Analysis on the Abnormal Distribution of Large-scale Rainstorm in Guangxi Caused by typhoon Bailu (1911)

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Abstract. Typhoon "Bailu" of 1911 caused extensive rainstorms in Guangxi, and its rain intensity and distribution were abnormal. The rainstorm was mainly concentrated in the east and south, and the rainstorm belt was northeast-southwest. Many forecast products, including subjective and objective forecasts, showed deviations in the area and intensity of this rainstorm. The weather dynamic diagnosis and analysis method was used here to analyze the causes of the abnormal distribution of the rainstorm based on conventional meteorological data and European centre reanalysis data, satellite cloud images, and mesoscale automatic stations. The results showed that this rainstorm caused by "Bailu" was formed by the coupling of low-and-upper level jets circulation and strong water vapor convergence. The guidance of the subtropical high airstream caused the clouds on the southwest side of the "Bailu" to move slowly westward. The input of the southwest monsoon airstream revived, strengthened and maintained the "Bailu" vortex. The plenishment of abundant water vapor caused continuous and concentrated rainstorm in the eastern and southern regions of Guangxi. The asymmetric structure of typhoons was also an important reason of abnormal precipitation distribution.

1. Introduction
Landing typhoons often cause huge loss of life and property to coastal and inland areas[1]. Numerous related research results showed that: After a typhoon makes landfall, its strength, structure, and movement path would change significantly due to the influence of terrain friction and changes in underlying surface sensible heat, latent heat, and water vapor flux[2-4]. The formation of its rainstorm was related to topographic forcing, cold air intrusion, interaction of multi-scale circulation systems at different latitudes, and the influence of factors such as the structure of the typhoon itself, water vapor transport, mesoscale fluctuations in the typhoon circulation, and energy fronts[5-7]. The complex diversity of the impact factors of landing typhoons and the differences in the formation mechanism of rainstorms cause rainstorms to occur at different locations of the typhoon. At present, the accurate forecast of typhoon rain and risk prevention in various places are still facing great challenges.

Typhoon No.11 "Bailu" in 2019 triggered a large-scale rainstorm in Guangxi. The current subjective and objective forecast methods in the meteorological forecast business were significantly different from actual observations in the forecast of this rainstorm area and intensity. Here, using the observation data from the Guangxi ground-encrypted automatic station, satellite cloud images, and grid data reanalysis by the European Centre, the characteristics of the circulation situation change when the typhoon "Bailu" triggered rainstorm were analyzed. Focus on revealing the reasons why the typhoon rainstorm belt was
located in the east and south of Guangxi. It was hoped to further understand the formation mechanism of the landing typhoon rainstorm and provide a reference for the accurate forecast of typhoon rainstorm.

2. "Bailu" path and overview of precipitation

Typhoon No.11 "Bailu" in 2019 was generated on the Northwest Pacific Ocean at 14:00 on August 21 (Figure 1), and at 13:00 on the 24th, it made landfall on the coast of Manzhou township, Pingtung county, Taiwan with a severe tropical storm (Level 11 wind speed, 30m/s). At 07:25 on the 25th, a severe tropical storm (Level 10 wind speed, 25m/s) made a second landing in the coastal area of Dongshan county, Fujian province. At 14:00 on the 25th, it weakened into a tropical depression in Pingyuan county, Meizhou city, Guangdong province, and the Central Meteorological Observatory stopped positioning it at 05:00 on the 26th.

