Analysis on the First Round of Continuous Heavy Precipitation Weather Process during the Starting Period of Rainy Season in Dehong Prefecture from May 24 to June 3, 2025

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Abstract Using multi-source meteorological observation data, the causes and forecast points of the first round of continuous heavy precipitation process during the starting period of rainy season from May 24 to June 3, 2025 in Dehong Prefecture were analyzed. The results showed that: ① this heavy precipitation was formed by the influence of multiple systems such as convergence shear line, Bay of Bengal storm, monsoon trough, and low-level jet stream. The action time of each system did not overlap, and the precipitation was mainly stable, with significant differences in daily falling area and magnitude. ② According to the development stage of the Bay of Bengal storm, the process can be divided into three stages: convergence and shear of the South China Sea monsoon, southwest airflow outside the low-pressure system, and dominant southwest airflow in front of the monsoon trough. The strongest rainfall occurred on June 2. Combined with terrain uplift, the establishment of 850 hPa of southwest low-level jet stream provides key driving force and water vapor conditions for heavy precipitation. Its establishment and strengthening were important indicators for heavy precipitation forecasting in Dehong Prefecture. ③ The first round of heavy precipitation in Dehong Prefecture in early summer was closely related to the starting period of rainy season, and the forecast deviation was mainly due to insufficient prediction about the weakening speed of low-pressure system and the amplification effect of low-level jet stream. This paper can provide technical support for forecasting similar heavy precipitation in low-latitude plateaus.

Key words Bay of Bengal storm; First round of heavy precipitation; Monsoon convergence; Low-level jet stream; Terrain uplift

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The Bay of Bengal is one of the most active sea areas for tropical storm activity in the world. The storms generated by it serve as a key influencing system for heavy precipitation in low-latitude plateau regions, and become an important triggering mechanism for early summer precipitation in the region through peripheral cloud system transport and strong southwest warm and humid air flow convergence[1-2]. The activity level and northward movement pattern of storms in the Bay of Bengal in early summer (May) not only directly determine the staring time of rainy season and the amount of rainfall in low-latitude plateau areas, but also have a significant dynamic correlation with the northward advancement of the Bay of Bengal branch of southwest monsoon and the establishment of summer monsoon in the Indo – China Peninsula[3-4]. It is one of the core signals for studying the climatic characteristics of rainy season in low-latitude plateau areas. Dehong Prefecture is located in the low-latitude plateau of southwestern Yunnan, dominated by the southwest monsoon of the Bay of Bengal. The climate presents typical differentiation characteristics of dry and wet seasons. The first heavy precipitation process in Dehong Prefecture mostly occurs during the critical period of transition between dry and wet seasons in May. Its occurrence time, precipitation intensity, and falling zone distribution are closely related to the activity of the Bay of Bengal tropical system, and have always been the focus and difficulty of meteorological forecasting operations[5-6]. In recent years, with the frequent occurrence of extreme weather events, the challenge of predicting the first round of heavy precipitation in Dehong Prefecture during the rainy season under the background of the Bay of Bengal storms has intensified. The core issues focus on the response mechanism of heavy precipitation area and center position to the Bay of Bengal storm and southwest jet stream in front of the monsoon trough, the accuracy of numerical models in predicting the magnitude and area of heavy precipitation under such backgrounds, and the quantification of amplification effect of complex terrain on precipitation[7]. These issues have not yet formed a systematic forecasting index system and urgently need to be further understood through typical case analysis. From May 24 to June 3, 2025, Dehong Prefecture experienced the first round of wide continuous heavy precipitation during the staring period of rainy season. This process was influenced by multiple systems such as convergence shear line, the Bay of Bengal low pressure, monsoon trough, and low-level jet stream, presenting the characteristics of long precipitation duration, large accumulated rainfall, uneven temporal and spatial distribution, and accompanied by strong convective weather. Although the business forecast accurately grasped the overall impact period of the precipitation process, there were significant deviations in the prediction about the location and magnitude of heavy precipitation. Based on this,

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using multi-source data such as regional automatic observation station, FY-4 meteorological satellite, EC fine grid, *etc.*, the actual situation, circulation characteristics, rainstorm causes, characteristics of key physical quantities, and forecast deviation in this precipitation process were analyzed in detail. It aimed to deepen the understanding of the first round of continuous heavy precipitation during the starting period of rainy season in Dehong Prefecture under the background of the Bay of Bengal storm, and provide support for operational forecasting.

