Comparative Analysis of the Precipitation Difference Between Sanya Airport and Haikou Airport Caused by Typhoon 2117

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Abstract: By using ECMWF and FNI reanalysis data, airport self-observation precipitation data, satellite TBB data, and precipitation distribution data of Hainan Meteorological Bureau, the rainfall characteristics of Sanya Phoenix Airport and Haikou Meilan Airport on the day of Typhoon Lionrock on the 17th, autumn 2021 were analyzed. The results found that: (1) The lifting effect of the terrain and the invasion of weak cold air intensified the intensity of the rainstorm in Hainan. The rainstorm center was located on the windward slope of Wuzhishan Mountain. Fenghuang Airport was in the leeward slope environment, while Meilan Airport was in the windward slope. (2) The convergence of southerly air flow and southeast air flow and the abundant water vapor brought by the dynamic action of upper low-level jet stream are favorable conditions for triggering and maintaining heavy rain. (3) There was a negative correlation between heavy precipitation and brightening temperature of black body. The direct influence system of this weather process was mesoscale convective cloud cluster. (4) The rainstorm occurs in the area of dense θse line, which is conducive to the development of inclined vorticity. (5) The positive vertical helicity of 850hpa is a good indicator of precipitation in the next 6 hours.

Keywords: A Typhoon; A Rainstorm; Circulation Pattern; Vertical Velocity; Water Vapor Condition; Helicity

1. Introduction

Sanya Phoenix International Airport is located in Tianya District, Sanya City, Hainan Province, China, located in the northwest of Sanya City, located at low latitude, north of the mountainous area, south of the sea, the terrain gradually slopes from north to south, the north side of the airport is distributed with endless hills, there is an altitude of about 1879m Five Finger Mountain, blocking the exchange of north-south airflow, so that the cold air affecting Sanya in winter and spring is often blocked and weakened[1].Haikou Meilan Airport is located in the north of Hainan Island, 10 kilometers away from Qiongzhou Strait, 40 kilometers away from the coastline in the east and 130 kilometers away from Wuzhishan in the southwest. It is flat and prone to heavy rain due to "train effect" [2]. In recent years, more and more attention has been paid to the study of typhoon rainstorm. Some studies have pointed out that typhoon rainstorm is related to many factors such as typhoon track, typhoon intensity, low-level jet stream, weak cold air activity, and topographic effect [3]. When studying tropical cyclones, Chen Lianshou et al. pointed out that the rainstorm generated by tropical cyclones is often associated with the low-level jet outside the tropical cyclone, and the existence of the jet provides convenience for the water vapor transport in the east and south sides of the tropical cyclone circulation [4].Zhou Guangyi et al. found that typhoons or tropical storms with different paths had different impacts on heavy precipitation in Jianfengling, Hainan [5].CAI Xiaohui et al. analyzed the process of heavy rain in Hainan Island caused by the strong typhoon Nesat in 2011, and pointed out that topography had a significant increase effect on precipitation [6].

At present, there are few comprehensive analyses of autumn typhoons using various physical quantities. In Hainan, there are many typhoons in autumn, and there are often multiple dances, so it is difficult to forecast the change of typhoon path and intensity. Autumn typhoon is one of the main weather affecting flight activities. By using a variety of physical quantities to analyze the characteristics and causes of rainstorm caused by typhoons, this paper explores the reasons for the large difference in precipitation between Fenghuang Airport and Meilan Airport on the day affected by typhoons, providing certain reference and experience for the refined forecast of typhoons in autumn in civil aviation.

2. Data

In this paper, typhoon track data from the National Meteorological Observatory are used. The data of altitude field, wind field, vertical velocity and vorticity divergence were all reanalyzed by ECMWF. The spatial resolution was 2.5°×2.5°. The helicity data were reanalyzed by FNL, and the spatial resolution was 1°×1°. FY2G 1h average blackbody brightness temperature products; Precipitation data came from airport self-observation station data; Precipitation distribution data came from Hainan Meteorological Bureau. The date will be October 8, 9 and 10, 2021.