Although only the intensity level of a severe tropical storm, the "Bailu" still caused strong rainstorms in Guangxi. The rainstorm was mainly manifested as asymmetric structure, wide rainfall range, and strong local rainfall. The spiral cloud belt was on the south side of the typhoon centre, and the rainstorm was mainly on the southwest side of the typhoon vortex. The impact of "Bailu" on the rainstorm in Guangxi began at 18:00 on August 25. The rain belt continued to press south, and the heavy rainfall was mainly concentrated in the east and south. The heavy rain belt was northeast-southwest. The rainfall area was pressed to the south and northward in these areas, and the coincidence of the rain areas was high. It lasted for 2 days. As the TC moved northwest on the night of the 26th, the rain area gradually moved northwest and its intensity weakened. Statistics showed that from 02:00 on August 26 to 02:00 on August 27, there were 33 national weather stations in Guangxi with daily rainfall >=50mm, of which there were 8 stations >=100mm. The maximum rainfall at the mesoscale automatic station was 262mm from the National Meteorological Observatory of Li village, Rong county, Yulin city (Figure 2), which was an extremely heavy rain. In the early morning of the 26th, the rainfall of 1h in this place reached 124.6mm, and the rainfall of 3h reached 230.3mm.

Regarding the intensity and falling area of the heavy rain caused by the "Bailu", there were large deviations in the forecasts of both subjective and objective models. The following was an analysis of the cause of the rainstorm's fall area and intensity.

3. Analysis of abnormal causes of rainstorm

3.1. Circulation situation

The analysis of the circulation situation that occurred at 08:00 on August 26 on the day when the “Bailu” caused the largest rainstorm in Guangxi showed that the 200hPa South Asian high was strong and maintained stably. The centre of the high pressure was located in the east of the plateau (Figure 3a). The strong divergence area on the east side covered the northern part of Jiangnan to South China, and the remnant vortex of "Bailu" typhoon moved under the high-altitude divergence area of the South Asian
High, which was beneficial for its maintenance for a longer period of time[8-9]. The 500hPa subtropical high presented the form of enclosed the "Bailu" remnant vortex, with an east-west belt-shaped high-pressure dam on the north side, a square-headed thick structure on the east side, and 592 closed lines along the east coast. The subtropical high slowly extended westward and strengthens, the ridge line was maintained at 32°N, and the west ridge point extended to Xinjiang. The continental ring subtropical high covered a wide range, and the large-scale enclosed subtropical high guided the "Bailu" remnant vortex to move slowly westward. The central circulation of the remnant vortex presented a northeast-southwest direction, formed an inverted trough connected to the monsoon low pressure area([10]), which provided environmental conditions for the monsoon airflow to transport water vapor and unstable energy (Figure 3b). The typhoon remnant vortex circulation centre at 850hPa was located on the Guangdong side at the junction of Hunan, Guangdong, and Guangxi. The remnant vortex circulation has a convergence line extending westward and southerly. The monsoon low pressure in the Bay of Bengal was located on the sea and was in a stage of development and strengthening. The monsoon airflows across the Indochina Peninsula and connected with the “Bailu” vortex circulation over South China (Figure 3c). Before the “Bailu” vortex entered Guangxi, the monsoon airflow had increased to more than 12m/s and reached the jet intensity, indicated that the “Bailu” vortex was connected to a low-altitude monsoon jet water vapor transport channel in the later stage. And “Bailu” interacted with the monsoon to obtain sufficient water vapor and latent heat energy, provided water vapor and energy conditions for the occurrence of rainstorm. On the ground map, the centre of the “Bailu” remnant vortex has a convergent line extending south-west (Figure 3d). The closed isobars were in the northeast-southwest direction and extend to the monsoon low pressure area. The 1002.5hPa, 1005.0hPa, and 1007.5hPa isobars were in the north-south direction in South China, and the pressure gradient was large, which was favorable for the “Bailu” residual circulation to stimulate active mesoscale convection to produce rainstorm.