1 Characteristics of actual situation and disaster situation

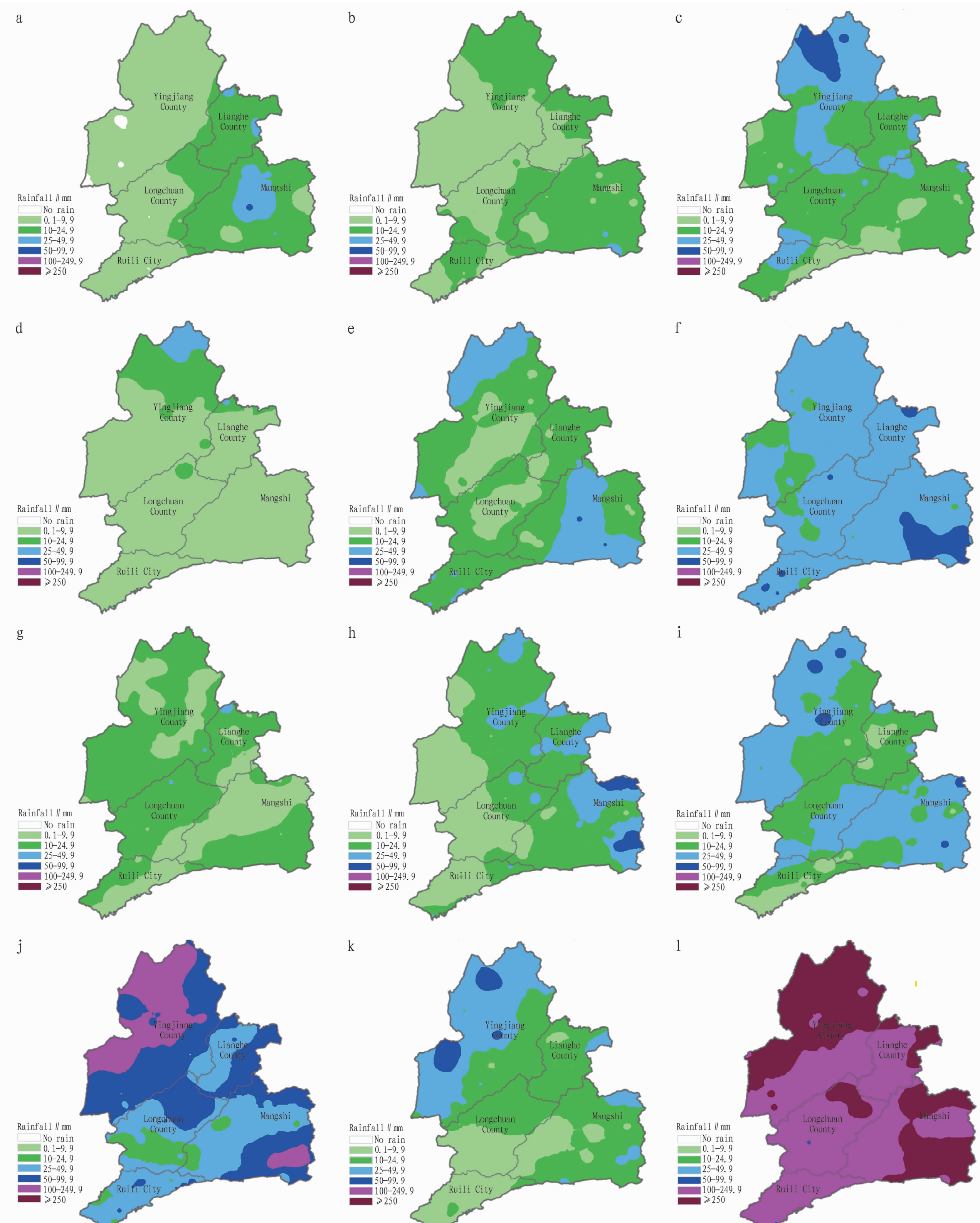
1.1 Characteristics of actual situation From May 24 to June 3, 2024, Dehong Prefecture experienced a sustained heavy precipitation process throughout the state, with a large amount of accumulated rainfall. The areas with high values of heavy precipitation mainly appeared in the western and northern parts of Yingjiang County, the southeastern and northeastern parts of Mangshi City, the northeastern part of Longchuan County, and the eastern and northern parts of Lianghe County. There were 41 regional observation stations in the entire state with a cumulative rainfall of over 250 mm, accounting for 29.50%; there were 95 stations between 100 and 250 mm, accounting for 68.35%; there were 3 stations between 50 and 100 mm, accounting for 2.15%. The cumulative rainfall of the five national observation stations in the whole state was 201.0 mm in Mangshi, 121.7 mm in Ruili, 180.3 mm in Longchuan, 176.2 mm in Yingjiang, and 173.2 mm in Lianghe. The actual distribution of rainfall in Dehong Prefecture was shown in Fig. 1. The strongest precipitation period in this process was on June 2, followed by May 29, and May 26, corresponding to three processes: precipitation by the southwest low-level jet stream in front of the monsoon trough during June 1 – 3, precipitation by the southwest airflow outside the Bay of Bengal low-pressure system during May 27 – 31, and precipitation by the South China Sea monsoon convergence shear line during May 24 – 26. On June 2, rainstorm to heavy rainstorm occurred in Yingjiang, heavy precipitation to rainstorm with local heavy rainstorm occurred in Mangshi, heavy precipitation to rainstorm occurred in Lianghe and Longchuan, and moderate to heavy precipitation with local rainstorm occurred in Ruili. The maximum rainfall occurred at the Changdifang Reservoir Station of Pingyuan Town, Yingjiang County, 187.5 mm (Fig. 2), while the maximum hourly rainfall intensity was 33.2 mm/h. There were 15 regional stations with heavy rainstorm and 55 stations with rainstorm.

1.2 Precipitation features This precipitation process was the first continuous heavy rainfall weather process in the whole state since the flood season began in 2025. The precipitation intensity was high, the duration was long, the accumulated rainfall was large, the impact range was wide, the spatial and temporal distribution of precipitation was uneven, and it was accompanied by strong convective weather such as thunder and lightning, strong winds, and hail. The top ten cumulative rainfall records of regional observation stations from May 24 to June 3 were shown in Table 1. Severe convective weather (Table 2) occurred mainly on May 25 – 26, May 29, May 31, and June 1 – 2, with 45 instances of short-term heavy rainfall, 30.8% more than the same period in the past five years. The maximum hourly precipitation of 42.1 mm/h occurred at Nabang Village Station in Nabang Town, Yingjiang County (05:00 – 06:00 on June 2). Most of the short-term heavy rainfall was accompanied by lightning and local strong winds. Dehong Prefecture experienced 47 instances of extremely strong winds per hour, with the largest peak occurring at Sanguojiang Station in Hexi Township, Lianghe County at 22.8 m/s (02:00 on June 2).

1.3 Disaster situation The heavy rainfall process from May 24 to June 3 caused rainstorm, flood, gale and geological disasters of varying degrees in Mangshi, Lianghe County, Longchuan County, Yingjiang County, Ruili City and other places in Dehong Prefecture, mainly causing damage to houses, crops and infrastructure, involving 4 202 people, emergency relocation of 5 households and 14 people, and direct economic loss of 18.253 million yuan. Among them, Mangshi suffered the most severe disaster, involving 100 people, 20 households, 7 villages, and 6 townships in the county. The direct economic losses amounted to 11.243 1 million yuan, including 100 000 yuan in housing and family property losses, 101 500 yuan in agricultural, forestry, animal husbandry, and fishery losses, 10 million yuan in industrial, mining, and commercial losses, and 1.041 6 million yuan in infrastructure losses.

Table 1 Details of the top ten accumulated rainfall stations in Dehong Prefecture from May 24 to June 3

Rank	County (city)	Township	Station name	Rainfall//mm
1	Yingjiang County	Pingyuan Town	Changdifang Reservoir	503.0
2	Yingjiang County	Sudian Township	Sudian	483.3
3	Yingjiang County	Zhina Township	Lushan	482.3
4	Mangshi	Zhongshan Township	Heihe Laopo	453.8
5	Mangshi	Zhongshan Township	Huangjiazhai	430.9
6	Lianghe County	Hexi Township	Guangping	405.7
7	Mangshi	Fengping Town	Pinghe	394.6
8	Yingjiang County	Sudian Township	Shimi Wadi	394.1
9	Yingjiang County	Zhanxi Town	Hebianzhai	380.8
10	Yingjiang County	Xima Town	Erpaizhai	369.7



Note: a. 20:00 on May 23 to 20:00 on May 24, 2025; b. 20:00 on May 24 to 20:00 on May 25, 2025; c. 20:00 on May 25 to 20:00 on May 26, 2025; d. 20:00 on May 26 to 20:00 on May 27, 2025; e. 20:00 on May 27 to 20:00 on May 28, 2025; f. 20:00 on May 28 to 20:00 on May 29, 2025; g. 20:00 on May 29 to 20:00 on May 30, 2025; h. 20:00 on May 30 to 20:00 on May 31, 2025; i. 20:00 on May 31 to 20:00 on June 1, 2025; j. 20:00 on June 1 to 20:00 on June 2, 2025; k. 20:00 on June 2 to 20:00 on June 3, 2025; l. 20:00 on May 23 to 20:00 on June 3, 2025.