3. Research Process

3.1 Typhoon Track and Intensity

Typhoon Lionrock formed at 2 o 'clock on October 4 and was officially classified as the 17th typhoon of 2021 on the morning of October 8. It made landfall on the coast of Qionghai City, Hainan Province at 22:50, with a maximum wind force of 8 near the center. At around 4:20 PM on October 10, it made landfall on the coast of Nam Dinh province in northern Vietnam with a maximum wind force of 8 near the center of the landfall. At 5 PM, it was centered in Nam Dinh Province of Vietnam with a maximum wind force of 7. It further weakened in the evening. Typhoon No. 17 moved slowly on the whole and affected South China for a long time [7]. It was a mid-path typhoon (south of Wenchang and north of Lingshui), and it had the highest probability of precipitation above heavy rain [8].

3.2 Precipitation Overview

Under the influence of Typhoon "Lion Rock", during October 8-10, the precipitation level of Hainan Island reached rainstorm to heavy rainstorm, and the local heavy rainstorm. As can be seen from the 48h accumulated precipitation distribution map, the heavy precipitation center of Hainan Island was located in the north and northwest of Hainan Island. According to the 6h accumulated precipitation map , it can be found that the rain belt was moving westward to the north. The rainfall intensity is increasing continuously, and the maximum range of downfall intensity is between 200-300mm. Affected by the northern topographic factors , Sanya Airport at this time is on the leeward slope, and mountains block most of the air flow, while Haikou is on the windward slope. Therefore, when the air flow passes over the terrain, due to the blocking effect of the terrain, the air flow is forced to climb along the slope. Such "rainfall mechanism on the windward slope" can produce significant precipitation differences between the two sides of the mountain [9]. The precipitation data from the observation stations of Sanya Phoenix Airport and Haikou Meilan Airport are selected for comparison. It can be seen that the difference between the two airports is the largest on the 8th, with the precipitation difference reaching 135.4mm.

3.3 Analysis of Circulation Situation

During the development of Lionrock, (FIG. 1a) the circulation pattern of 500hpa in East Asia was two trough and one ridge, and the circulation pattern from Lake Baikal to Xinjiang was a transverse trough. There was a high-altitude jet belt from west to east over 30m/s at 200hpa. The existence of upper-level jet enables the ambient wind field with strong vertical shear under the jet stream to provide the development of convection, and at the same time is conducive to enhancing the mass divergence of the cloud top and maintaining the upward motion [19]. (FIG. 1b) A large amount of cold air was accumulated in Mongolia and Xinjiang. In the process of the transverse trough gradually turning vertical to the east on August 8, a large amount of cold air would move southward, and a weak cold air located in Guizhou would invade the outer part of the typhoon, causing obvious disturbance to the unstable air in the typhoon and forming large-scale precipitation [11]. The easterly air flow at the bottom of the subtropical high continuously conveys water vapor in the eastern ocean, and sufficient water vapor constantly condenses and releases latent heat inside the typhoon, providing favorable conditions for the maintenance of the warm core structure of the typhoon and the development of convection in the rain belt [10].

It can be seen from the surface situation field (Figure 1c) that at 8:00 on August 8, Hainan Island was mostly affected by the 15-18m/s southwest low-level jet, which provided horizontal shear and relative vorticity of wind field for tropical cyclones [11]. At 20 o 'clock on August 8 (Figure 1d), the southerly air flow from the South China Sea and easterly air flow outside the subtropical high converged on the north side of the typhoon, and a 24m/s low-level jet zone began to appear. The north of Hainan Island was just in the exit zone of the jet stream. As the typhoon continued to move northwest, the center of the jet stream moved out of Hainan Island at 0800 on September 9 (picture omitted).

3.4 TBB Analysis of Satellite Data

Studies show that before and after the occurrence of short-time heavy precipitation, the brightness temperature of black body first drops and then rises, showing a negative correlation trend [12]. (Figure 2a) Typhoon No. 17 did not officially land at 8 o 'clock on 8th, but it could be clearly seen that the typhoon's peripheral cloud system had begun to affect the eastern part of Hainan Island. As the typhoon gradually landed, (Figure 2b) TBB low value area had affected most parts of the island at 20 o 'clock on 8th, and then due to the influence of the island's topography and other factors, By 8 o 'clock on the 9th, the intensity was obviously weakened in the southern part of Hainan Island, but it was still strong in the northern part (Figure 2c). Due to its impact, the entire line of Qiongzhou Strait was suspended and the high-speed railway around Hainan Island was suspended on the morning of 9th. More than 200 flights were canceled at Meilan Airport, and some areas were flooded seriously [13]. By 20 o 'clock on the 9th, mesoscale convective cloud [14] had basically moved away from Hainan Island (FIG. 2d). Compared with the cumulative rainfall in 3h (FIG. Omitted), the distribution of precipitation was basically the same, and it could be concluded that the direct system affecting the precipitation difference between the two airports was mesoscale convective cloud cluster in typhoon.