3.2. Characteristics of physical quantities

3.2.1. Water vapor transportation

Figure 4 shows the evolution of water vapor flux and wind field at 925hPa from August 25 to 26. Throughout the entire activity period of “Bailu”, there was always a southwest-northeast water vapor conveyor belt with a water vapor flux greater than 10×10⁻⁴ g/(s•cm•hPa) on the southwest side of the typhoon connected to the east side of the typhoon circulation. From the perspective of the average wind vector, the water vapor conveyor belt was mainly transported eastward from the southwest monsoon from the Bay of Bengal. After the typhoon made landfall on August 25 (Figure 4a), the water vapor channel weakened, but at 02:00 on the 26th, the airflow gradually strengthened to transport water vapor and energy into the typhoon remnant vortex (Figure 4b). The “Bailu” vortex was recovered and maintained. The strengthening of the airflow lasted for nearly 24 hours. The maximum water vapor area of the strengthened typhoon vortex extends from near its centre to the east and south of Guangxi (Figure 4c). At 20 o’clock on the 26th, the water vapor transmission channel weakened and tended to break, and the “remnant vortex” weakened accordingly (Figure 4d). The above analysis showed that the
maintenance of the strength of the “Bailu” remnant was closely related to the replenishment of the southwest monsoon airflow. And the abnormality of the precipitation area was closely related to the tangent line on the southwest side of the “Bailu” vortex.

3.2.2. Vorticity and divergence

Figure 5 shows the 500hPa vorticity change from August 25 to 26. It can be seen that the centre of the large vorticity value corresponds well to the position of the “Bailu” residual vortex. At 20 o’clock on the 25th (Figure 5a) in Guangdong, the vorticity was divided into two interconnected north and south centres, and the southern centre has a stronger value. At 02:00 on the 26th (Figure 5b) as the centre of the typhoon gradually moved westward, the centre of high vorticity also gradually moved westward, and the range of the positive value area expanded and extended to the eastern and southern regions of Guangxi. And this area has been maintained until 20 o’clock on the 26th (Figure 5c, 5d), which was very consistent with the strong rainstorm in Guangxi.

The 500hPa divergence was shown in Figure 6, which corresponds to the remnant centre of “Bailu”, and its southern part was a large negative centre, which corresponds well to the position of the “Bailu” rainstorm in the east and south of Guangxi. The configuration and evolution of these vorticity and divergence all indicated that the eastern and southern regions of Guangxi have a strong vertical convergence of circulation, which provided favorable dynamic conditions for the occurrence of rainstorm.

4. Typhoon asymmetric structure

The asymmetric structure of the typhoon was also one of the important reasons for the abnormal distribution of rainstorms in Guangxi caused by the “Bailu”. After the formation of “Bailu”, the distribution of its cloud system showed the characteristics of asymmetric structure. Analysis showed
that before and after the landing of "Bailu", the spiral cloud system structure was obviously asymmetrical, the southern half of the ring cloud system was dense and connected to the monsoon cloud system, the outer spiral cloud belt was clearly distinguishable, and the water vapor transportation channel was clear. The cloud system in the northern half of the ring was loose, the boundary was fuzzy and indistinguishable, convective monoliths develop locally, the intensity was unevenly distributed, and the typhoon centre eye area was blurred. Before "Bailu" stopped positioning, the cloud structure remained strong in the southern half of the ring and weak in the northern half, but the intensity weakened slowly. At 20 o'clock on the 25th (Figure 7a), the centre intensity was 15998, located in the northern part of Guangdong Province (24.8°N,114.1°E), move to the northwest and west at a speed of 20km/s. At 02:00 on the 26th (Figure 7b), the centre intensity was 12002, located in the northern part of Guangdong province (25.1°N,113.1°E), moving to the northwest and west, moving at an undetermined speed. This was the last positioning of the Central Meteorological Observatory. And it was expected that the intensity of “Bailu” would continue to weaken and the impact would be reduced.

The actual observation data showed that the rainfall intensity did not weaken after the “Bailu” stopped releasing the positioning at 05:00 on the 26th. The convective cloud system along the coast of Guangdong strengthened from 02:00 to 08:00 on the 26th (Figure 7c). The convective cloud system moved northward to connect with the residual vortex cloud system. The intensity did not decrease significantly, but slightly strengthened. This indicated that there were still active mesoscale convective activities in the typhoon circulation at this time, while maintaining a certain amount of water vapor supply, and the strength of the remnant vortex has recovered. It was not until 20 o'clock on the 26th (Figure 7d) that the remnant vortex cloud system showed weakening characteristics. However, the pattern of strong southern half-ring and weak northern half-ring was still maintained, and rainstorm in the southern half-ring remained until the night of the 26th.