Fig. 1 Distribution of rainfall in Dehong Prefecture

Table 2 Overview of strong convection in continuous heavy precipitation in Dehong Prefecture from May 25 to June 3

Date	Short-term heavy precipitation	Positive lightning	Negative lightning	Hourly-level strong wind
05 – 25	0	359	119	13
05 – 26	0	166	21	14
05 – 29	11	228	164	0
05 – 31	1	425	105	4
06 – 01	4	1 019	384	2
06 – 02	29	712	636	14

2 Forecast service status, forecast inspection, and forecast difficulties

2.1 Forecast and service status On May 22, the Dehong Prefecture Meteorological Observatory issued an important weather forecast stating that "there will be a heavy precipitation process in the prefecture from May 24 to 27". At 21:00 on May 26, 2025, the Dehong Prefecture Meteorological Bureau launched the level IV emergency response order for major meteorological disasters (rainstorm). On May 27, the Dehong Prefecture Meteorological Observatory issued an important weather forecast stating that "there will be a continuous heavy precipitation process in the prefecture from May 28 to 30". At 22:00 on May 28, Vice Governor Liu Yipeng organized a flood prevention consultation and judgment, and the Prefecture Flood Control Headquarters launched a level IV emergency response for flood prevention at 22:30 on May 28. At 10:00 on May 29, the Office of the Prefecture Geological Disaster Emergency Command Center launched a level IV emergency response for geological disaster prevention. At 11:00 on May 29, the Commander of the Prefecture Flood Control Headquarters and the Governor Weigang organized the dispatch, and the main leaders of the Prefecture Meteorological Bureau attended. At 10:30 on May 31, Vice Governor of the Prefecture Government Xuelin organized the dispatch, and the on duty leaders of the Prefecture Meteorological Bureau attended.

Decision-making service materials: on May 22 and 27, the Dehong Prefecture Meteorological Observatory released the 2 issues of the *Important Weather Forecast*. On May 19, May 26 and June 2, 3 issues of the *Weather Weekly Report* were released. From May 24 to June 3, 11 issues of the *Important Weather Bulletin* were released. On May 29, 1 issue of the *Dehong Prefecture's Special Topic Weather Forecast on 2025 Dragon Boat Festival* was released. On May 30, 1 issue of the *Monitoring and Analysis of the Starting Period of Rainy Season in Dehong Prefecture* was released. "1262" forecast service: the Dehong Prefecture Meteorological Observatory released the 67 issues of the "1262" *Refined Forecast Special Service* materials from 20:00 on May 23 to 20:00 on June 3.

Disastrous weather warning: the Dehong Prefecture Meteorological Observatory issued rainstorm level IV warning for 3 periods and rainstorm level III warning for 2 periods; the Dehong Prefecture Hydrological and Water Resources Bureau, the Dehong Prefecture Meteorological Bureau, and the Dehong Prefecture Water Resources Bureau jointly issued level IV warning for flash flood disaster risk for 3 periods, level III warning for flash flood disaster risk for 3 periods, and level II warning for flash flood disaster risk for 1 period; the Dehong Prefecture Natural Resources and Planning Bureau and the Dehong Prefecture Meteorological Bureau jointly issued level II warning for geological hazards and meteorological risks for 8 periods.

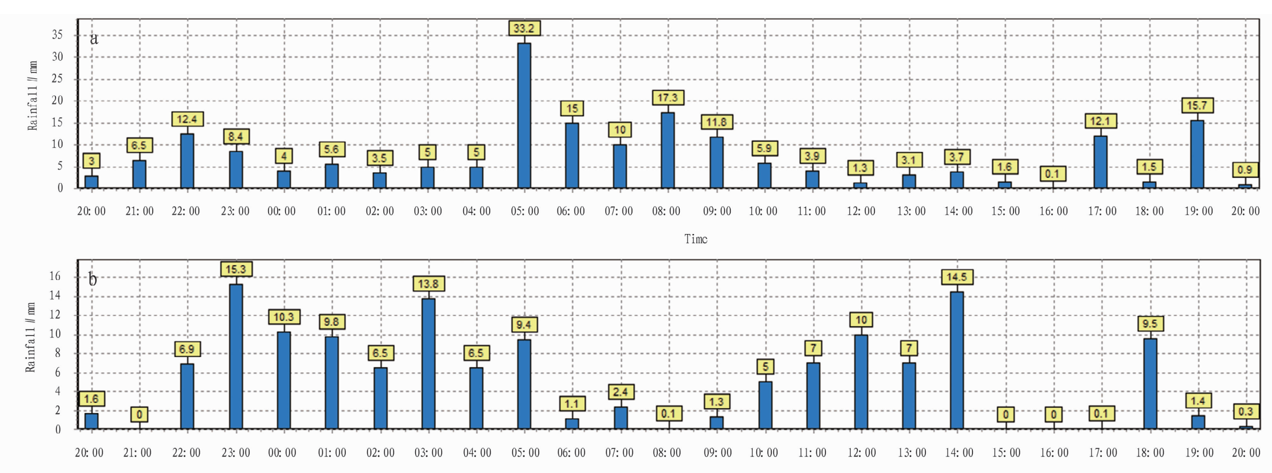


Fig. 2 Hourly rainfall at Changdifang Reservoir Station in Pingyuan Town, Yingjiang County, Dehong Prefecture (a) and Heihe Laopo in Zhongshan Township, Mangshi City (b) from 20:00 on June 1 to 20:00 on June 2