3.5 Analysis of Water Vapor and Dynamic Conditions

Lionrock is located on the southwest side of the subtropical high. Southerly and southeast air from the South China Sea converge on the east side of the typhoon, bringing abundant water vapor to the island. The overall direction of water vapor transport is a moving direction from northeast to southwest. (Figure 3a).

According to the divergence field analysis, Sanya and Haikou are both in a suction environment with low-level convergence and high-level divergence (FIG. 3a). Compared with the vorticity conditions, Haikou is affected by positive vorticity advection, while Sanya is affected by negative vorticity advection (FIG. 3b). The research shows that the developed tropical cyclone disturbance is located in a large range of high relative vorticity value region [11]. Such configuration enhanced the convergence and ascending motion of the low level in Haikou area, which resulted in the precipitation intensity of Meilan Airport being greater than that of Fenghuang Airport on August 8.

3.6 Diagnostic Analysis of Wet Potential Vorticity

Pseudoequivalent potential temperature is a parameter of potential instability and baroclinic instability, reflecting the pooling degree of baroclinic unstable energy in the atmosphere, and its vertical distribution can reflect the convective instability of the atmosphere [20].

It can be seen from the figure that the lower level of the two airports showed a high value center of equivalent potential temperature at 8 o 'clock on August 8, which is because the southerly air flow from the South China Sea and the easterly air flow from the edge of the subtropical high continuously transported the warm and wet air to the rainfall region, forming a high energy tongue, which increased the thermal instability of the lower level and was a wet convective unstable air layer ($\Delta\theta se/\Delta p>0$) [15]. (Figure. 4a) The air over Phoenix Airport was wet neutral ($\Delta\theta se/\Delta p\approx0$) between 700hpa and 500hpa. Above 400hpa, the atmosphere layer is convection-stable ($\Delta\theta se/\Delta p<0$). At the same time, the low level convective stability is small. In order to maintain the conservation of wet potential vorticity, the decrease of convective stability at lower level will lead to the significant growth of cyclonic vorticity at lower troposphere, which is conducive to the development of ascending motion. For Fenghuang Airport, the instability condition at lower level is satisfied, but the vertical velocity is not as good as Meilan Airport. The latter has a maximum vertical velocity of -4.5pa/s (Figure. 4b), which is conducive to the generation of rainstorm. The phenomenon of high and low layers opening up on the is θse surface is conducive to the transfer of high vortex cold air

