To Evaluate the Characteristics of Cloud Parameters Retrieved by Satellite and Cloud Structure of the Northward Typhoon In-Fa

Xiaorui Zhang[1,2], Wenxia Yang[1,2,*], Tuanjie Hou[3], Zhiqiang Shen[4], Shuai Li[4], Shaoyu Hou[1,2] and Jing Meng[4]
[1]*Weather Modification Office of Hebei Province, Shijiazhuang 050021, China*
[2]*Key Laboratory of Meteorology and Ecological Environment of Hebei Province, Shijiazhuang 050021, China*
[3]*Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China*
[4]*Qian Xuesen Laboratory, China Academy of Space Technology (CAST), Beijing 100094, China*

Keywords: Northward typhoon, Cloud parameters retrieved by Satellite, Cloud structure

Abstract: Cloud parameters retrieved by Satellite and model data with detailed cloud microphysical processes are used in this paper to conduct a comprehensive analysis of the precipitation process of the northward typhoon "In-fa" in Hebei Province. The main conclusions are as follows: optical thickness (>20), cloud top temperature (-10℃~-25℃), and cloud top height (>9km) of cloud characteristics parameters retrieved by FY-2 satellite (Fengyun meteorological satellite) have obvious indications for the range and intensity of precipitation. The effective radius of cloud particles needs to be combined with multi-parameter comprehensive analysis. Satellite monitoring products can be used to compare and correct cloud model forecast products. In the early stage of the low-pressure precipitation process of this typhoon, cold clouds are thicker, and the content of hydrometeor and supercooled water in cold clouds are abundant. After 17:00 on the 29th, the hydrometeor and supercooled water contents of cold clouds have decreased significantly and increased obviously in warm cloud, the large value center of water content have also decreased, ice crystals number concentration and snow-graupel mixing ratio have declined, and the main precipitation mechanism changed from cold cloud precipitation to warm cloud precipitation.

1 INTRODUCTION

As an important observation method, meteorological satellites can monitor the evolution of the cloud system on a large scale. The cloud parameters retrieved by the multi-channel radiation characteristics of the satellite can not only reflect the macro and micro physical evolution characteristics in the cloud, but also have a certain degree of precipitation. (Wang et al, 2019). With the continuous development of China's satellite technology in recent years, China's geostationary satellite data of FY series has been widely used. Zhou et al. (2008; 2011) used the observation data of FY geostationary satellites, combined with other observation data, retrieved nearly 10 cloud macro and micro physical characteristic parameters, such as cloud top height, cloud top temperature, cloud optical thickness, cloud particle effective radius, etc. Since 2006, related cloud characteristic products have been released one after another and have been commercialized. Satellite retrieval of cloud parameters plays a key role in disaster prevention and mitigation and high-impact weather forecasting and early warning.

There is plenty of scientific research achievements in domestic and foreign using meteorological satellites data, mainly focus on the development and evolution of the weather system, and the relationship between the satellite inversion of cloud parameters and the occurrence and development of precipitation. Rosenfeld & Gutman (1994) studied the relationship between the effective radius of cloud particles retrieved by NOAA satellites and precipitation, and proposed that the effective radius greater than 14μm is the threshold for precipitation in the cloud. The relationship between cloud parameters and precipitation in different regions of China has been studied by Cai, Zhou, & Zhu, (2010; 2011) and Chen et al. (2007; 2009; 2013a; 2013b) successively, and found that FY-2C and MODIS data can consistently reflect the main characteristics of particle effective radius

Zhang, X., Yang, W., Hou, T., Shen, Z., Li, S., Hou, S. and Meng, J.
To Evaluate the Characteristics of Cloud Parameters Retrieved by Satellite and Cloud Structure of the Northward Typhoon In-Fa.
In *Proceedings of the 7th International Conference on Water Resource and Environment (WRE 2021)*, pages 475-482
ISBN: 978-989-758-560-9; ISSN: 1755-1315

distribution, the large value area of the cloud liquid water path is basically the same as the location of the ground heavy precipitation center, the ground hourly rainfall is positive with the cloud optical thickness and the effective radius of the cloud particles, the probability of precipitation is more closely related to cloud optical thickness, and cloud parameters precede changes in surface precipitation, etc. The correlation between cloud characteristic parameters and precipitation in North China is studied by Wang Lei et al. (2019), and revealed that cloud optical thickness greater than 20 and cloud top temperature less than -15°C can be used as satellite monitoring indicators to predict the upcoming precipitation in North China.