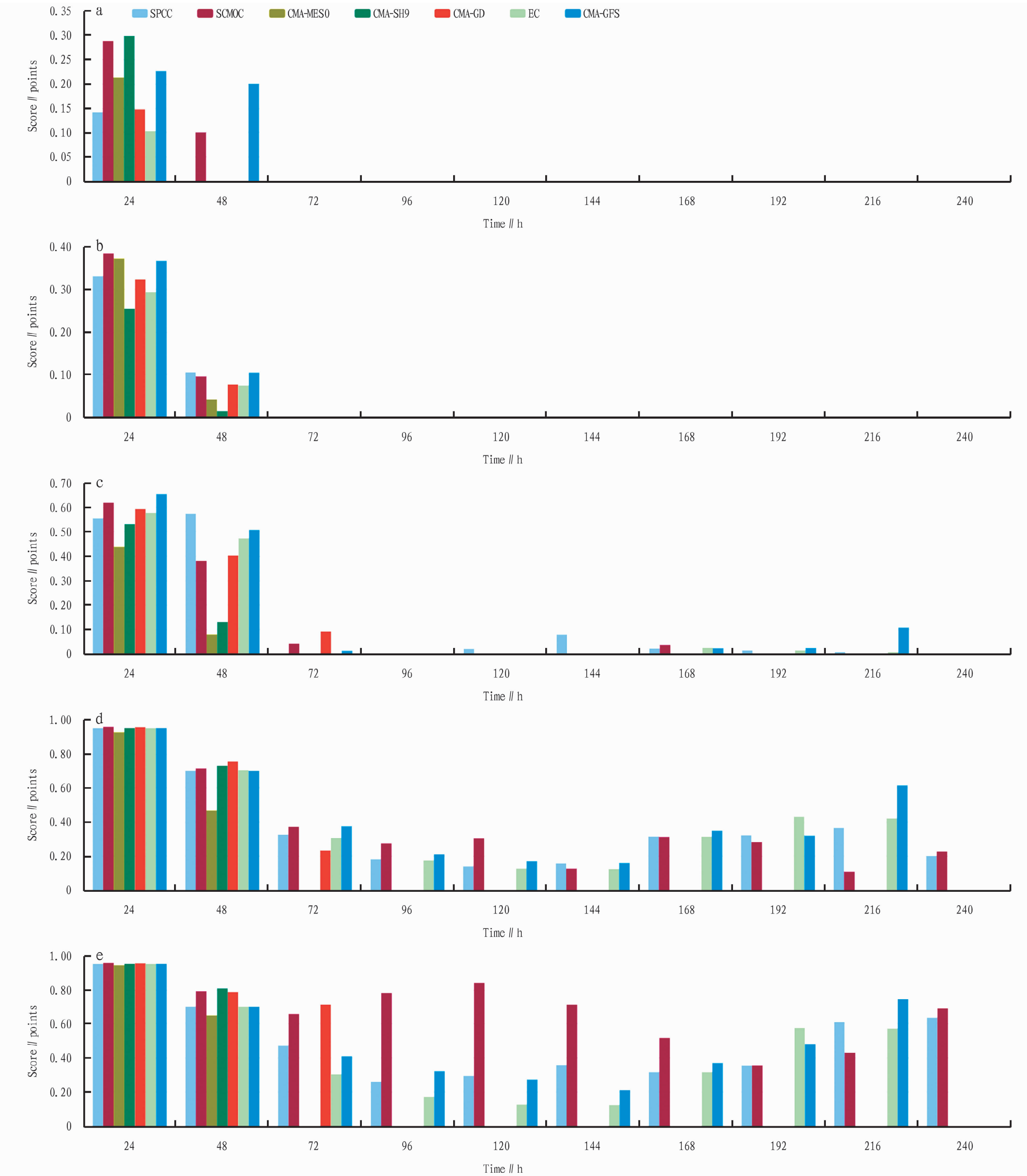
2.2 Subjective and objective forecast testing and evaluation The subjective forecast was accurate in the prediction of precipitation time, but there was obvious deviation in the forecast of magnitude and falling area, which was mainly manifested in the forecast deviation of two key periods. ① The forecast magnitude on May 30 was too large. On May 27, it was forecasted that "moderate to heavy precipitation with local rainstorm will occur in Yingjiang during May 29 – 30, and moderate to heavy precipitation will occur in other counties (cities)". At 16:00 on May 29, the nowcasting was further adjusted to that "moderate to heavy precipitation with local rainstorm will occur in the whole prefecture". But the actual situation was light to moderate precipitation throughout the prefecture and heavy precipitation in single point, with only 3 stations experiencing heavy precipitation (2.1%), 70 stations experiencing moderate precipitation (49.3%), and 66 stations experiencing light precipitation (46.5%). The forecast for precipitation magnitude was significantly higher. ② The forecast magnitude on June 2 was too small. At 16:00 on June 1, "moderate to heavy precipitation with local rainstorm in Mangshi, Longchuan and Yingjiang, moderate precipitation with local heavy precipitation in Ruili and Lianghe" was forecasted. However, the actual situation was that there was heavy precipitation to rainstorm in the whole prefecture, with local heavy rainstorm. There were 15 stations (10.6%) of heavy rainstorm, 55 stations (38.7%) of rainstorm, and 50 stations (35.2%) of heavy precipitation. The maximum rainfall of 187.5 mm appeared at the Changdifang Reservoir Station of Yingjiang County, and the precipitation magnitude forecast was significantly smaller.

The strongest precipitation period of this process (20:00 on June 1 to 20:00 on June 2) was selected as the test object. The test results based on the Yunnan Intelligent Forecasting Business Platform showed that the objective forecasting products had the characteristics: significant differences between provincial and central stations, and uneven forecasting performance of various models. ① Comparison of forecasts by provincial and central stations. The accuracy of 0 – 72-hour weather forecast at the provincial level was lower than that at the central station. In the TS score of 24-hour cumulative rainfall, the central station with light precipitation and above was slightly higher than the provincial level, and the central station with moderate precipitation and above was better than the provincial level, while the provincial level with moderate precipitation and above was better than the central station in the TS score of 48-hour cumulative rainfall. The central station with heavy precipitation and above, rainstorm and above was significantly better than the provincial level in the TS score of 24-hour cumulative rainfall. The forecasting ability of both in 48 – 72 h was significantly reduced, and the TS score was close to 0 or 0. For heavy rainstorm and above, the forecast by central station and provincial level was both 0. ② Comparison of forecast models. Light precipitation and above: the TS scores of each mode were close within 24 h (all above 0.9). The TS score of CMA-MESO mode was significantly lower within 48 h, and the CMA-GFS mode performed the best within 72 h. Moderate precipitation and above: the CMA-GFS mode dominated from 0 – 48 h, while the CMA-GD mode performed well within 72 h. Heavy precipitation and above: The CMA-MESO and CMA-GFS modes had significant advantages within 24 h, while the CMA-GFS mode outperforms other modes within 48 h. Rainstorm and above: the CMA-SH9 mode performed the best within 24 h, and the CMA-GFS mode was dominant within 48 h. Heavy rainstorm and above: only the TS score of CMA-SH9 mode reached 0.316 within 24 h, and the TS scores of rest modes were 0. Extremely heavy rainstorm and above: the TS scores of all model forecasts were 0. ③ Forecast deviation of falling area: only CMA-SH9 mode and YNKG mode reported the heavy rainstorm falling area of Yingjiang County in the north of Dehong Prefecture, but the heavy rainstorm falling area in the southeast of Mangshi was not forecasted among the precipitation falling areas reported since 08:00 on June 1, and the other modes failed to report the above two heavy rainstorm falling areas. Meanwhile, all models' forecasts for precipitation levels across the entire state were 1 – 2 orders of magnitude lower.

2.3 Analysis of forecast difficulties The core difficulty of the forecast for this heavy precipitation process lied in the phased evolution and non overlapping effects of the impact systems, which led to the transfer of daily precipitation areas and uncertainty in the magnitude. Specifically, there were two key issues. One was insufficient prediction of the weakening speed of the Bay of Bengal low-pressure system: the Bay of Bengal low-pressure system rapidly weakened after its landfall on May 30, with a weakening speed much faster than the previous forecast results of the EC mode, and the actual intensity of its peripheral airflow was weaker than expected and the impact time was shorter than expected. The forecaster overestimated the precipitation contribution brought by the high-level southwest airflow and did not fully consider the problem of unclear low-level southwest airflow, resulting in actual precipitation being 1 – 2 orders of magnitude smaller than the forecast. The other was the underestimation of the precipitation amplification effect of the low-level jet stream at 850 hPa: on June 2, there was a jet stream area in the southwest of Dehong Prefecture at 850 hPa, with two outlets pointing to Yingjiang County and Mangshi respectively. However, due to the distance between the outlet area and Dehong Prefecture, the forecaster underestimated the water vapor and dynamic transport effects brought by the jet stream, and did not consider the precipitation amplification effect of the entire-level southwest airflow combined with terrain uplift, resulting in actual precipitation being 1 – 2 orders of magnitude higher than the forecast. In addition, numerical modes lacked the ability to simulate heavy precipitation in complex terrains, and forecasters had insufficient understanding of the mechanism of terrain triggered precipitation, which further exacerbated forecast biases in terms of location and magnitude.