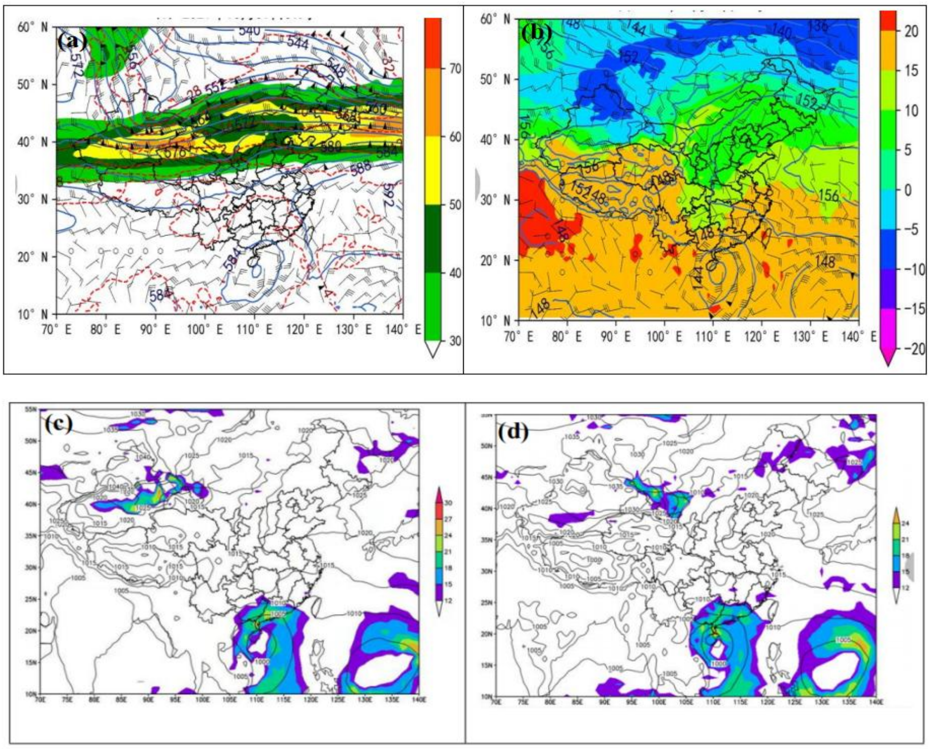

Figure 1 (a) Superposition Diagram of 500hpa Geopotentic Height (Solid Black Line), Temperature (Dotted Red Line), Wind Field And 200hpa High-Altitude Jet Stream (Shaded Green Part) at 8:00 On August 8; (b) Superimposed Diagram of 850hpa Geopotentical Height (Solid Black Line), Temperature (Shaded Part) And Wind Field; Surface Form Field Superimposed 925hpa Jet (c)8 At 8:00 (d)8 At 20

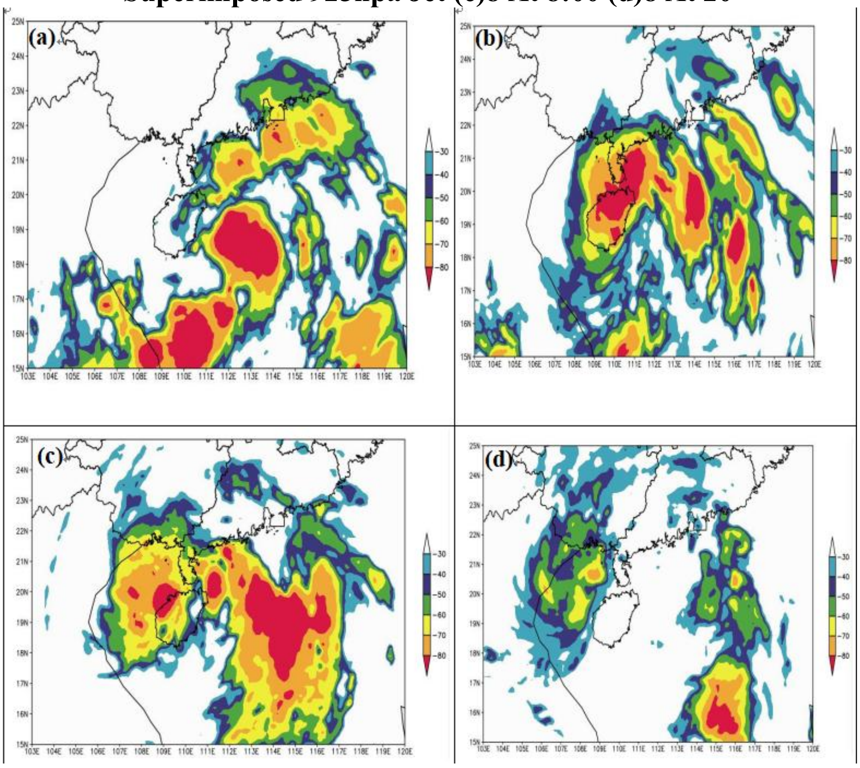

Figure2 Satellite TBB Distribution Shadow (Unit ℃) (a) at 8 o 'Clock on 8th (b) at 20 o 'Clock on 8th (c) at 8 o 'Clock on 9th (d) at 20 o 'Clock on 9th

