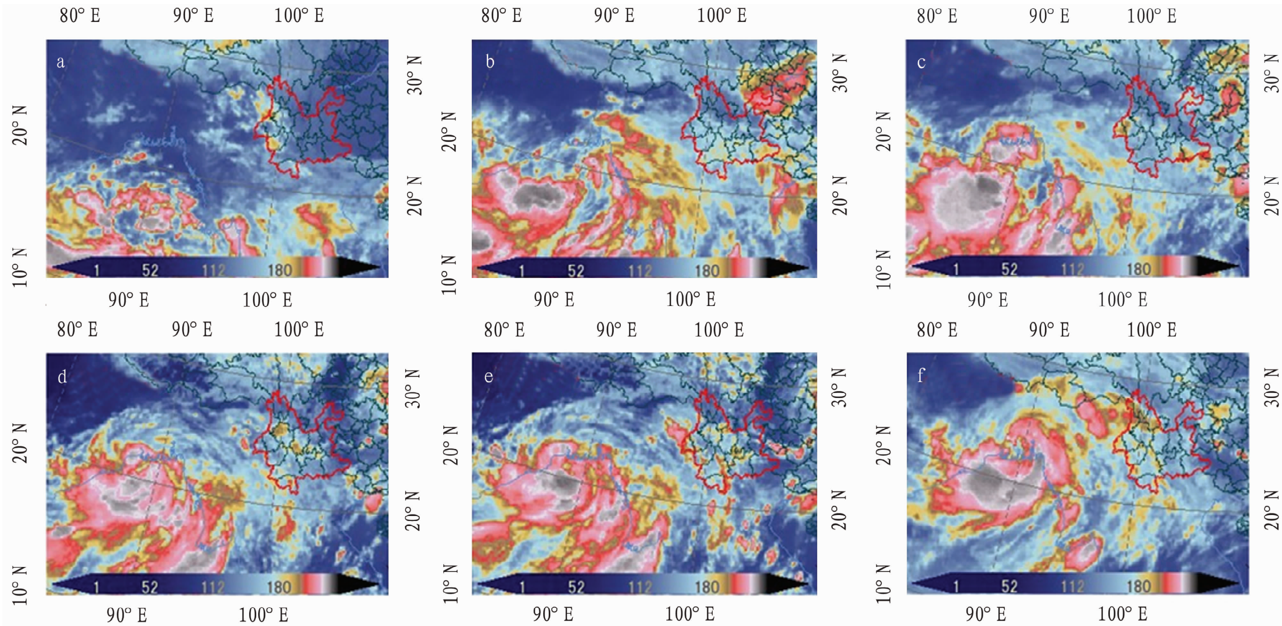
Yunnan at 500 hPa, a plateau trough in the east of the Qinghai – Tibet Plateau, a broad trough area from the east of the Indian Peninsula to the north of the Bay of Bengal, a high-pressure circulation in the west of the Indian Peninsula, and a subtropical ridge line from the center of the Indo – China Peninsula to the southern edge of Yunnan. As a result, the whole Yunnan was in the convergence area, which provided a good environmental condition for the southwest flow of Bengal Bay to transport warm and wet air to Yunnan. By 20:00 on May 25 (Fig. 3a), the high pressure over western India remained stable and intensified; the subtropical high moved westwards, and rose northwards; the ridge crossed 100° E, while the low-pressure circulation over the northern Bay of Bengal intensified. Due to the confrontation between the eastern and western high pressures, the low-pressure circulation over the Bay of Bengal remained stable and strengthened. Seen from the potential height field at 500 hPa, the storm center value was the lowest (only 576 dagpm) at 08:00 on May 26 (Fig. 3b), and remained until landing. As the subtropical high continued to extended westwards and rose northwards, guided by the southwest air flow on the west side of the subtropical high, Remal moved to the northeast after landing, and gradually weakened. Until about 20:00 on May 28, it weakened and disappeared in Myanmar to the east of 90°E on the southern side of the Qinghai – Tibet Plateau.