3 Analysis of the causes and forecast deviation of heavy precipitation

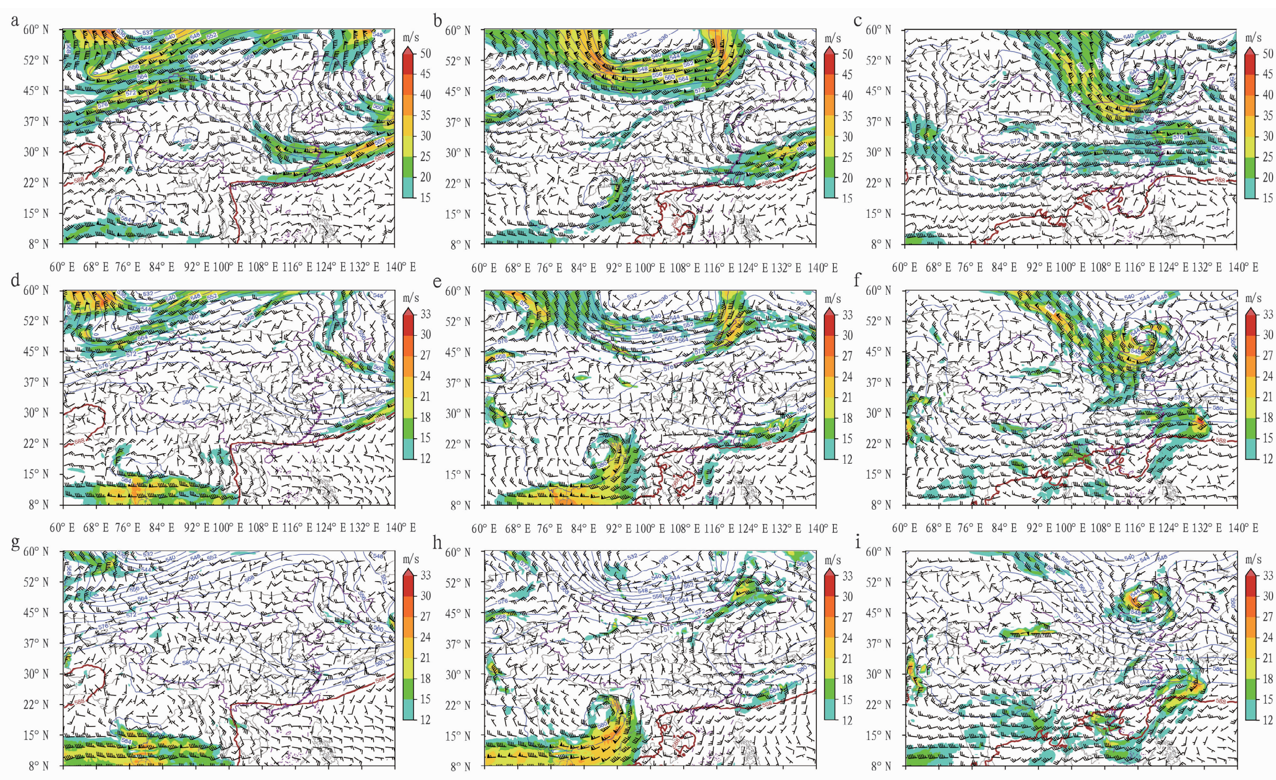
3.1 Development and evolution of atmospheric circulation patterns and major weather systems This heavy precipitation process showed obvious stage characteristics with the development and evolution of the Bay of Bengal storm. Based on the characteristics of the 500, 700, and 850 hPa of wind fields and geopotential height fields, it was divided into three stages according to the differences in dominant influence systems, and the circulation configuration and water vapor dynamic conditions in each layer were



Note: a. ≥50.0 TS score (subjective forecast at 20:00 (20:00 – 20:00)/mode forecast at 08:00), from June 1 to 2, 2025, 24 h; b. ≥25.0 TS score (subjective forecast at 20:00 (20:00 – 20:00)/mode forecast at 08:00), from June 1 to 2, 2025, 24 h; c. ≥10.0 TS score (subjective forecast at 20:00 (20:00 – 20:00)/mode forecast at 08:00), from June 1 to 2, 2025, 24 h; d. ≥0.1 TS score (subjective forecast at 20:00 (20:00 – 20:00)/mode forecast at 08:00), from June 1 to 2, 2025, 24 h; e. Accuracy of weather forecasts for sunny, rainy, and snowy conditions (subjective forecast at 20:00 (20:00 – 20:00)/mode forecast at 08:00), from June 1 to 2, 2025, 24 h.

Fig. 3 TS score for testing subjective and objective prediction of precipitation time and accuracy of weather forecasts for sunny, rainy, and snowy conditions

significantly different (Fig. 4). In the first stage (May 24 – 26), the Bay of Bengal low pressure was formed in the open sea, and Dehong Prefecture was dominated by the convergence shear of the South China Sea monsoon and southerly airflow. At 500 hPa, the subtropical high first extended westward and then weakened, while the southwest – southern airflow continued to transport water vapor. At 700 hPa, the southeast airflow changed to a southwest airflow, and convergence shear occurred in Yingjiang. After the establishment of the Somali jet stream, the atmospheric precipitation reached 30 – 50 mm, which combined with systematic dynamic uplift, stable precipitation was formed. At 850 hPa, the eastward airflow was dominant, with wind direction convergence in the west. On the 26th, the low-level wind speed increased to 8 – 10 m/s. In the second stage (May 27 – 31), the Bay of Bengal low-pressure system matured, made landfall and northward advancement, rapidly weakening. Dehong Prefecture was controlled by the southwest airflow from its periphery. At 500 hPa, the eastward movement of plateau trough and the eastward retreat of subtropical high, as well as the westward extension and northward uplift of subtropical high, drove the attenuation of the low-pressure system, causing the airflow to shift from southwest to south and then return to southwest direction. At 700 hPa, the southward airflow was dominant, with weak shear in the east. The peripheral jet stream of the low-pressure system moved northward, and the specific humidity increased to 12 g/kg, resulting in improved water vapor transport. At 850 hPa, there was an easterly wind field, and the southwest jet stream was located to the west, with average low-level dynamic conditions. In the third stage (June 1 – 3), the Bay of Bengal low pressure disappeared, and the southwest airflow in front of the monsoon trough became the dominant system. At 500 hPa, the monsoon trough remained stable, and the southwest airflow continued to control the Dehong Prefecture. The southwest airflow at 700 hPa was stable and turned into a westward airflow on the 3rd. At 850 hPa, the southwest low-level jet stream was established, and it exhibited a daily variation characteristic of strengthening at night and weakening during the day. The two outlets of the jet stream area pointed to Yingjiang County and Mangshi respectively, providing the core driving force for heavy precipitation. On 3rd, the jet stream weakened, and the precipitation gradually ended.