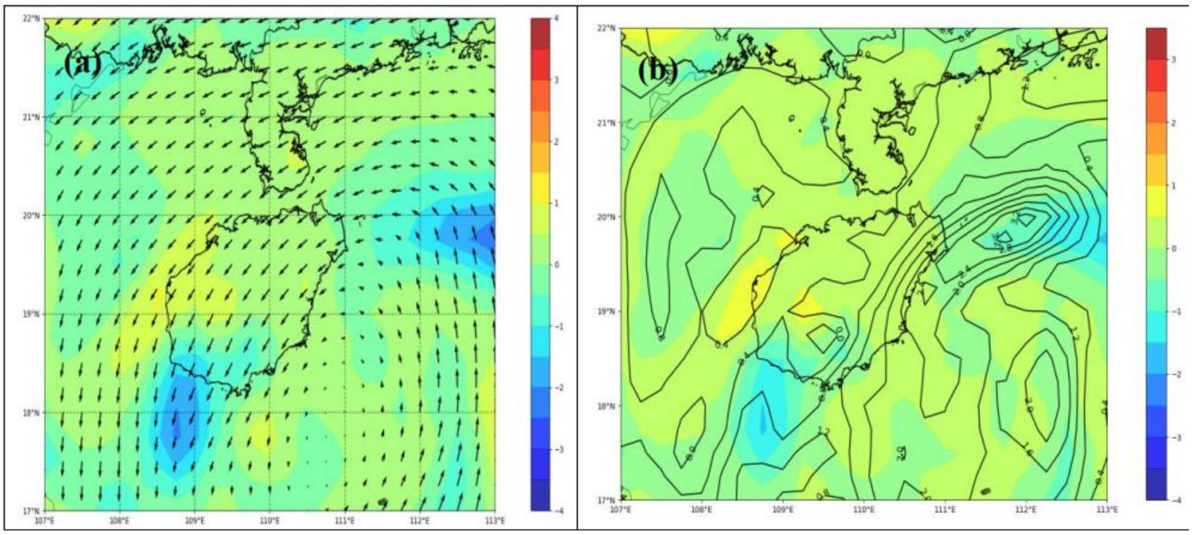

Figure 3. (a) Divergence of Water Vapor Flux and Water Vapor Flux at 8:00 on 8th Day 700hpa (b) Vorticity Divergence at 8:00 on 8th Day 700hpa (Unit: 10-7g/(s·Hpa·Cm)

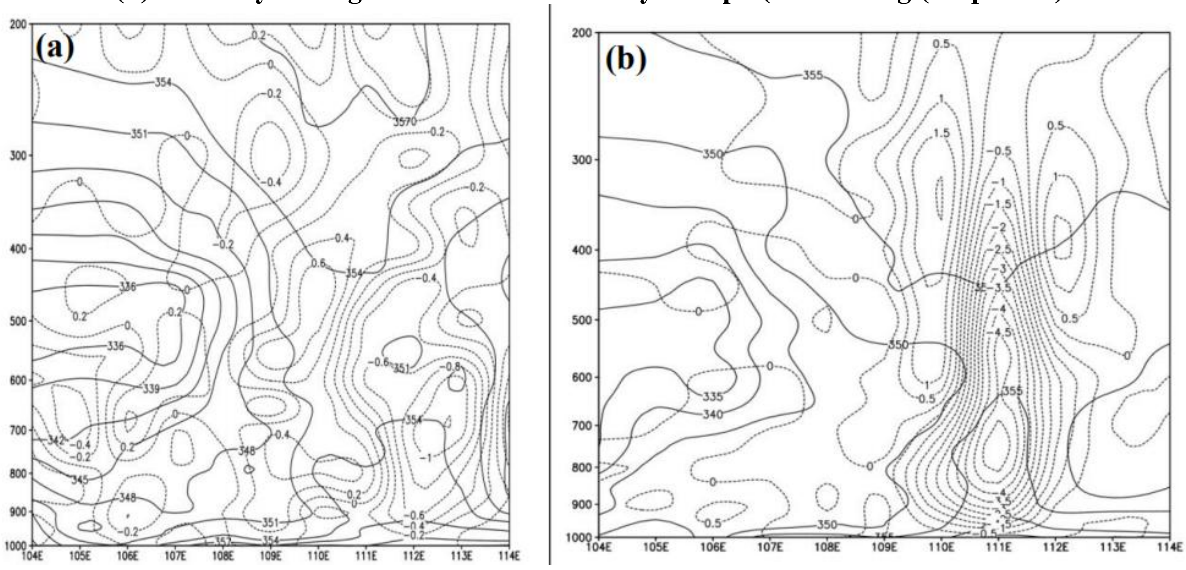

Figure 4. Vertical Profile of False Equivalent Potential Temperature (unit K) and Vertical Velocity (unit Pa/s) Along (a)18.18°N and (b)21.03°N on October 8

from the middle and upper troposphere to the lower layer, while the warm and wet air from the lower layer is also transported to the upper layer through this channel, which promotes the frontogenesis of the descending water region, enhances the instability of the atmospheric junction of typhoon rainstorm, and corresponds to the emergence of strong precipitation.