According to the wind field at 700 hPa, before the generation of the Bay of Bengal storm, wind speed was small from the north of the Bay of Bengal to the west of Dehong, and the wind mainly blows from the southeast. At 08:00 on May 25, with the strengthening of low pressure over the Bay of Bengal, the southwest air flow near the center of the low pressure and on the east side of the low pressure increased significantly, reaching the standard of low-level jet stream. Most of Yunnan was controlled by the outer southwest air flow, among which the west and south of Dehong were affected by the southerly air. At 08:00 on May 26 (Fig. 3c), the low pressure in the Bay of Bengal developed into a storm, and the low-level jet stream on the east side of the storm center continued to strengthen and extended to the central part of Yunnan, resulting in a heavy rainfall weather process in the western part of central Yunnan from May 25 to 28. From May 25 to 26, Dehong Prefecture was located in the left front of the exit area of the low-level jet stream, which was conducive to the convergence and uplift of low-level water vapor here, and brought abundant water vapor and unstable energy to Dehong. The wind field at 850 hPa (Fig. 3d) was similar to that of 700 hPa. From 08:00 on May 25 to 08:00 on May 28, the southwest jet stream on the east side of the storm continued to strengthen and remained stable. Yunnan was in the left front of the exit area of the jet stream, which provided better water vapor and energy transport for the occurrence of strong precipitation in Yunnan. In Dehong area, the southerly air component was more obvious. The more obvious the southerly air was, the more favorable it was for water vapor transport and stronger vertical upward movement, and the more favorable it was for the generation and maintenance of heavy precipitation.

In conclusion, in late May, there was a convergence zone between the Indian Peninsula and the Indo – China Peninsula. The formation of this convergence zone made the convective activities between the Bay of Bengal and the tropical area on the east side of the Indo – China Peninsula vigorous, which provided a good environmental background for the formation and development of the storm in the Bay of Bengal, so that the storm "Remal" in the Bay of Bengal moved northeastwards after landing. In addition, with the establishment of southwest monsoon flow, a steady flow of monsoon flowed into the low-pressure circulation, so that the weakened low pressure maintained stably for a long time. The establishment and strengthening of the low-level southwest jet provided better dynamic, water vapor and energy conditions for the generation of this heavy precipitation.

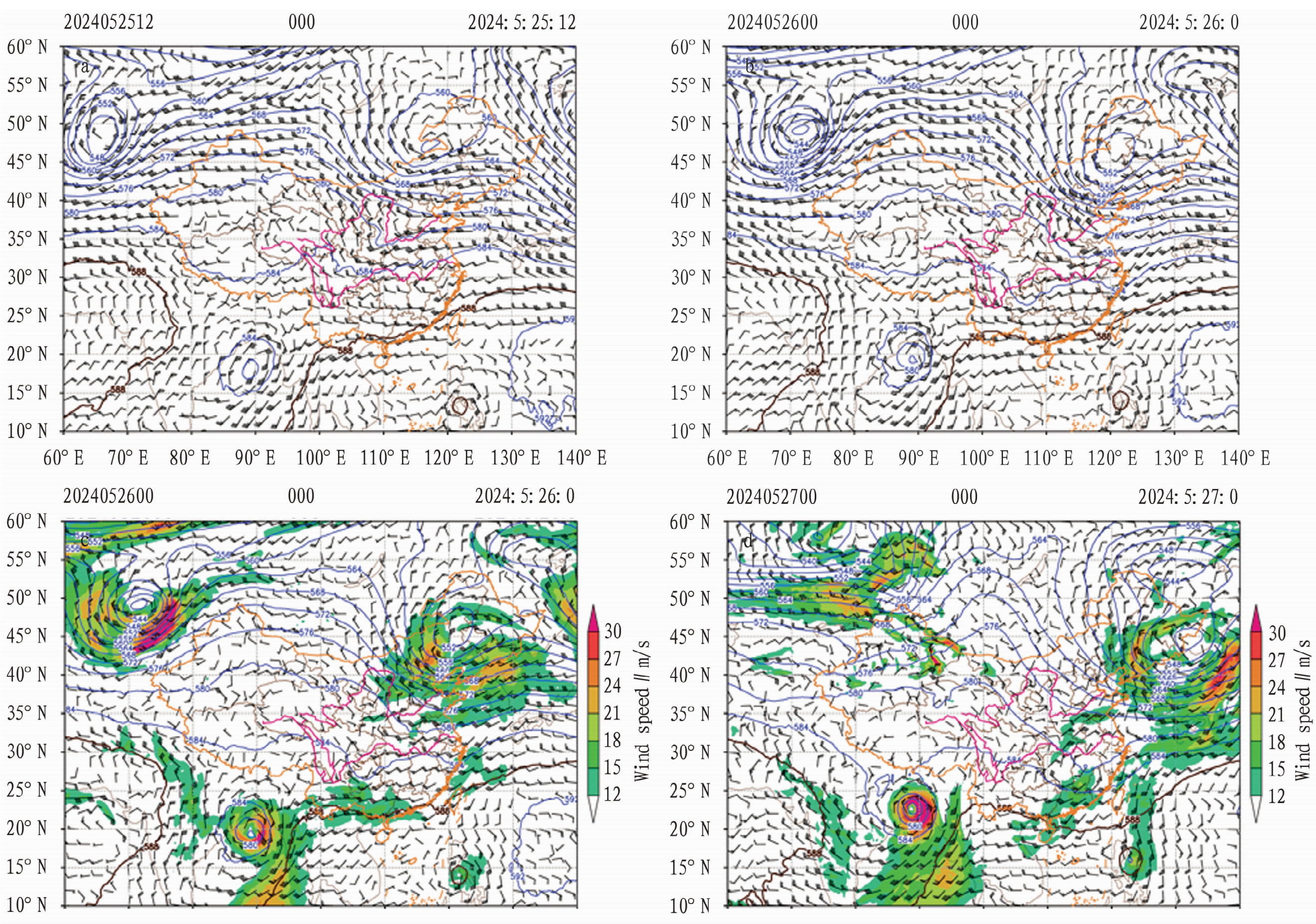
2.3 Water vapor conditions in the heavy precipitation process During the heavy precipitation process, the dynamic conditions were mainly provided by the storm in the Bay of Bengal and the low-level jet stream, with sufficient power and obvious vertical upward movement, which is not analyzed. The water vapor conditions of heavy precipitation are mainly analyzed.