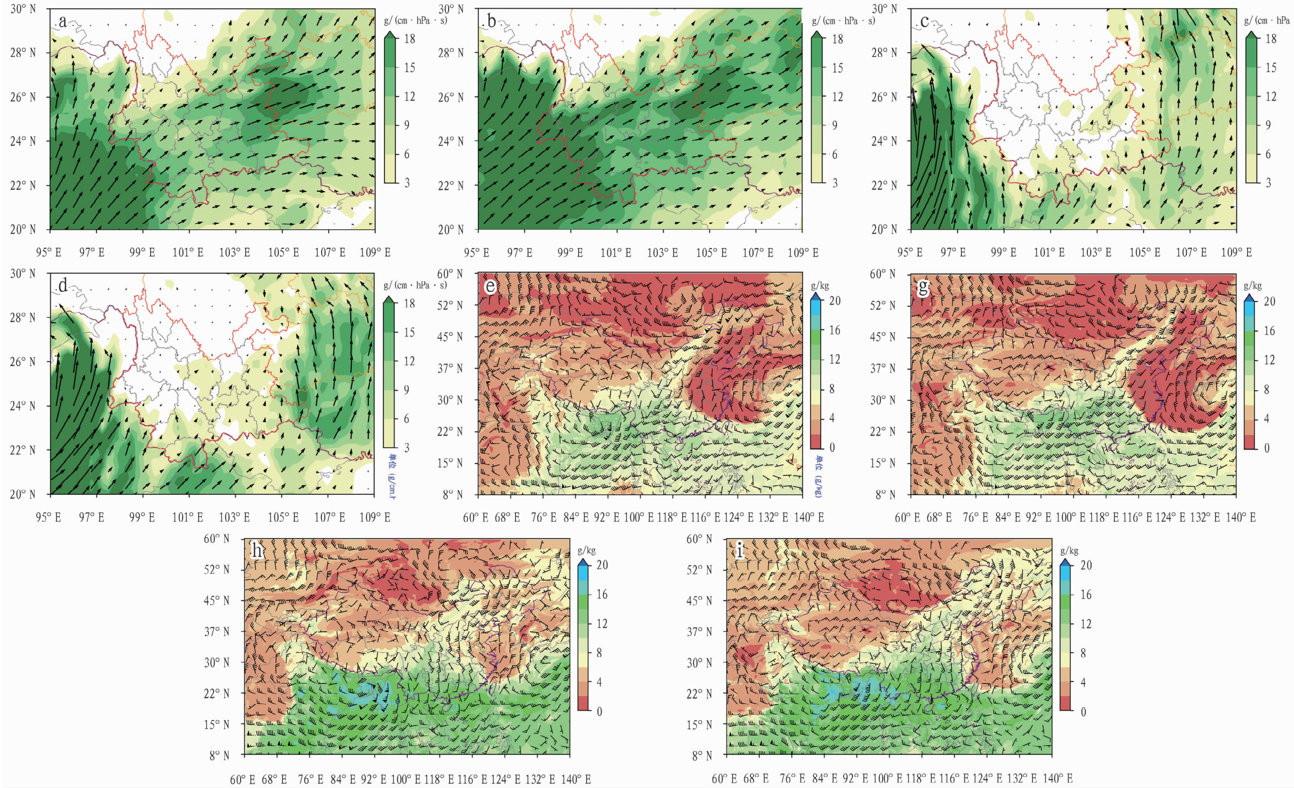


Note: a. 500 hPa of height field and 500 hPa of wind field at 08:00 on May 26; b. 500 hPa of height field and 500 hPa of wind field at 08:00 on May 29; c. 500 hPa of height field and 500 hPa of wind field at 08:00 on June 2; d. 500 hPa of height field and 700 hPa of wind field at 08:00 on May 26; e. 500 hPa of height field and 700 hPa of wind field at 08:00 on May 29; f. 500 hPa of height field and 700 hPa of wind field at 08:00 on June 2; g. 500 hPa of height field and 850 hPa of wind field at 08:00 on May 26; h. 500 hPa of height field and 850 hPa of wind field at 08:00 on May 29; i. 500 hPa of height field and 850 hPa of wind field at 08:00 on June 2.

Fig. 4 Composite map of geopotential height (unit: dagpm) and wind field (unit: m/s)

3.2 Causes of deviation in heavy precipitation forecast

3.2.1 Reason for the precipitation magnitude on May 30 significantly lower than the forecast. The actual precipitation on May 30 was significantly lower than the forecast, mainly due to the rapid attenuation of the Bay of Bengal low pressure after landfall, and insufficient low-level water vapor and dynamic conditions. Moreover, the forecast had a high dependence on numerical mode results, and the actual trend of low pressure weakening was not cor-



Note: a. 700 hPa water vapor flux and wind vector at 08:00 on May 30; b. 700 hPa water vapor flux and wind vector at 20:00 on May 30; c. 850 hPa water vapor flux and wind vector at 08:00 on May 30; d. 850 hPa water vapor flux and wind vector at 20:00 on May 30; e. 700 hPa specific humidity and wind field at 08:00 on May 30; f. 700 hPa specific humidity and wind field at 20:00 on May 30; g. 850 hPa specific humidity and wind field at 08:00 on May 30; h. 850 hPa specific humidity and wind field at 20:00 on May 30.

Fig. 5 Composite map of water vapor flux and wind vector and composite map of specific humidity and wind field

