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Analysis of the Rapid Intensification of Typhoon "Mekkhala" (2006) over the Offshore Area Based on Satellite Data

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Abstract

Analysis of the cloud macro characteristics of typhoon "Mekkhala" is based on FY-4A stationary meteorological satellite data. Aiming at the precipitation process during the "Mekkhala" tropical storm and typhoon, the precipitation structure characteristics were analyzed using the precipitation data retrieved from polar orbiting satellites. The results show that: in the life process of "Mekkhala", its cloud system always presents an asymmetric structure, and the cloud area and cloud top height on the north and south sides also change constantly. When the intensity of "Mekkhala" reaches the maximum, its minimum brightness temperature range is also the largest, and the spiral structure is also the most obvious; during the precipitation process of the "Mekkhala" tropical storm and typhoon, the near-surface precipitation rate is roughly distributed in a ring shape, from the precipitation rate of the FY3-D polar-orbiting satellite and the GCOM-W1 satellite. In terms of product comparison, the precipitation rate product of the GCOM-W1 satellite responds better to low-level precipitation.

Keywords

Typhoon, Rapid Intensification, Cloud Macro Characteristics, Satellite

1. Introduction

Research on typhoon track and intensity has made great progress in the past decade. However, compared with typhoon tracks, the study of typhoon intensity changes; especially the rapid intensification of typhoons, still faces great challenges. In order to improve research in this area, it is necessary to deepen our understanding of the physical process of this phenomenon. The refined analysis of individual cases based on satellite observation data helps us reveal the specific details of typical typhoon cases on the ocean surface.

In recent years, some studies have been carried out on the characteristics and causes of typhoon strengthening offshore, mainly in the following three aspects. The first aspect is based on statistical analysis of multiple samples and individual cases, revealing the large-scale weather characteristics of offshore strengthening typhoons. Yu, 2007; Yu & Yao, 2006; Yu et al., 2007 used the NCEP/NCAR reanalysis data from 2000 to 2006 to reveal the thermal characteristics of the rapid intensification of typhoon intensity offshore China, and concluded that the increase in diabatic heating in the upper troposphere near the typhoon center is conducive to the rapid intensification of typhoon intensity. Zheng Feng (2015) analyzed the reasons for the sudden intensification and weakening of typhoons offshore China based on the NCEP/NCAR reanalysis data and the Japanese geostationary meteorological satellite TBB data, and concluded that the sea surface temperature, vertical wind shear and convective density in the typhoon core are all related to the rapid intensification of typhoons. The second aspect is to study the reasons for the strengthening of the offshore area only for actual typhoon cases. Qin Li et al. (2019) used reanalysis data to analyze the causes of the rapid intensification of typhoon Hato offshore in 2017, and concluded that the rapid increase of the typhoon offshore is closely related to the subtropical high and the intensification of the southwest monsoon. Wang Licheng et al. (2020) used ERA reanalysis data to analyze the rapid change process of the intensity of the super typhoon “Moranti” in 2016, and concluded that the change in typhoon intensity was negatively correlated with the intensity of the South Asian High and the subtropical high, and was closely related to the intensity of the high troposphere. The divergence is closely related, and the weak vertical wind shear is conducive to the maintenance and enhancement of the typhoon’s warm core structure. The third aspect is to analyze the influence of factors such as the internal structure of the typhoon cloud system and the ice and water content of the cloud on the typhoon intensity based on satellite data such as the Tropical Rainfall Measurement Satellite (TRMM). The Jet Propulsion Laboratory team analyzed typhoon intensity variation indicators based on a large number of satellite observation data, and concluded that the stronger the precipitation near the typhoon eye area, the greater the possibility of typhoon intensification. Gao Yang and Fang Xiang (2018) analyzed the microphysical characteristics of typhoon cloud systems based on cloudsat satellite data, and concluded that the changes of ice water content and liquid water content in the typhoon center were positively correlated with typhoon intensity, and the area with large ice water content was mainly located 300 kilometers from the typhoon center.