2.3.1 Water vapor flux. . Abundant water vapor supply is a necessary condition for the occurrence of heavy precipitation. The occurrence of large-scale heavy precipitation has not only good local water vapor conditions but also a steady supply of water vapor[2]. The waters of the Bay of Bengal are one of the important water vapor sources affecting the precipitation in Yunnan, as well as the most important water vapor transport area affecting the precipitation weather in Dehong Prefecture. Studies and years of experience have found that whether the water vapor channel can be successfully established from the Bay of Bengal to the west of Dehong Prefecture was often positively correlated with the precipitation level in Dehong Prefecture. The physical quantity that characterizes the intensity and direction of water vapor transport in meteorology is called water vapor flux. Before the occurrence of heavy precipitation, there is usually a strong water vapor flux zone on the upwind side (upstream direction), which transports a large amount of water vapor to the rainstorm area[2]. According to the analysis of the water vapor flux of this process, at 08:00 on May 25, the large-value area of water vapor flux at 700 and 850 hPa was mainly distributed in the northeast of the Bay of Bengal. Guided by the low-level jet stream, with the strengthening of the low-level jet stream, the large-value area gradually extended to western Yunnan. From May 26 to 27, an obvious wet tongue was formed in the west of Dehong and distributed from south to north, indicating that the water vapor channel from the Bay of Bengal to Yunnan had been established. As can be seen from the diagrams of water vapor flux at 850 hPa (Fig. 4), the intensity of the wet tongue center was the strongest at 20:00 on May 25, showing that water vapor transport was the strongest on the night of May 25. This corresponded to the strongest rainfall from the night of May 25 to the morning of May 26 in Dehong Prefecture, thus demonstrating that the occurrence of a large range of heavy precipitation required a steady supply of water vapor. From the wind vector diagrams, it can be seen that the position of the low-level jet stream at 700 and 850 hPa was consistent with that of the wet tongue, revealing that the low-level jet stream was conducive to the transport of warm and wet air. As can be seen from the diagram of water vapor flux at 500 hPa, at 20:00 on May 25, the water vapor flux in Yunnan was larger only



Note: a. 08:00 on May 24; b. 01:00 on May 26; c. 08:00 on May 26; d. 14:00 on May 26; e. 16:00 on May 26; f. 08:00 on May 27.

Fig. 2 Evolution of FY2G satellite infrared cloud images



Note: a, b. Geopotential height and wind field at 500 hPa; c. Geopotential height at 500 hPa and wind field at 700 hPa; d. Geopotential height at 500 hPa and wind field at 850 hPa.