In recent years, with the operational of numerical model data with detailed cloud microphysical processes, cloud parameters retrieved by satellite as a large-scale live monitoring data is often used for comparison and correction of model data. Typhoon In-fa (No.6 of 2021) landed and northward on July 25, and due to its slow-moving speed, it stayed on inland for 95 hours, which is the longest since 1949; the accumulated rainfall is large, and the maximum accumulated rainfall at a single point exceeds 1000mm, significant precipitation was brought to most areas of Hebei Province on July 28th to 30th. This article uses the cloud parameters retrieved by satellite and the model data with detailed cloud microphysical processes released by the National Weather Modification Center to analyze this process.

2 ANALYSIS OF SYNOPTIC BACKGROUND AND CIRCULATION PATTERNS

From July 28th to 30th, due to the combined effect of the peripheral airflow and cold air of Typhoon In-fa, significant precipitation occurred in most parts of Hebei Province, and the rainfall distribution was more in the east and less in the west. In this paper, cloud characteristic parameters retrieved by FY-2 satellite and CPEFS cloud model data during 29th in North China has been used for comprehensive analysis.

As showed in Figure 1, the northern part of Hebei was in front of the 500hpa trough, and the center of tropical depression In-fa was in the southern part of Shandong Provinceat at 08:00 on the 29th, moving slowly to the northeast at a speed of 15 m/s, and the warm humid air streams on the sea were supplemented by the low pressure in the southeast wind direction. A deep moisture layer and an obvious vertical upward movement area above 700hpa in the lower layer was existed, The apparent precipitation process was jointly affected by the cold air and the northward typhoon. “cold pad” was formed by the interaction of weak cold air pile in internal boundary layer and warm humid air streams , which is come from low-latitude. The pad has played a role of forcing ascending motion,dry cold air intrusion and warm humid air streams transferred by low-level jet(LLJ) cause potential instability, which is conducive to the occurrence of heavy rainfall.

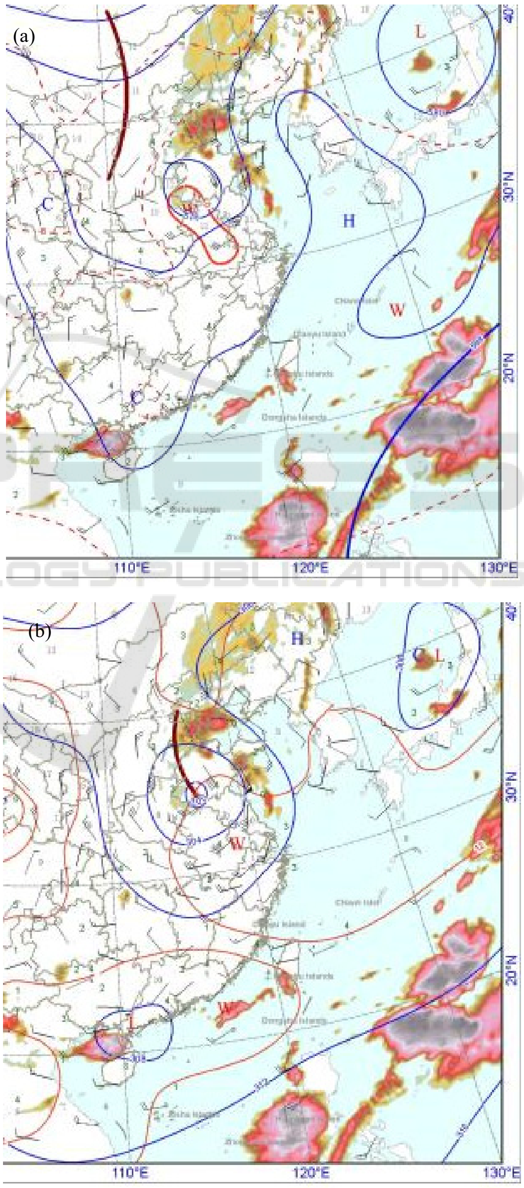

Figure 1: The overlay map of 500hpa(a) and 700hpa(b) synoptic situation and satellite cloud picture at 08:00 on July 29th, 2021.

3 ANALYSIS OF CLOUD PARAMETER RETRIEVED BY SATELLITE

Lots of researches has been presented by using cloud optical thickness and effective particle radius, which is retrieved by using airborne or satellite visible light and near-infrared/mid-infrared channel detection data (Twomey & Cocks, 1982; Twomey & Cocks, 1989; King, 1987; Nakajima & King, 1990; Nakajima & Nakajima, 1995; Arking & Childs, 1985), the theoretical basis is that the reflection function is mainly a function of cloud optical thickness in the non-water vapor absorption band, and the reflection function is mainly a function of the size of the cloud particle in the water vapor absorption band. Cloud characteristic parameters retrieved by FY-2E satellites has been used in this paper to analyze the evolution characteristics of cloud optical thickness, cloud top height, cloud top temperature, and effective radius of cloud particles, which have the widest range of service applications and are indicative of cloud and precipitation. The data is provided by the National Weather Modification Center.