5. Summary
Through the analysis of the circulation situation combined with satellite cloud images, mesoscale automatic stations and other data, it was concluded that the reasons for the rainstorm and the abnormal distribution of the landing area in Guangxi caused by the "Bailu" typhoon were as follows:

1) The 200hPa “Bailu” remnant vortex moved under the strong divergence zone on the east side of the South Asian High. (2) The 500hPa subtropical high presents the shape of the enclosed “Bailu” remnant vortex. The central circulation of the remnant vortex was northeast-southwest, forming an inverted trough connected to the monsoon low pressure area, providing environmental conditions for the monsoon air flow to transport water vapor and unstable energy. (3) The 850hPa “Bailu” remnant vortex was connected to the water vapor transport channel of the low-altitude monsoon jet in the later stage, interacts with the monsoon, and obtains sufficient water vapor and latent heat energy. (4) The configuration and evolution of vorticity and divergence showed that the eastern and southern regions of Guangxi have strong vertical convergence of circulation, which provides favorable dynamic conditions
for the occurrence and development of heavy rain in these regions. (5) “Bailu” has obvious structural asymmetry features, and the degree of denseness of the cloud system in the southern and northern half of the ring varies greatly. The cloud system of the southern half-ring was dense, and the cloud system of the northern half-ring was loose, and the central eye area was fuzzy. The largest rainstorm was distributed in the southern region.

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References
[1] Chen, Y.L., Zhou, J., Ma,F.H. (2005) Recent Progress of Study on China Landfalling Typhoons. Journal of the Meteorological Sciences, 3:319-329.
[2] Chang, C.P., Yeh, T.C., Chen, J.M. (1993) Effects of terrain on the surface structure of typhoons over Taiwan. Mon Wea Rev, 121(3):734-752.
[3] Zhao,Y.C., Wang, Y.H., Chen, J.K., Huang, H.R. (2018) Numerical investigation on detailed structure of Typhoon "Meranti"(2016) and extreme heavy rainfall event induced by it before and after landfall in Fujian. Torrential Rain and Disasters, 37(2):135-148.
[4] Li, Y., Chen, L.S., Lei, X.T. (2013) Study on Rainfall Variation Associated with Typhoon Winnie (9711) during its Extratropical Transition Process. Chinese Journal of Atmospheric Sciences, 37(3):623-633.
[5] Zhao, J.B., Han, S.Y., Li, J.Y. (2014) Comparative analysis of two heavy rain events affecting Guangxi associated with typhoon Kai-tak and Nesat, Torrential Rain and Disasters, 33(2):156-162.
[6] Cheng, Z.Q., Chen, L.S., Li, Y. (2009) Diagnostic analysis of large-scale circulation features associated with strong and weak landfalling typhoon precipitation events, Acta Meteorologica Sinica, 67(5):840-850.
[7] Yue, C.J., Han, Z.H., Gu, W., Tang, Y.Q., Tan, J.G. (2005) Study on the cause of torrential rainfall and its asymmetric structure from typhoon Haitang, Torrential Rain and Disasters, 2017, 36(4):293-300.
[8] Li, Y., Chen, L.S., Wang, J.Z. (2004) The Diagnostic Analysis on The Characteristics of Large Scale Circulation Corresponding to The Sustaining and Decaying of Tropical Cyclone After It's Landfall, Acta Meteorologica Sinica, 62(2):167-179.
[9] Dong, M.Y., Chen, L.S., Zheng, P.J., Pan, J.S. (2009) Research Progress on Abrupt Intensification of Heavy Rainfall and Super Heavy Rainfall Associated With Landfalling Tropical Cyclones, Journal of Tropical Meteorology. 25(4):495-502.
[10] Gao, A.N., Tan, Q.M. (2007) Analysis for the Extreme Rainstorm in Guangxi Caused by "Billis" Typhoon, 28(2):7-10.