Fig. 3 Evolution of situation fields at 500, 700 and 850 hPa

from the southwest of Yunnan to the northeast of the Bay of Bengal. After 20:00 on May 25, the water vapor flux in the west of Dehong gradually increased, and showed an obvious positive correlation with the enhancement of the southwest air flow. Seen from the profile charts, water vapor flux decreased gradually from 850 to 500 hPa, indicating that water vapor transport weakened gradually from low to high levels.

The above analysis shows that after "Remal" landed and weakened, the southwest flow outside the low-pressure center formed near (90° E, 20° N) established a deep water vapor channel for the heavy precipitation process in western and southwestern Yunnan from May 26 to 27. Besides, the locations of the low-level jet stream and wet tongue were consistent, showing that the low-level jet stream was conducive to the transport of warm and wet air, and could provide abundant water vapor transport conditions for the generation and maintenance of heavy precipitation.

2.3.2 Water vapor flux divergence. It is found that heavy precipitation is inevitably accompanied by strong convergence of low-level water vapor flux, and the concentration degree of water vapor transport can be represented by water vapor flux divergence (A). $A>0$ means water vapor flux divergence, and $A<0$ stands for water vapor flux convergence. There is usually strong water vapor convergence in a rainstorm area[14]. In the process of the heavy precipitation in Dehong Prefecture (from May 25 to 27), seen from the water vapor flux divergence fields at all levels, water vapor divergence (*i. e.*, $A>0$) was basically maintained over Dehong and its upstream regions above 500 hPa. There was a significant large-vale area of water vapor flux convergence ($A<0$) over Dehong and the western region above 700 hPa on May 24. On May 25, except for the obvious water vapor convergence in the north of Dehong, the convergence in other areas was relatively weak. On May 26 (Fig. 5a), with the formation of the Bay of Bengal storm, the southwest jet strengthened, bringing obvious water vapor convergence to Dehong Prefecture, resulting in an obvious large-value center of water vapor convergence from north to south in the water vapor flux divergence field. On May 27, with the landing and northward movement of the storm on May 27, the convergence area of wind speed on the east side of the storm rose northwards, and the large-value area of water vapor flux convergence also moved northwards. It can be seen from the diagram of water vapor flux divergence field superimposed on wind vector at 850 hPa that before the storm, the wind speed in the upstream area of Dehong was small, and there was weak convergence in the western edge area of Dehong. With the formation and strengthening of the storm, the southerly air flow on the east side of the storm also strengthened, and a low-level jet stream appeared. The water vapor convergence in the northern part of the Bay of Bengal – Myanmar – Dehong area increased, and the water vapor convergence was the strongest at 08:00 on May 26 (Fig. 5b). The water vapor convergence was obvious all day long over Dehong region on May 26, and the precipitation was also the strongest on May 26. Moreover, it is found that the location of the water vapor convergence area was consistent with that of the low-level jet stream. It can be seen that the emergence of the low-level jet stream can not only strengthen the water vapor transport from the Bay of Bengal to Dehong, but also provide the conditions for the water vapor convergence and uplift for the heavy precipitation in Dehong Prefecture from May 25 to 27.

From the above analysis, it can be concluded that the generation and maintenance of rainstorm required a steady flow of water vapor to the rainstorm area, and there was strong water vapor convergence in the rainstorm area. The emergence of the low-level jet stream could not only better guide the water vapor from the Bay of Bengal into Dehong Prefecture, but also make the water vapor produce strong convergence upward movement in the rainstorm area, which provides better water vapor and dynamic conditions for the maintenance of heavy precipitation. Therefore, in the forecast of rainstorm in summer, whether the low-level jet stream is produced or not is very important for the forecast of rainstorm. In addition, there was a good corresponding relationship between the falling area of heavy precipitation, precipitation intensity and duration, and low-level water vapor convergence area.