3.1 Cloud Optical Thickness

Figure 2 shows the large value areas of cloud optical thickness mainly appear in the northeast and northwest quadrants of the typhoon. The intensity and range of cloud optical thickness gradually increased from 16:00 on July 28 to 14:00 on the 29th. Satellite data can Real-time monitoring of the changes in the precipitation center in the typhoon spiral rain belt.

Recent work by Wang Lei et al. showed that cloud optical thickness is more indicative of precipitation than other cloud parameters, followed by cloud top temperature and cloud top height. When the optical thickness is greater than 20, the probability of precipitation increases significantly. At 17:00 on the 28th, the optical thickness in the southeastern part of Hebei gradually increased, and in some areas, it exceeded 20, corresponding to the beginning of light rain in the eastern areas of Handan, Xingtai and other places. As the cloud system moved northward, the cloud optical thickness increased at 08:00 on the 29th, exceeding 50 in some areas. Light to moderate rains appeared in central and southern Hebei, and the hourly rain intensity exceeded 10 mm in Hengshui and Cangzhou. At 12:00 on the 29th, the optical thickness of the cloud band and the area of the large value area greater than 50 reached the maximum. Until 14:00, the central large value gradually weakened to 30-40, and the area of the large value decreased, the hourly precipitation was below 10mm. During the process, the optical thickness has a good indication of the hourly rain intensity.

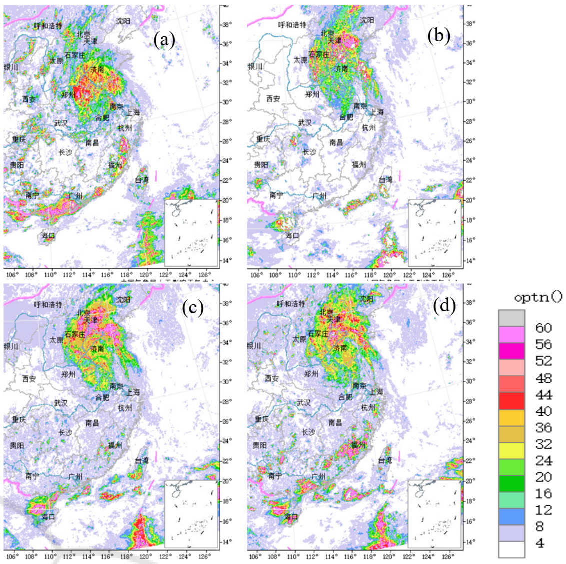

Figure 2: The evolution of optical thickness of FY-2 cloud characteristic parameter: 16:00 on July 28th(a), 08:00 on July 29th(b), 12:00 on July 29th(c), 14 :00 on July 29th(d).

3.2 Cloud Top Temperature

Figure 3 shows when the low-pressure cloud system began to affect North China at 17:00 on 28th, the minimum temperature of the cloud top in the center of the cloud system was less than -50℃, and the temperature of the cloud top over the surrounding Hebei region was between -15℃ and -25℃.

With the system moving northward and eastward, the temperature of the cloud top gradually increased, while the range of the low value center of the cloud top temperature gradually decreased. At 06:00 on 29th, the low value center of cloud top temperature is located in the southeast of Hebei, lower than -25℃, and the range of low value center corresponds to the maximum range of hourly precipitation, the precipitation has reached moderate to heavy rain in the past 3 hours. Until 20:00 on 29th, the cloud top temperature continued to increase, corresponding to the decrease of hourly rainfall on the ground, and the cloud top temperature over Hebei increased to -10℃~-20℃. Since the early morning of 30th, the cloud top temperature in northeast Hebei gradually decreased, the lowest temperature was less than -35℃ at 05:00, the precipitation area and hourly rainfall increased. The change of the low value center of cloud top temperature in this process has a good indication for the precipitation area.

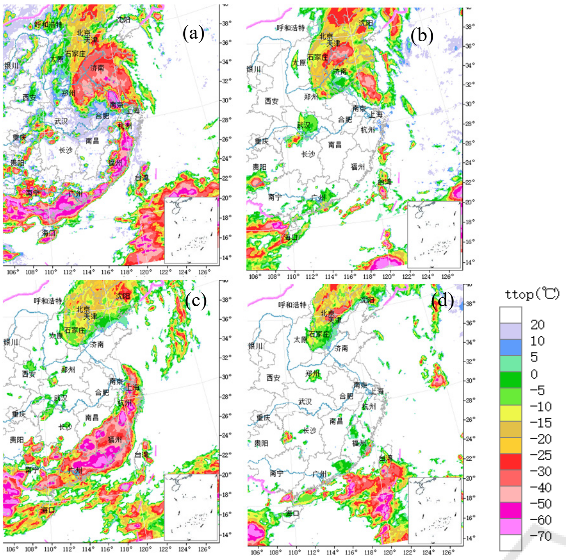

Figure 3: The evolution of cloud top temperature (unit: ℃) of FY-2 cloud characteristic parameter: 16:00 on July 28th(a), 08:00 on July 29th(b), 12:00 on July 29th(c), 14 :00 on July 29th(d).