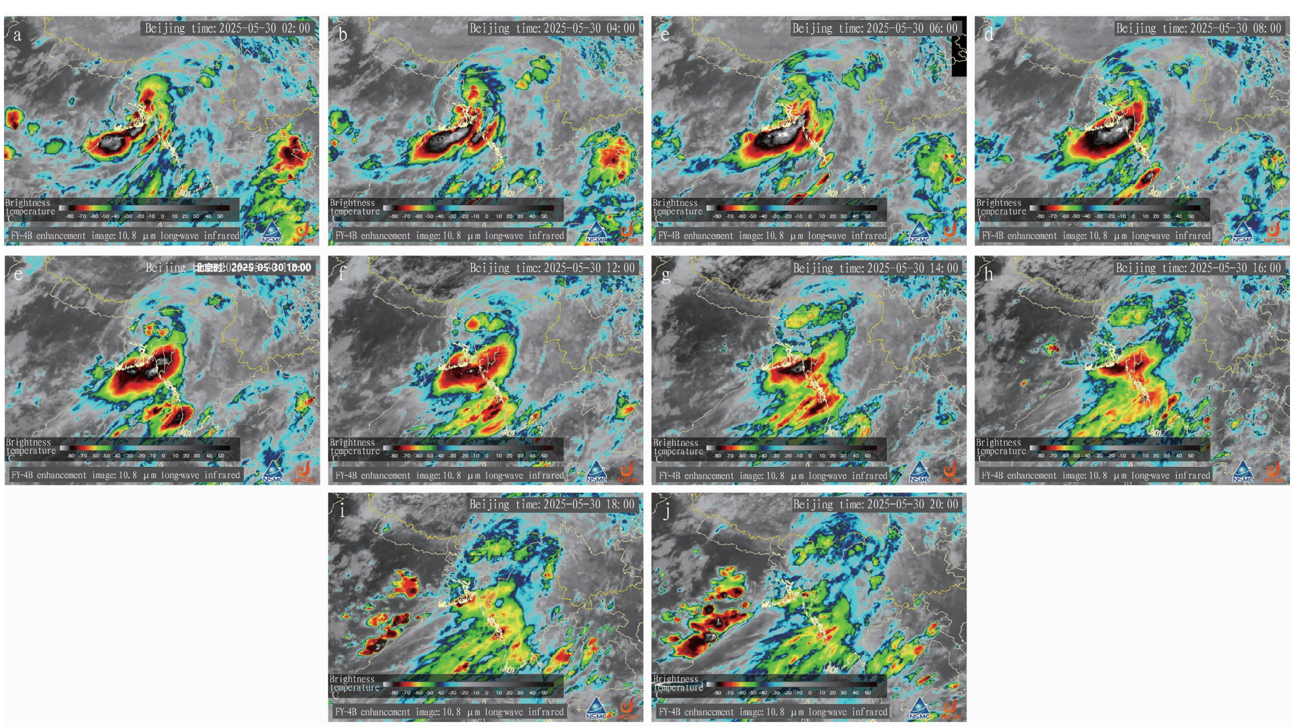
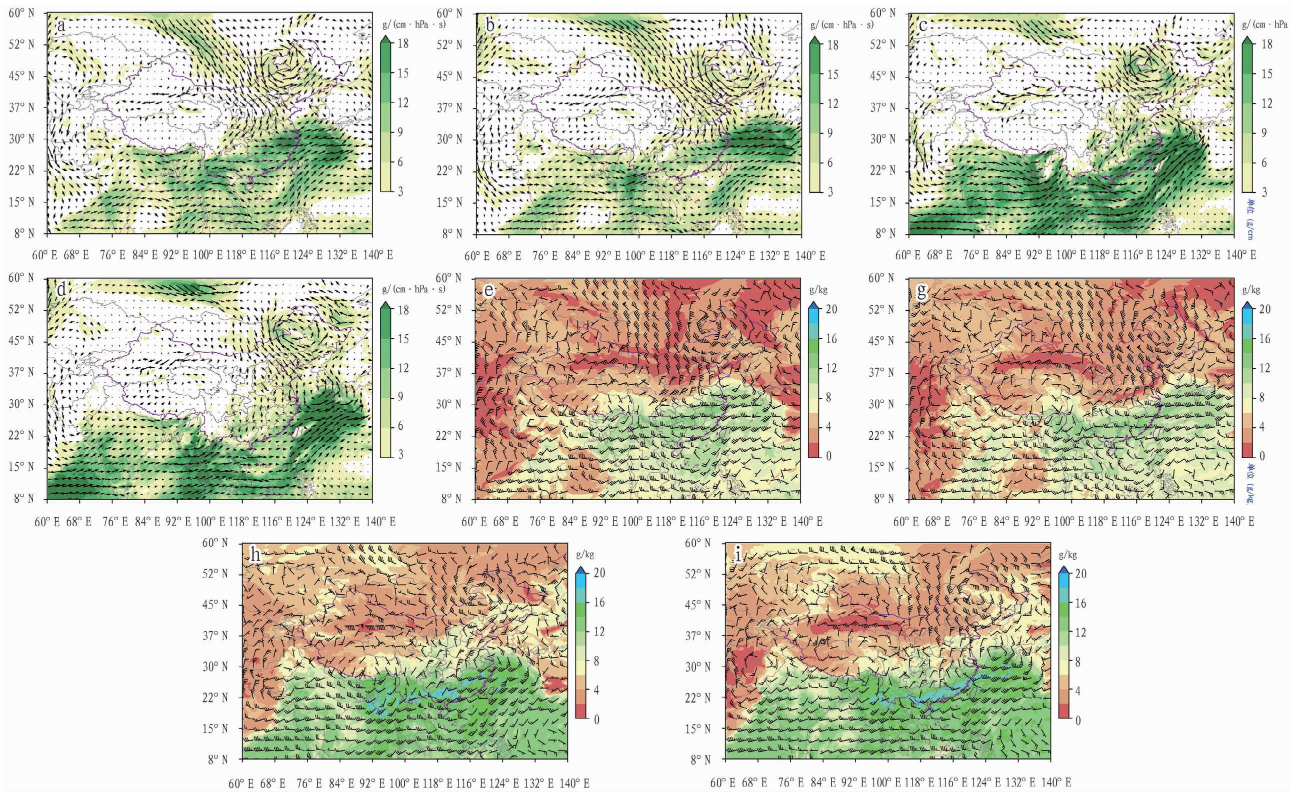


Fig. 6 FY-4B enhancement image (10.8 μm long-wave infrared) at 02:00 (a), 04:00 (b), 06:00 (c), 08:00 (d), 10:00 (e), 12:00 (f), 14:00 (g), 16:00 (h), 18:15 (i), 20:00 (j) on May 30, 2025



Note: a. 700 hPa water vapor flux and wind vector at 08:00 on June 2; b. 700 hPa water vapor flux and wind vector at 20:00 on June 2; c. 850 hPa water vapor flux and wind vector at 08:00 on June 2; d. 850 hPa water vapor flux and wind vector at 20:00 on June 2; e. 700 hPa specific humidity and wind field at 08:00 on June 2; f. 700 hPa specific humidity and wind field at 20:00 on June 2; g. 850 hPa specific humidity and wind field at 08:00 on June 2; h. 850 hPa specific humidity and wind field at 20:00 on June 2.

Fig. 7 Composite map of water vapor flux and wind vector and composite map of specific humidity and wind field

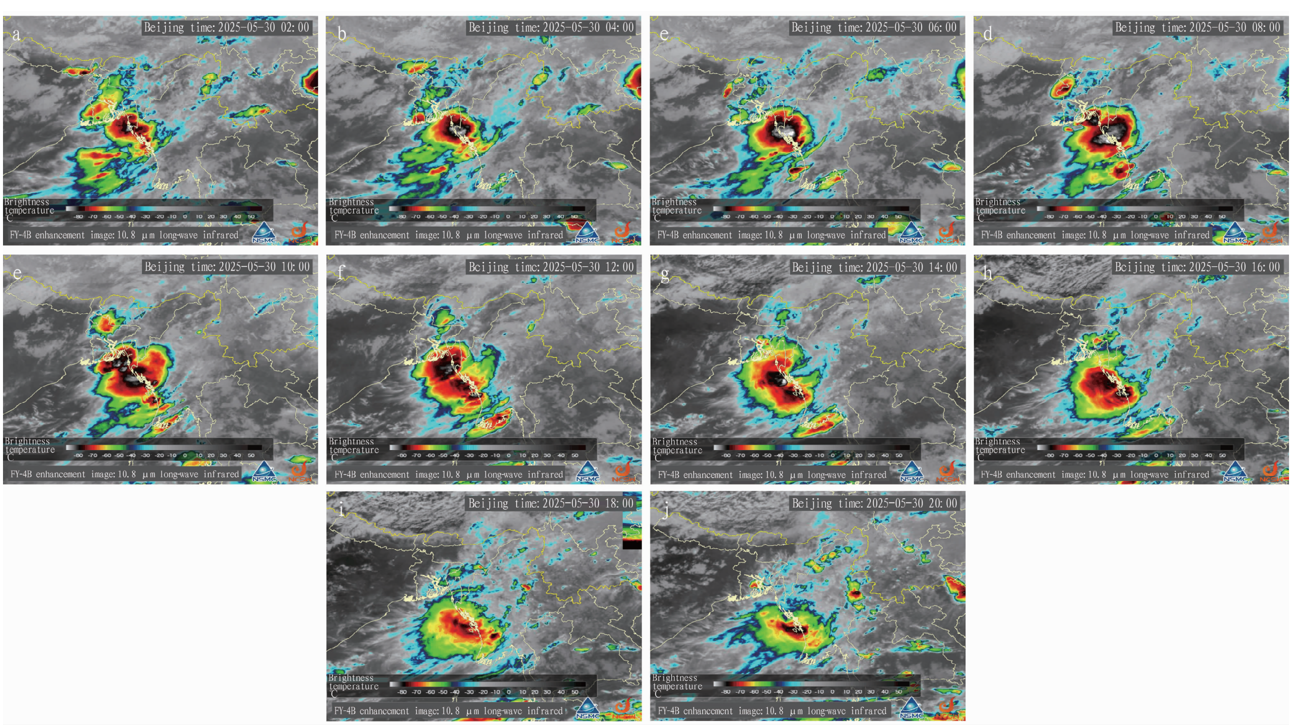


Fig. 8 FY-4B enhancement image (10.8 μm long-wave infrared) at 00:15 (a), 02:00 (b), 04:00 (c), 06:00 (d), 08:00 (e), 10:00 (f), 12:00 (g), 14:00 (h), 16:00 (i), 18:00 (j) on June 2, 2025