3.7 Analysis of Helicity

Vertical helicity is a physical quantity combining vertical vorticity and vertical velocity. It takes into account both horizontal and vertical transport effects as well as the characteristics of atmospheric rotation and distortion. It is an excellent factor that can be used in weather analysis and prediction,From this point of view, this paper attempts to analyze its relationship with the precipitation falling area, hoping to get meaningful conclusions [16].

The positive center of helicity began to affect the northeastern part of Hainan Island from 14:00 on the 8th, and basically covered the whole island at 2:00 on the 9th. During this period, the precipitation gradually increased from 14:00 to 20:00 on the 8th, and the helicity reached 500×10-8hPa/s2 in the northern part of Hainan, which was the strongest from 20:00 to 2:00 on the 9th. It gradually weakens between 2:00 and 8:00, and it can be seen that the positive area of helicity has a good correspondence with the subsequent 6h precipitation area (omitted).This is consistent with the research results of Liu Huahan et al. [17].

In the vertical profile, the maximum positive area over Phoenix Airport is about 350hpa, but the intensity is 15×10-8hpa/s2. In contrast, over Meilan Airport, the maximum positive area appears at about 800hpa, and the intensity reaches 650×10-8hpa/s2. And the range was expanding rapidly, extending to the altitude of 300hpa, which indicates that the low level rotating air flow has a strong upward movement, resulting in heavy rain in Meilan Airport, while Sanya only saw moderate to heavy rain on that day.

4. Conclusion

This paper adopts the method of synoptic diagnosis and analysis to analyze the circulation situation and other related physical quantities of the rainfall weather process caused by Typhoon Lionrock at Fenghuang Airport, and draws the following conclusions:

The path of the 17th typhoon "Lionrock" was a middle category typhoon (south of Wenchang and north of Lingshui), and the intensity of precipitation was above the magnitude of heavy rain when it landed.

Analysis of formal field shows that: The convergence of southerly flow and southeast flow, the existence of low-level jet stream and the topography are all important mechanisms that trigger heavy rain in Hainan. The pumping configuration of low-level convergence and high-level divergence is conducive to the formation of heavy rain in Hainan. Meanwhile, the intrusion of weak cold air in the north makes the instability disturbance in typhoon strengthened. The low-level easterly jet brought water vapor on the eastern ocean surface, which maintained the warm core structure of the typhoon and strengthened the intensity of rainfall. It should be noted that the formation of No. 18 "Compasses" at the rear of "Lion Rock" was observed in the form field. The "Fujiwara effect" [18] caused by the formation of double typhoons may be the reason for the long duration and long influence period of Typhoon No. 17.

As can be seen from satellite TBB, there is a negative correlation between heavy precipitation and brightening temperature of black body, resulting in that the direct influence system of precipitation intensity of the two airports is the strength of the mesoscale typhoon on the cloud.

Based on the comprehensive analysis of the distribution of the pseudo equivalent temperature and vertical velocity in the airport area, there were convective instability areas in the middle and low levels of the airport on August 8. The θse surface near Fenghuang Airport was sparse, while the θe surface over Meilan Airport was steep and dense. The steep and dense θe surface over Meilan Airport was easy to lead to the development of wet barotropic vorticity, which was one of the reasons for the large difference in precipitation between the two airports.

For typhoon rainstorm, the positive helicity area of 850hpa has a certain indication effect on the falling area of heavy precipitation in the future 6h.At the same time, when analyzing the vertical helicity over the airport area, it is found that compared with Meilan Airport, the helicity over Phoenix Airport is much less than that over Haikou Meilan Airport, which means that the upward intensity of rotating air flow over Phoenix Airport is weak, and the dynamic conditions of precipitation are poor.

References

[1] Aviation Climatology of Sanya Phoenix International Airport (2012-2017), [M]2019(01).