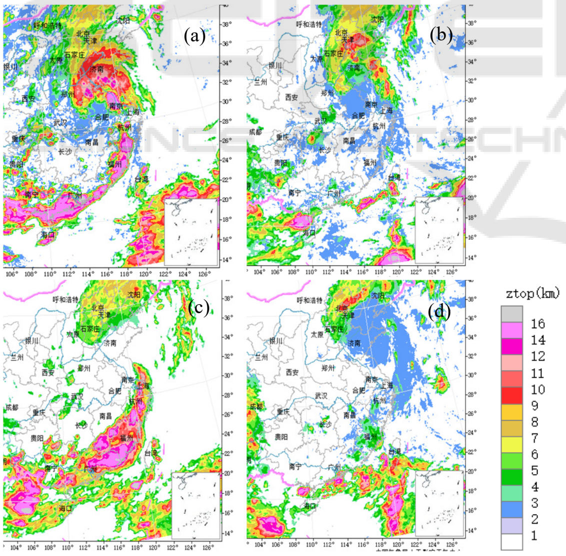

Figure 4: The evolution of cloud top height (unit: km) of FY-2 cloud characteristic parameter: 16:00 on July 28th(a), 08:00 on July 29th(b), 12:00 on July 29th(c), 14 :00 on July 29th(d).

3.3 Cloud Top Height

Before the main cloud band moved to north China, as showed in Figure 4, the central part of the cloud top height was more than 14km. At 17:00 on 28th, the cloud top height of cloud system over the southeast of Hebei increased from 7~8km to more than 9km, and precipitation began. With the main cloud band northward, the cloud top height of main cloud system gradually decreases to 7km at night, hourly precipitation is basically below 4mm. At 08:00 on 29th, the cloud system of low-pressure center moved to the east of Hebei, cloud top height in 9~12 km and local hourly precipitation in more than 10 mm. In the afternoon on 29th, the cloud system was weakened, cloud top height was reduced, and hourly precipitation was also decreased. By the early morning of 30th, the cloud system was strengthened, and the cloud top height over northeast Hebei was more than 9km, and the hourly precipitation intensity increased. The change of cloud top height in this process had a good indication of precipitation intensity.

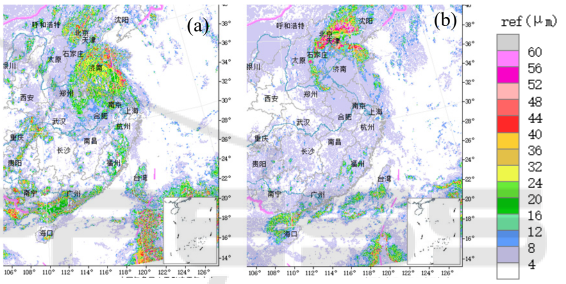

Figure 5: The evolution of effective particle radius (unit: μm) of FY-2 cloud characteristic parameter: 16:00 on July 28th(a), 08:00 on July 29th(b), 12:00 on July 29th(c), 14 :00 on July 29th(d).

3.4 Effective Particle Radius

The effective radius of cloud particles can be used to judge the size of cloud top particles. However, false large particles also appear in the clear air, so non-cloud zone cannot be identified. Therefore, a comprehensive analysis is required by combining cloud optical thickness, cloud top temperature and cloud top height. As showed in Figure 5, at 16:00 on 28th, the maximum effective radius of cloud particles above 40μm appears in some areas of southern Hebei, then the hourly precipitation was greater than 5 mm. It shows that in addition to the cloud system needing to reach a certain height and temperature, cloud droplets need to reach a certain scale to produce precipitation. Until 12:00 on 29th, effective radius of cloud particles in northern Hebei reached more than 50μm, However, the large value area of surface hourly precipitation is still in the southeast of Hebei, and the corresponding effective particle radius is less than 20μm. Only the effective radius of cloud particles does not significantly reflect the quantification of precipitation.