rected in a timely manner. ① Unfavorable weather system configuration: after the low pressure landed, it rapidly weakened due to ground friction. Although it was southwest airflow at 500 and 700 hPa, the 850 hPa was only a southerly airflow, and the wind speed did not reach the jet standard, with insufficient low-level dynamic uplift conditions. At 850 hPa, the whole prefecture was a low value area for water vapor flux, with a specific humidity of only 14 - 18 g/kg. The low-level water vapor conditions were average and cannot support the occurrence of heavy precipitation (Fig. 5). ② The limited influence of cloud systems: satellite cloud images (Fig. 6) showed that the low pressure cloud system in the Bay of Bengal was generally westward, far away from Dehong Prefecture, and there were no obvious convective cloud clusters over the entire prefecture. Until 16:00 on the 30^{th}, the low-pressure residual cloud system approached Dehong Prefecture from west to east with the southwest airflow in front of the monsoon trough, and the effective precipitation period was short and the intensity was weak. ③ The deviation of the mode forecast was not corrected in time: the early forecast of the EC mode showed that the southwest airflow outside the low-pressure system would continue to affect Dehong Prefecture until the 30^{th} after the low-pressure system landing, but the actual weakening speed of the low-pressure system was much faster than the mode forecast, and the duration and intensity were not as expected. The forecaster failed to subjectively correct the mode results in time, overestimating the contribution of the high-level southwest airflow to precipitation, and resulting in a larger forecast magnitude.

3.2.2 Analysis of the causes of heavy precipitation on June 2. The actual precipitation on June 2 was significantly higher than the forecast, mainly due to the water vapor and dynamic transport of the southwest low-level jet stream at 850 hPa in front of the monsoon trough (Fig. 7), combined with the precipitation amplification effect of terrain uplift. However, the forecaster underestimated this superposition effect. ① The coordinated coordination of the entire-layer southwest airflow: on June 2, the monsoon trough was established, and Dehong Prefecture was all controlled by the southwest airflow at 500, 700, and 850 hPa, forming a favorable configuration of the entire southwest airflow, with continuous and sufficient water vapor transport. The two outlets of the southwest jet stream at 850 hPa pointed respectively towards Yingjiang County and Mangshi, providing strong dynamic transmission for heavy precipitation in both areas. ② Abundant water vapor conditions: there was a high water vapor flux area on the west side of Dehong Prefecture at 850 hPa, with a specific humidity of 16 - 18 g/kg. The water vapor flux at 700 hPa at 08:00 was close to that at 20:00, achieving continuous water vapor transport and excellent hydrodynamic conditions. ③ Continuous cloud coverage + terrain amplification: satellite cloud images (Fig. 8) showed that the southwest airflow in front of the monsoon trough guided the precipitation cloud system to continuously reach the airspace over Dehong. From 20:00 on June 1 to 20:00 on June 2, there were always precipitation cloud clusters covering the prefecture. At the same time, the terrain from Myanmar to Dehong gradually rises, and the forced uplift of the terrain on water vapor further amplified the precipitation intensity, forming a heavy rainstorm falling area. ④ Inadequate prediction of jet effect: at 08:00 on June 1, EC mode has predicted the southwest air flow at 850 hPa and the exits of the two wind speed high-value areas pointing to Yingjiang County and Mangshi (consistent with the actual heavy rainstorm falling area). However, the forecasters underestimated the water vapor and dynamic amplification effect of the low-level jet at 850 hPa under the background of the whole layer of southwest air flow, and failed to timely improve the forecast of precipitation magnitude, resulting in conservative forecast results.

4 Ideas and countermeasures for improving forecasting services

The starting date of the rainy season in all counties and cities of Dehong Prefecture in 2025 was earlier than the first round of heavy precipitation in this process. After entering the flood season, the probability of nationwide heavy precipitation was significantly increased, and the forecast needed to quickly complete the transition from dry season to rainy season. In combination with the forecast deviation of this process, targeted improvement measures were proposed. ① It should focus on the key signals of the southwest low-level jet at 850 hPa, continuously track the changes of the situation field at all levels, and timely revise the forecast conclusions of numerical modes in combination with the actual observation to avoid relying on a single mode. ② It should strengthen the research on the correlation between the Bay of Bengal monsoon and the rainy season, improve monitoring indicators at the beginning of the rainy season, and enhance early warning capabilities for heavy precipitation. ③ By integrating multiple sources of observation data such as regional stations, satellites, and radars, and historical cases with similar atmospheric circulation were compared and analyzed, aimed to use refined short-term forecasting to compensate for mid- to short-term forecasting biases. ④ It should deepen the research on the mechanism of precipitation in complex terrain, systematically test the forecasting performance of various modes in Dehong Prefecture, strengthen the recognition of terrain precipitation triggering mechanism by forecasters, and enhance their subjective correction ability. ⑤ It should improve the early warning linkage mechanism between meteorological department and water conservancy, natural resources and other departments, achieve real-time sharing of information such as rainfall and water conditions, release targeted and refined forecasting service products, and enhance the accuracy of meteorological support for flood prevention and disaster reduction.

5 Conclusions and discussion

The first round of continuous heavy precipitation process during the rainy season in Dehong Prefecture from May 24 to June 3, 2025 was analyzed, and the conclusions were as below. ① This heavy precipitation was formed by multiple systems including the convergence shear line of the South China Sea monsoon, the Bay of Bengal storm, the monsoon trough, and the southwest low-level jet stream. It had the characteristics of high intensity, large accumulated rainfall, and uneven spatial and temporal distribution. The time of action of each system did not overlap, resulting in significant daily differences in precipitation areas and magnitudes. The process can be divided into three stages, with the strongest precipitation on June 2, triggered by the 850 hPa southwest low-level jet stream combined with terrain uplift. The establishment and strengthening of this jet stream were the core indicators for heavy precipitation forecasting in Dehong Prefecture. ② The main cause of forecast deviation was underestimation of the attenuation rate of the Bay of Bengal low pressure system, insensitivity to the precipitation amplification effect of low-level jet streams and terrain, and insufficient simulation of topographic precipitation by the mode. ③ The establishment of the Bay of Bengal monsoon had important indicative significance for the beginning of the rainy season in Dehong Prefecture. In the future, it is necessary to deepen the research on the synergistic effect of tropical systems and monsoon troughs and the quantitative effect of terrain uplift under the complex terrain of low-latitude plateaus, improve the forecasting index system, and enhance the accuracy of similar heavy precipitation forecasts.

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