3 Relationship between the establishment of southwest monsoon and the first rainstorm in Dehong

Southwest monsoon is a summer monsoon prevalent in South Asia and Southeast Asia, and the Indian summer monsoon is the most typical. It originates from the southeast trade winds in the Indian Ocean. After crossing the equator, the southeast monsoon originating from in the Indian Ocean turns to the southwest under the influence of the deflection force of the earth's rotation, and passes through the tropical ocean, carries a lot of water vapor, and is the main source of precipitation in the Indian Peninsula and Southeast Asia. Through the Indian Peninsula and the Bay of Bengal to the east, it can affect South China. When the southwest monsoon develops strongly, it can also go deep into the Yangtze River basin. Southwest monsoon is a tropical monsoon, and the main area of southwest monsoon is at 0° – 30° N, with the characteristic of high temperature throughout the year, so it is a monsoon system with strong summer monsoon force[3-4]. The activity of summer rainband is closely related to the retreat and retreat of summer monsoon. For a certain region, the stay of rainband causes the rainy season in that region, so the average date line of the establishment of Asian summer monsoon can be determined according to the changes of rainy season and wind direction. It can be seen that the beginning of rainy season is closely related to the establishment of summer monsoon[19]. For Dehong, southwest monsoon is one of the most important summer monsoon affecting the rainy season in Dehong. It can be seen that the establishment of southwest monsoon is of great significance to the beginning of the rainy season in Dehong. It is found that the dominant air flow between the western Yunnan and the Indian Peninsula in early summer is the southwest air flow, and the southwest air flow can maintain for a long time, bringing continuous rainfall weather to Yunnan. It is generally believed that southwest monsoon has been established.

In 2024, the rainy season in Dehong started on May 6 in Ruili, May 24 in Mangshi, May 25 in Yingjiang and Lianghe, and May 26 in Longchuan. Except Ruili, the rainy season of the other four counties and cities all started around the time of the first statewide heavy rainfall after Dehong Prefecture entered flood season in 2024. It can be seen that the heavy rainfall process contributed significantly to the beginning of the rainy season this year, so the beginning date of the rainy season in Dehong Prefecture was closely related to the first heavy rain process in Dehong in early summer. As a whole, it is particularly important to pay attention to the first statewide rainstorm in early summer when the beginning date of the rainy season is predicted. Through the analysis of this process, three key points for the forecast of the first rainstorm process in early summer in Dehong Prefecture were summarized as follows.