4 COMPARATIVE ANALYSIS THE EVOLUTION OF CLOUD PARAMETERS AND NUMERICAL MODEL

4.1 Forecast Adjustment and Error Analysis of Cloud Band Simulated by Model

The CPEFS cloud model is a cloud precipitation display and forecast system launched by the National Weather Modification Center in 2017. Based on the dynamic framework of WRF, the country is divided into 8 regions with double nesting. The first layer has a resolution of 9Km×9Km, and the second layer has a resolution of 3Km×3Km, the output product time resolution is 1 hour.

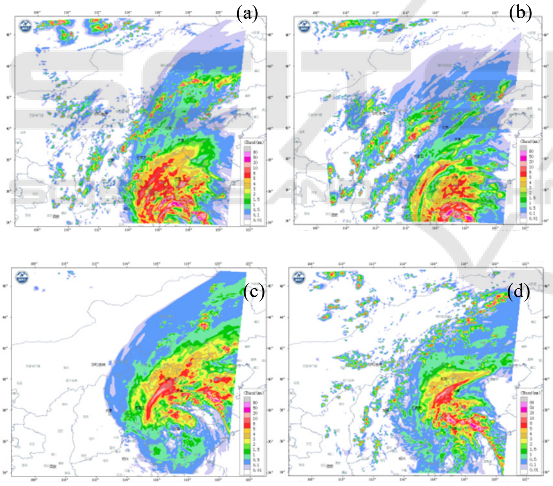

Figure 6: The horizontal distributions of total hydrometeors simulated (unit: mm) by CPEFS model in this process: 14:00 on July 28th(a), 14:00 on July 28th(b), 08:00 on July 29th(c), 14:00 on July 29th(d).

The cloud bands reported by CPEFS cloud mode since 20:00 on 27th and 08:00 on 28th were selected for evolution analysis as showed in Figure 6. It shows that the cloud system move faster at 20:00 on 27th, and at 14:00 on 28th, the southeastern of Hebei is influenced by the top of cloud system of low pressure, and the intensity is stronger, vertical accumulation of condensate water content to reach more than 5 mm. Weather system intensity change is not obvious at night on 28th, and the late adjustment system move slow, weak strength, vertical accumulation of condensate water content was 3 to 5 mm, and weakening process of the system was obviously at night. By 08:00 on 29th, the late adjusted position of forecast was more southerly, and the moving direction of the cloud band's main body was more easterly. Meanwhile, the range of the large value area and the intensity of the center were weakened.

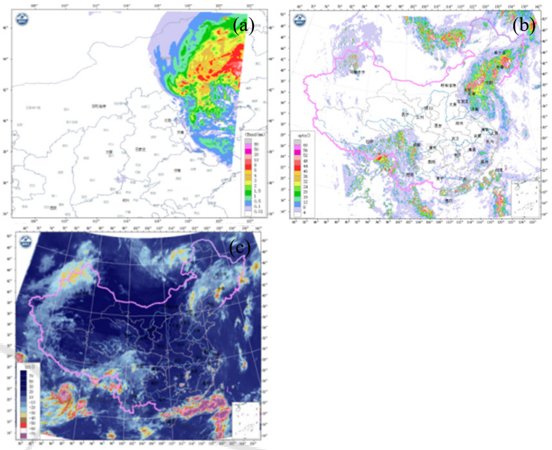

Figure 7: The comparision of Cloud band simulated by CPEFS (a, unit:mm) , and optical thickness of FY-2 cloud characteristic parameter(b), and black body temperature(c, unit: °C) at 08:00 on July 30th, 2021.

Comparing and analyzing the optical thickness and black body temperature of the observation data and the model forecast data (Figure 7), and the result showed that the movement of observation datawas still slow after the adjustment of the model, the system weakened more obviously at night on the 28th by observation data; and on the 29~30th, the model forecast was generally a slow weakened, changing process existed in the cloud band presented by observation data was weakened and then strengthened; on the 30th, the model forecasted that the cloud band moved faster, and the cloud band moved to the Chengde-Tangshan area at 08:00 on the 30th, and from the observation data, a certain intensity of optical thickness was seen over eastern Hebei at 08:00. Precipitation cloud system existed obviously in northeast region of Hebei on afternoon, and hourly precipitation at some areas can reach 5~10 mm. The influence of low-pressure cloud band on Hebei was later then the model forecast in this process, and the movement speed was slow, hence the time of influence was longer. Intensity variations of cloud system were not reflected in forecast. Difference existed between model forecast data and observation data in this process, however, the trend direction of model adjustment has guiding significance for forecasting.