Summarizing the existing research results, it can be seen that there are many factors affecting the intensity of typhoons, such as subtropical high pressure, outflow temperature at the top of the typhoon, vertical wind shear, etc. (Wang & Shen, 2018; Zeng, Lin, & Gao, 2018). However, the characteristics of each typhoon are not the same, and different typhoons have their own specificities.

Therefore, it is necessary to conduct a detailed analysis of more offshore typhoon cases. Therefore, this paper uses satellite observation data to analyze the changes in structural characteristics of the offshore strengthening process of typhoon "Mekkhala" in 2020, raising awareness of enhanced typhoons offshore.

2. Study Area and Data

2.1. Study Area

The study area is South China Sea (116˚E - 121˚E, 16˚ - 26˚), which is located in Southern Chinese mainland.

2.2. FY-4A Data

FY-4A is a three-axis stable geostationary meteorological satellite with a minimum sub-satellite point resolution of 0.25 km and a time resolution of 5 - 15 minutes (Yang et al., 2017; Zhang et al., 2019; Chen et al., 2020; Chu et al., 2020). The satellite is equipped with multiple payloads, such as radiation imagers and lightning imagers. There are 14 detection bands in total, from visible light to very long-wave infrared. 10.3 - 11.3 μm channel data, the research period is August 9-11, 2020.

2.3. Polar-Orbiting Satellite Retrieval of Precipitation Data

FY-3D is China's second-generation polar-orbiting satellite. The satellite is equipped with a microwave imager, a medium-resolution spectral imager, and other instruments. The microwave imager has five detection bands (Tang et al., 2020; Liu & He, 2022), and the detection data can be used to generate the surface Inversion products such as temperature, precipitation rate, sea surface temperature, and sea surface wind speed are applied to the precipitation rate inversion products of FY-3D in this study. GCOM is a polar-orbiting meteorological satellite launched by Japan. It is also equipped with a microwave imager, and the precipitation rate products retrieved from it are used in this study. The main difference between the two types of satellites is the different manufacturers of the instruments carried by each.

3. Overview and Main Features of Typhoon "Mekkhala"

Typhoon "Mekkhala" formed in the South China Sea at 20:00 on August 9, 2020 (Beijing time, the same below) (**Figure 1(a)**), intensified into a tropical storm at 11:00 on the 10th, and intensified into a severe tropical storm at 17:00 on the 10th, developed into a typhoon at 06:00 on the 11th. "Mekkhala" made landfall on the coast of Zhangpu County, Fujian Province,at around 7:30 on the 11th. At the time of landing, the maximum wind force near the center was 12 (33 m/s), and the minimum pressure in the center was 980 hPa (**Figure 1(b)**), which weakened at 11:00 on the 11th. For tropical storms, its numbering stops at 14:00.