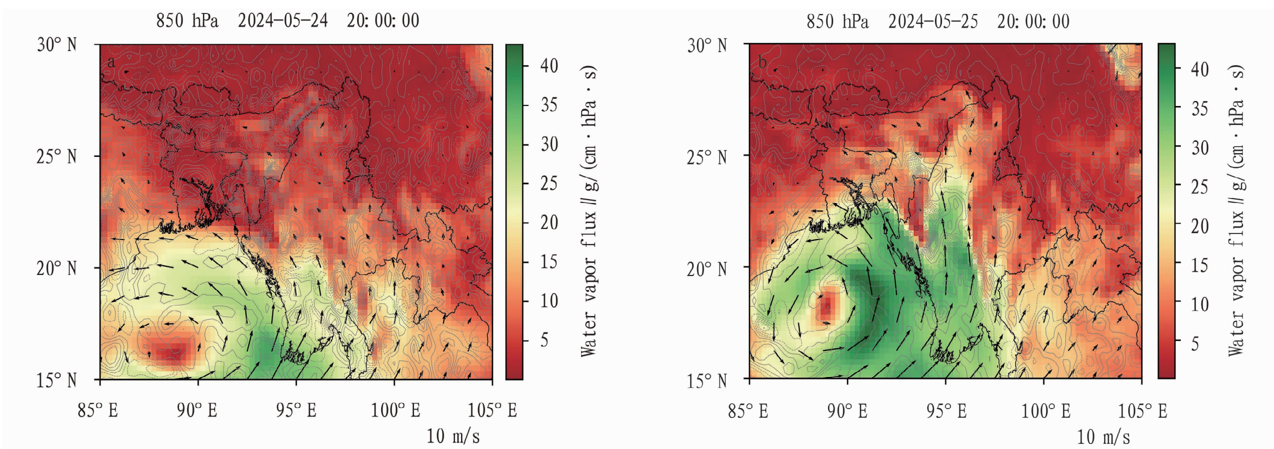


Fig. 4 Diagrams of water vapor flux superimposed on wind vector at 850 hPa

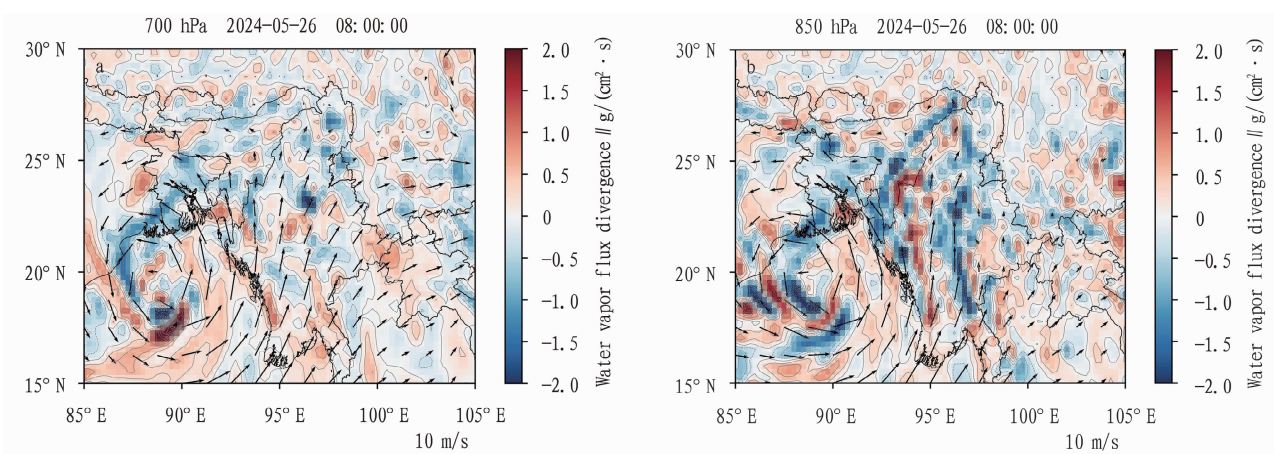


Fig. 5 Diagrams of water vapor flux divergence superimposed on wind vector at 700 (a) and 850 hPa (b)

At first, the general situation of atmospheric circulation in early summer was analyzed. When the subtropical high extended westwards and was strengthened, Dehong Prefecture was affected by the southwest air in front of the south trough at 500 hPa, and was controlled by the southwest air at 700 - 850 hPa. Especially when southwest wind was obviously strengthened at 850 hPa, low pressure was generated and strengthened in the north of the Bay of Bengal, and the peripheral southwest air affected western Yunnan, it was worthy of attention. Secondly, it is needed to pay attention to the circulation in the middle and low latitudes. If it was controlled by the southwest air flow instead of the west wind flow and the southwest air flow was stable, southwest monsoon had been established, and precipitation would increase significantly[19]. Thirdly, as far as Dehong is concerned, whether there is a low-level jet stream at 850 hPa, the intensity of the low-level jet stream and the location of the jet exit area all have good indication significance for the occurrence of heavy precipitation in summer.

4 Conclusions

(1) This precipitation process was the first statewide heavy

precipitation weather process since the flood season in 2024. The main characteristics of this precipitation process were high precipitation intensity, long duration, large cumulative rainfall, wide influence area, uneven temporal and spatial distribution of precipitation, and being accompanied by strong convective weather such as lightning, gale and hail.

(2) This heavy rainfall weather process made five counties and cities in Dehong Prefecture enter the rainy season successively (the rainy season began on May 6 in Ruili, May 24 in Mangshi, May 25 in Yingjiang and Lianghe, and May 26 in Longchuan). It can be seen that the first statewide heavy rainfall (rainstorm) process in Dehong Prefecture in early summer was closely related to the beginning date of the rainy season in Dehong Prefecture.

(3) The two-high convergence area between the Indian Peninsula and the Indo – China Peninsula provided a good environment for the formation and development of the storm in the Bay of Bengal. The strengthening and northeastward movement of the Bay of Bengal storm "Remal" was the main influencing system for the generation of continuous heavy precipitation in Dehong Prefecture from May 25 to 27, 2024. The establishment and strengthening of the low-level southwest jet stream provided better dynamic, water vapor and energy conditions for the generation of this heavy precipitation.

(4) The generation and maintenance of rainstorm required the transportation of a steady stream of water vapor to the rainstorm area, and there was strong convergence of water vapor in the rainstorm area. Therefore, in the forecast of summer rainstorm, whether the low-level jet stream is generated or not is very important for the forecast of rainstorm. In addition, there was a good corresponding relationship between the falling area of heavy precipitation, precipitation intensity and duration, and low-level water vapor convergence area.

(5) The establishment of southwest monsoon is of great significance to the beginning date of rainy season in Dehong Prefecture. It is found that the dominant air flow between western Yunnan and the Indian Peninsula in early summer was southwest air flow, and southwest air flow can maintain for a long time, bringing continuous rainfall weather to Yunnan. It is generally believed that southwest monsoon had been established.