4.2 Comparison of Cloud Top Height and Cloud Top Temperature Simulated by Model with Actual Cloud Parameters

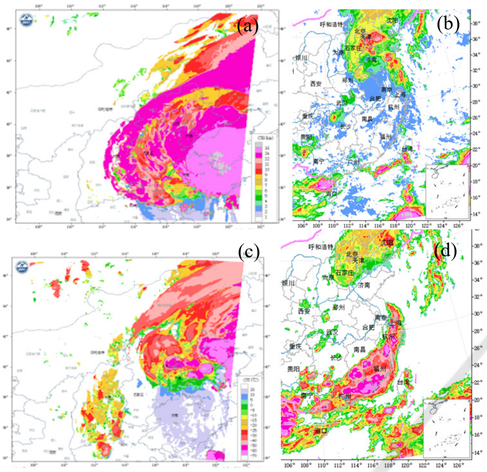

Figure 8: Cloud top height simulated by CPEFS(a, unit:mm) and optical thickness of FY-2 cloud characteristic parameter(b, unit: km) at 08:00 on July 29th, cloud top temperature simulated by CPEFS(c, unit: °C) and cloud top temperature of FY-2 cloud characteristic parameter(d, unit: °C).

The cloud top height and cloud top temperature reported by CPEFS cloud model since 08:00 on 28th were compared with satellite cloud parameters (Figure 8), and it revealed that the cloud top height was forecasted to have a false large value area in the edge of cloud system at 08:00 on 29th in Hebei, the center of cloud top height was above 9km. From the satellite cloud parameter field, the large value area of cloud top height was located in the bohai Rim area of eastern Hebei, and the center of large value was about 9~11 km, hence compared to forecasts, observation data is on the low side; forecast field of cloud top temperature also had a false low value area of temperature over Shanxi at 20:00 on 29th, the low center of cloud top temperature in northeast Hebei is below -25°C. However, according to the analysis of the satellite cloud parameter field, the cloud top temperature in the same region was between -15°C and 25°C, which was lower than the actual forecast.

False value area of cloud top height and cloud top temperature forecasted by the cloud model is obviously, and satellite monitoring product can be used to comparisons and correction. After eliminating false value area from cloud model data, the typhoon center and the scope and intensity of spiral rain band closed to center is consistent with the result of satellite inversion, and can be used to analyze the vertical characteristics of cloud structure in typhoon low pressure center.

5 ANALYSIS OF TYPHOON LOW PRESSURE CENTER BY VERTICAL CROSS SECTION

At 17:00 on the 28th, the beginning of precipitation (Figure 9), low-pressure cloud system began to affect the southern part of Hebei. The southern cloud system developed strongly, dominated by cold-warm mixed clouds. The height of 0°C layer was 5km, the height of -5°C layer was about 6km, and the cloud top height was above 8km. The supercooled water was mainly distributed between 5~8 km, corresponding to the temperature is 0~20°C and the large value center of supercooled is 1g/kg, ice crystal number concentration is 1-100 L^{-1}, and the center value of snow-graupel mixing ratio is 1g/kg.

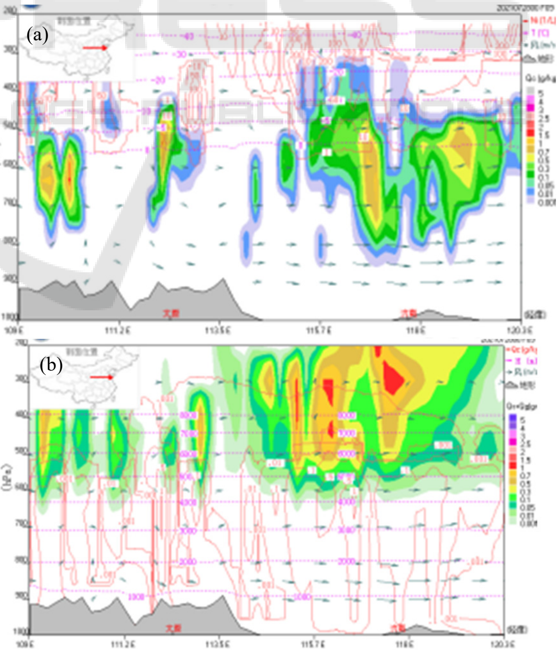

Figure 9: Cloud-water mixing ratio (unit: g/kg) forecasted by CPEFS model at 17:00 on July 28th along the 36°N and ice crystal number concentration (unit: 1/L) (a, cloud-water mixing ratio: shadow, ice crystal number concentration: red line), snow-graupel mixing ratio (unit: g/kg) and height (unit: m) (b, snow-graupel mixing ratio: shadow, height: red line).

At 08:00 on 29th (Figure 10), the low-pressure cloud system moved northward to the central and southern part of Hebei, dominated by cold-warm mixed clouds. The height of 0℃ layer was 5.5 km, the height of -5℃ layer was about 6.5 km, and the cloud top height was about 10 km. The supercooled water was mainly distributed between 5.5-8.5 km, corresponding to the temperature is 0-20℃ and the large value center of supercooled is 1g/kg, ice crystal number concentration is 1-100 L-1, and the center value of snow-graupel mixing ratio is 4g/kg.