[2] Li Minghua, Chen Fangli, JIANG Shuai, Gan Quan, Lin Huifeng, Zeng Dandan, LI Jiaojiao, MA Zeyi, ZHANG Zifan. "Train Effect" Analysis of Extreme Heavy Rainfall in "18.8" Rainstorm Center in Eastern Guangdong [J]. Heavy rain Disaster, 2019,38(04):329-337. (in Chinese).

[3] Lu Guirong, Wang Wen, Zheng Meiqin, CAI Qinbo. Spatial and temporal distribution characteristics of Typhoon rainstorm in Hainan [C]// Proceedings of S2 Subtropical Monsoon and Extreme Weather and Climatic Events of the 34th Annual Meeting of the Chinese Meteorological Society., 2017:65-66.

[4] Chen L S. Development of tropical cyclone research and operational forecasting techniques [J]. Journal of Applied Meteorology, 2006(06):672-681. (in Chinese.

[5] Zhou Guangyi, Qiu Jianrui, Qiu Zhijun, Wu Zhongmin. Effects of typhoon or tropical storm on heavy precipitation in Jianfengling, Hainan Province [J]. Acta Ecologica Sinica, 2004(12):2723-2727.

[6] Yang Renyong, CAI Xiaohui, Zheng Yan. Numerical experiment on the heavy rainstorm process of Typhoon Nassat 1117 [C]// S2 Disaster Weather Monitoring, Analysis and Forecast of the 31st Annual Meeting of the Chinese Meteorological Society., 2014:949-956.

[7] Ma Xuefu, Huang Yiwu, The superimposed effects of Typhoon "Lionrock" and "Compasus" on the cooling and precipitation in central and eastern South China obviously need to be protected against the impact of flood control and relief, [N], China Meteorological News, 2021(10).

[8] Lu Guirong, Wang Wen, Zheng Meiqin, CAI Qinbo. Spatial and temporal distribution of typhoon rainstorm in HainanProvince [J].Journal of Atmospheric Sciences, 2015,38(05):710-715.

[9] Smith R B． T he influence of mountains on the atmosphere． Advances in Geophysics 1979 21： 169～194.

[10] Li Ying, Chen Lianshou, Xu Xiangde. Numerical experiment on influence of water vapor transport on landfall maintenance and precipitation of Tropical cyclones [J]. Chinese Journal of Atmospheric Sciences, 2005(01):91-98.

[11] Guangdong Meteorological Bureau, Guangdong Weather Forecast Technical Manual [M], Beijing Meteorological Press, 2006(05).

[12] Wang Fen, Wang Wenyong, Liu Xiang, Fan Qian, Du Xiaoling, Chi Zaixiang. Relationship between Black body bright Temperature TBB of FY-2 satellite and Short-time heavy precipitation in southwestern Guizhou [J]. Middle and low latitude Mountain Meteorology, 201,45(01):1-8. (in Chinese).

[13] Ministry of Emergency Management releases National Natural disaster Situation in October 2021 [J]. Disaster Reduction in China, 2021(23):9.

[14] Li Zhinan, Zheng Xin-jiang, ZHAO Ya-min, ZHANG Ming-ying. Occurrence and development of mesoscale storm clouds outside the low pressure of Typhoon 9608 [J]. Journal of Tropical Meteorology, 2000(04):316-326.

[15] Zhu Gangen, Lin Jinrui, Principles and Methods of Weather Science (4th Ed.) [M], Beijing Meteorological Press, 2007.

[16] Li Huiqin, Li Jiangnan, Yu Yan, Yang Jinchao, Song Yuntao, Feng Yirong. Characteristics and causes of a typhoon rainstorm in Hainan in Autumn [J]. Journal of Tropical Meteorology, 2018,34(01):133-144.

[17] Liu H H, Tang W M, Zhao L G. Analysis of water vapor and helicity of Typhoon Fenghuang in 2008 [J]. Acta Meteorologica Sinica, 2010,30(03):344-350.

[18] Wang C Z. Fujiwhara effect [J]. Advances in Meteorological Science and Technology, 201,11(06):81.

[19] Wu Rongsheng. Principles of Modern Weather Science [M]. Higher Education Press, 2019(06).

[20] Analysis of thunder weather process at Pudong Airport in early 2019. Journal of Civil Aviation, 2021,5(03):53-58.