(6) The beginning date of rainy season in Dehong Prefecture was closely related to the first rainstorm process in Dehong Prefecture in early summer. In the future prediction of the beginning date of rainy season in Dehong Prefecture, the first statewide rainstorm process in early summer should be the key point for the prediction.

References

[1] MI RZ, NIU FB, XIANG Y, *et al.* Cause analysis on the first provincial range heavy rain process under the influence of MJO in Yunnan Province in 2016[J]. Journal of Arid Meteorology, 2017, 35(2): 232 – 249.

[2] ZHU GG, LIN JR, SHOU SW. Synoptic principles and methods[M]. Beijing: China Meteorological Press, 2000: 320 – 337, 398 – 400.

[3] QIN J, JU JH, XIE ME, *et al.* Weather and climate of low-latitude plateau[M]. Beijing: China Meteorological Press, 1997: 98 – 107.

[4] XU ML, DUAN X, QI MH, *et al.* Handbook of weather forecasters in Yunnan Province[M]. Beijing: China Meteorological Press, 2011: 84 – 152.

[5] ZHANG TF, DUAN X, ZHANG J. Mesoscale analysis of Yunnan successive heavy precipitation caused by storms over the Bay of Bengal in the early summer[J]. Journal of Tropical Meteorology, 2006, 22(1): 67 – 73.

[6] MIN Y, ZHOU H, LI X, *et al.* Analysis of characteristics and forecast deviation of a sustained heavy precipitation process in Yunnan under the influence of the Bay of Bengal storm "Mucha" in 2023. Review of high-impact weather monitoring and forecasting service technology in Yunnan Province, 2023: 33 – 46.

[7] ZHENG JM, DUAN X. The Bengal Bay monsoon onset and its relationship with rainy season of Yunnan in 2001[J]. Meteorological Monthly, 2001, 31(2): 59 – 63.

[8] LU YB, ZHANG TF, XU BL, *et al.* Mesoscale analysis on a heavy rain associated with a Bengal Bay storm and cold air in west Yunnan[J]. Journal of Applied Meteorological Science, 2006, 17(2): 201 – 207.

[9] XU ML, ZHANG XN, YANG SY. Ambient fields and satallite pictures characteristic analysis by the Bengal Bay storm in low-latitude plateau [J]. Journal of Tropical Meteorology, 2007, 23(4): 395 – 400.

[10] HUANG W, LIU Y. Temporal and spatial feature of the beginning date of rainy season in Yunnan Province and its relationship with monsoon [J]. Chinese Journal of Agrometeorology, 2012, 33(3): 348 – 354.

[11] YAN HH, LU YB, YOU WH, *et al.* A study of weather and climate features of precipitation in may in Yunnan[J]. Chinese Journal of Applied Meteorology, 1995, 6(1): 124 – 128.

[12] TAO Y, CAO J, DUAN X. The research of the may rainfall turning abrupt change in Yunnan Province[J]. Journal of the Meteorological Sciences, 2002, 22(3): 287 – 293.

[13] LIANG JC, SHEN CM. Analysis on rainfall characteristics in May of Yunnan during 1959 – 2012[J]. Heilongjiang Agricultural Sciences, 2016(9): 24 – 29.

[14] MA T, ZHANG, WC, ZHENG JM, *et al.* Research on the relationship between water vapor transportation and May rainfall in Yunnan[J]. Journal of Catastrophology, 2017, 32(2): 109 – 116.

[15] NIU FB, MA LX, MIN Y. Genetic analysis of "10. 05. 25" heavy precipitation process in Yunnan Province[J]. Yunnan Meteorology, 2010, 30(2): 40 – 46.

[16] NIU FB, PU GM. Circulation characteristics and diagnostic analysis of "08. 07. 15" heavy precipitation process in Yunnan[J]. Yunnan Meteorology, 2009, 29(2): 23 – 28.

[17] GUO NN, LIN J. Analysis of the May 2024 atmospheric circulation and weather[J]. Meteorological Monthly, 2018, 50(8): 1024 – 1032.

[18] LIU Y, ZHAO EX, HUANG W, *et al.* The lows over the Bay of Bengal in early summer and beginning time of rainy season of Yunnan Province [J]. Plateau Meteorology, 2007, 26 (3): 572 – 578.

[19] FENG LL, HUA W. Influence of the synergy between westerly wind and monsoon on late spring precipitation over Yunnan Province[J]. Plateau and Mountain Meteorological Research, 2019, 42(4): 42 – 48.