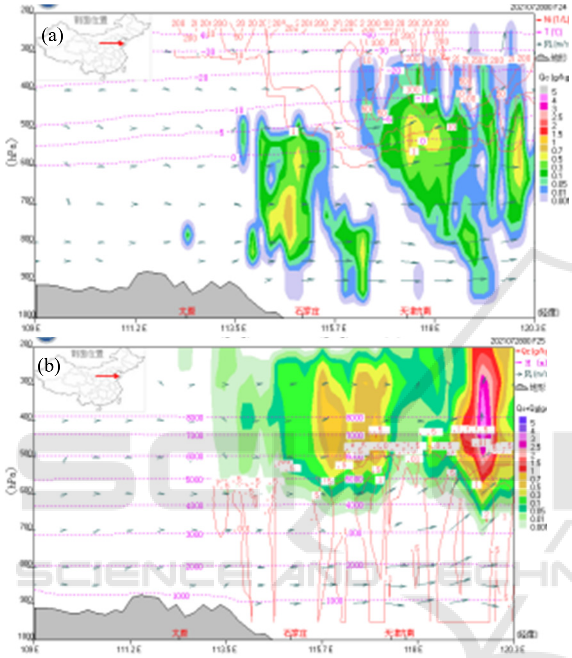

Figure 10: As figure 9, but on 29th, July 2021 along the 38°N.

At 17:00 on 29th (Figure 11), the central and eastern part of Hebei was influenced by the low-pressure cloud system dominated by warm clouds. The height of the 0℃ layer was 5.5 km, the height of the -5℃ layer was about 6 km, and the cloud top height was about 10 km. The supercooled water was distributed between 5.5-8km, corresponding to the temperature is 0-20℃ and the large value center of supercooled is 0.3 g/kg, ice crystal number concentration is 1-50 L-1, and the center value of snow-graupel mixing ratio is 1g/kg.

From the vertical cross section, there was thick clod cloud, and the content of hydrometeorsand supercooled water is abundant at the beginning of the precipitation process. After 17:00 on 29th, the content of hydrometeors and supercooled water in cold cloud was decreased significantly and increased in warm cloud correspondingly. The large value center of water content and snow-graupel mixing ratio have declined, and ice crystals number concentration decreased. The precipitation mechanism changed from cold cloud precipitation to warm cloud precipitation.

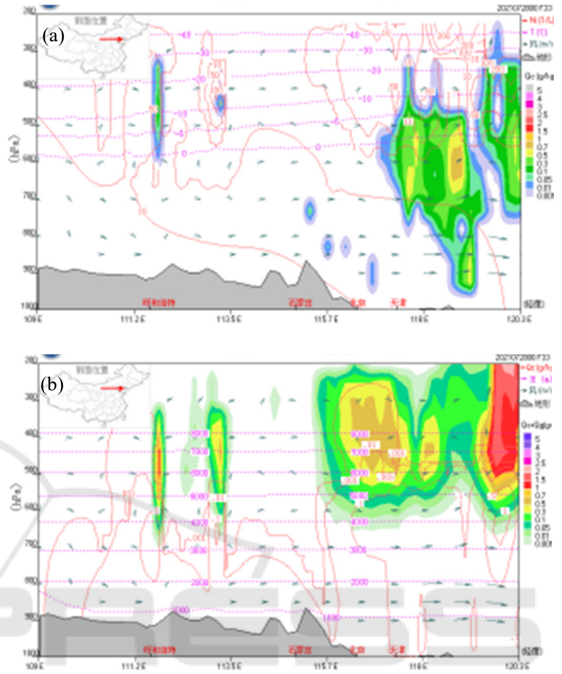

Figure 11: As figure 9 but on 29th, July 2021 along the 40°N.

6 SUMMARY AND DISCUSSION

The evolution's characteristics of the scope, intensity and cloud characteristic parameters of Northward typhoon's cloud band can be monitored by FY-2 satellite product, and the optical thickness (>20), cloud top temperature (-10℃~-25℃) and cloud top height(>9km) of cloud characteristic parameters have obvious indication significance to the range and intensity variation of surface precipitation. The single variable of cloud particle effective radius does not significantly reflect the quantitative precipitation, need combined with multi-parameter comprehensive analysis.

Satellite monitoring products can be used to compare and correct cloud model prediction products. In this process, the simulated typhoon center moves slowly, and false large value areas appear in the outer and distant areas of the spiral cloud belt. The range and intensity of the spiral cloud belt at the typhoon center and near the center are consistent with the actual satellite inversion.

The typhoon low pressure at the beginning of the precipitation process, the cold cloud is deep, content of hydrometeors and supercooled water in cold cloud is abundant, After 17:00 on 29th, the content of hydrometeors and supercooled water decreased obviously in the cold cloud, and it increased significantly in warm cloud, the large value center of water content, ice crystals number concentration and snow-graupel mixing ratio have declined obviously, The precipitation mechanism changed from cold cloud precipitation to warm cloud precipitation.

ACKNOWLEDGEMENTS

This work is supported by the fund of the Collaborative innovation of Meteorological Technology in BohaiRim (QYXM202004), and the civil space pre-research project of the 13th Five-Year plan “the key technology of the emergency observation & information support for domestic satellite”, and the “S&T Program of Hebei (19275420D)”.

REFERENCES

Arking, A., & Childs, J. D. (1985). Retrieval of cloud cover parameters from multi-spectral satellite images. *Journal of Applied Meteorology and Climatology*, *24*, 322-333.

Cai, M., Zhou, Y. Q., & Zhu, B. (2010). Analysis of Cloud Characteristic Parameters Retrieved by FY-2C/D Satellite and the Parsivel Observation on Surface. *Meteorological and Environmental Sciences, 33*(1), 1-6.

Cai, M., Zhou, Y. Q., & Zhu, B. (2011). Comprehensive analysis of satellite and other observations from a convective cloud merging event. *Transactions of Atmospheric Sciences, 34*(2), 170-179.

Chen, Y. Y., Zhou, Y. Q., Mao, J. T., & Yang. J. (2007). Experimental Research of the Retrieval of Cloud Effective Particle Radius by FY-2C Geostationary Satellite Data. *Meteorological Monthly, 33*(4), 29-34.

Chen, Y. Y., Tang, R. M., Zhou, Y. Q., & Mao, J. T. (2009). Microphysical Characteristic Parameters Product Retrieved by F Y-2C/D Satellite and Its Application in the Precipitation Analysis. *Meteorological Monthly, 35*(2), 15-18.

Chen, Y. Y., Xiong, S. Q., Zhou, Y. Q., Zhu, B., & Mao, J. T. (2013a). Research on Effective Particle Radius of Water Clouds Retrieved from the Data of FY 3A Three Channels. *Meteorological Monthly*, *39*(4), 478-485.

Chen, Y. Y. (2013b). Analysis on characteristic cloud parameters of a heavy rain event based on satellite cloud images from FY-3A. *Torrential Rain and Disasters, 32*(1), 24-31.

King, M. D. (1987). Determination of the scaled optical thickness of clouds from reflected solar radiation measurements. *Journal of the Atmospheric Sciences, 44*, 1734-1751.

Nakajima, T. Y., & King, M. D. (1990). Determination of the optical thichness and effective particle radius of clouds from reflected solar radiation measurements. PartI, Theory. *Journal of the Atmospheric Sciences, 47*(15), 1878-1893.

Nakajima, T. Y., & Nakajima, T. (1995). Wide-area determination of cloud microhpysical properties from NOAA AVHRR measurements for FIRE and ASTEX regions. *Journal of the Atmospheric Sciences, 52*, 4043-4059.

Rosenfeld, D., & Gutman, G. (1994). Retrieving microphysical properties near the tops of potential rain clouds by multispectral analysis of AVHRR data. *Atmospheric Research, 34*, 259-283.

Twomey, S., & Cocks, T. (1982). Spectral reflectance of clouds in the near-infrared, Comparison of measurements and calculations. *Journal of the Atmospheric Sciences*, *60*, 583-592.

Twomey S, & Cocks T, 1989. Remote sensing of cloud parameters from spectral reflectance in the near infrared. *Beitr Phys Atmos, 62*, 172-179.

Wang, L., Zhou, Y. Q., Cai, M., & Shen, S. H. (2019). Study on Correlation Between Cloud Characteristic Parameters and Precipitation in North China. *Meteorological and Environmental Sciences, 42*(3), 9-16.

Zhou, Y. Q., Chen, Y. Y., Li, J., Huang, Y. M., He, X. D., Zhou, F. F., Wu, M. X., Hu, B., & Mao, J. T. (2008). Retrieval and Preliminary Test of Cloud Physical Parameters from Combination of FY-2C/D Geostationary Satellite Data and Other Observation Data. *Meteorological Monthly*, *34*(12), 27-35.

Zhou, Y. Q., Cai, M., Ou, J. J., Cai, Z. X., & Shi, A. L. (2011). Correlation between cloud characteristic parameters and precipitation. *Transactions of Atmospheric Sciences*, *34*(6), 641-652.