Typhoon "Mekkhala" has three main characteristics: first, it moves fast, and it

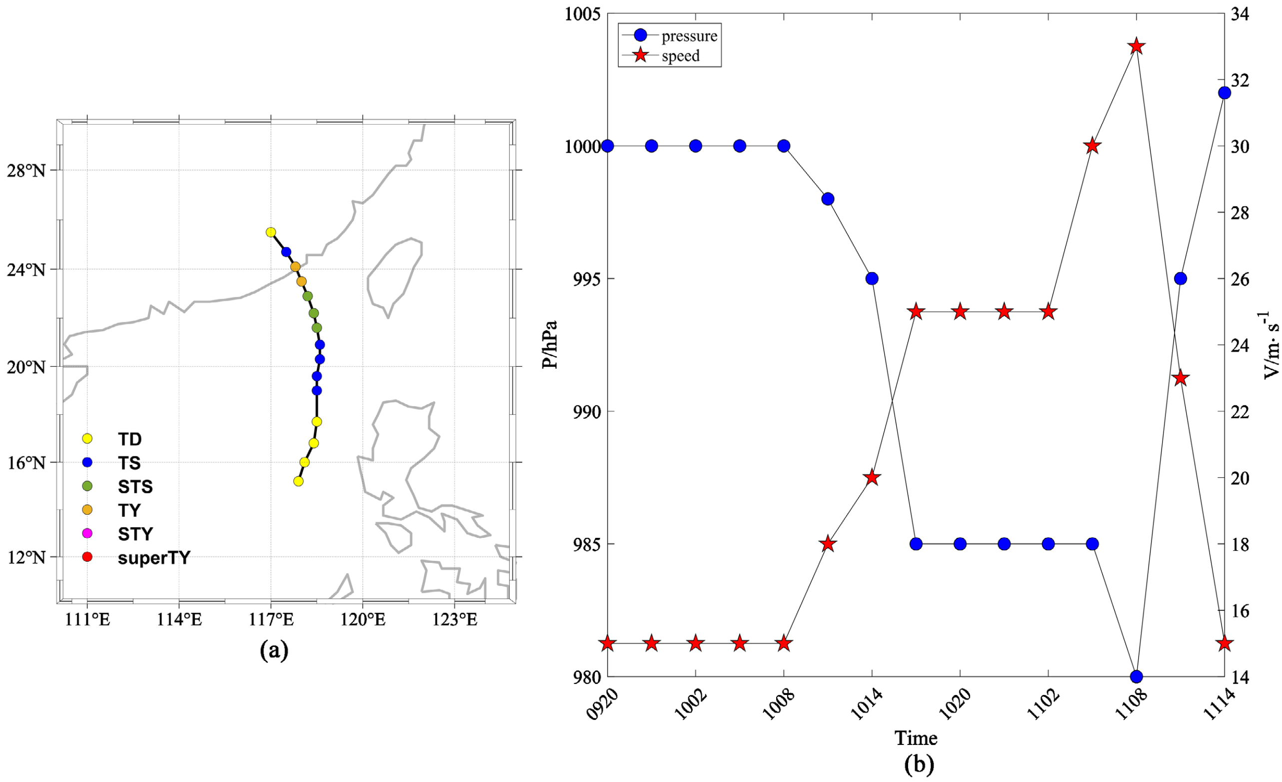

Figure 1. (a) Path of Typhoon Mekkhala; (b) Minimum sea level pressure (blue) and maximum sea level wind speed (red).

only takes 36 hours from its formation to landing on the coast of Fujian; second, it strengthens offshore. After typhoon "Mekkhala" is formed in the South China Sea, its intensity gradually increases. It took only 14 hours for the tropical storm level to strengthen to typhoon level. The third is the rapid weakening after landing. Typhoon "Mekkhala" stopped numbering only 6 hours after it landed on the coast of Zhangpu County, Fujian Province.

4. Results and Analysis

4.1. Distribution Characteristics of Typhoon-Cloud Systems

4.1.1. FY-4A Infrared Cloud Image

Using the brightness temperature data of the 10.3 - 11.3 μm infrared channel of the FY-4A satellite to analyze the macroscopic distribution characteristics of the typhoon "Mekkhala" in various stages. As shown in Figure 2(a) (in the red box), at 05:00 on August 10, when the "Mekkhala" was in a tropical depression, the cloud system was relatively small in scope, did not show obvious spiral structure characteristics, and the cloud system was relatively loose. The brightness temperature in the center of the storm is generally between 200 - 210 K, and the overall low value area is not obvious. As shown in Figure 2(b) (in the red box), when Mekkhala was in a tropical storm state at 15:00 on August 10, the cloud system showed a certain spiral structure trend, but the distribution of the cloud system showed a spiral trend structure and the storm center at a certain distance, the brightness temperature of the storm center is between 190 - 200 K, and the

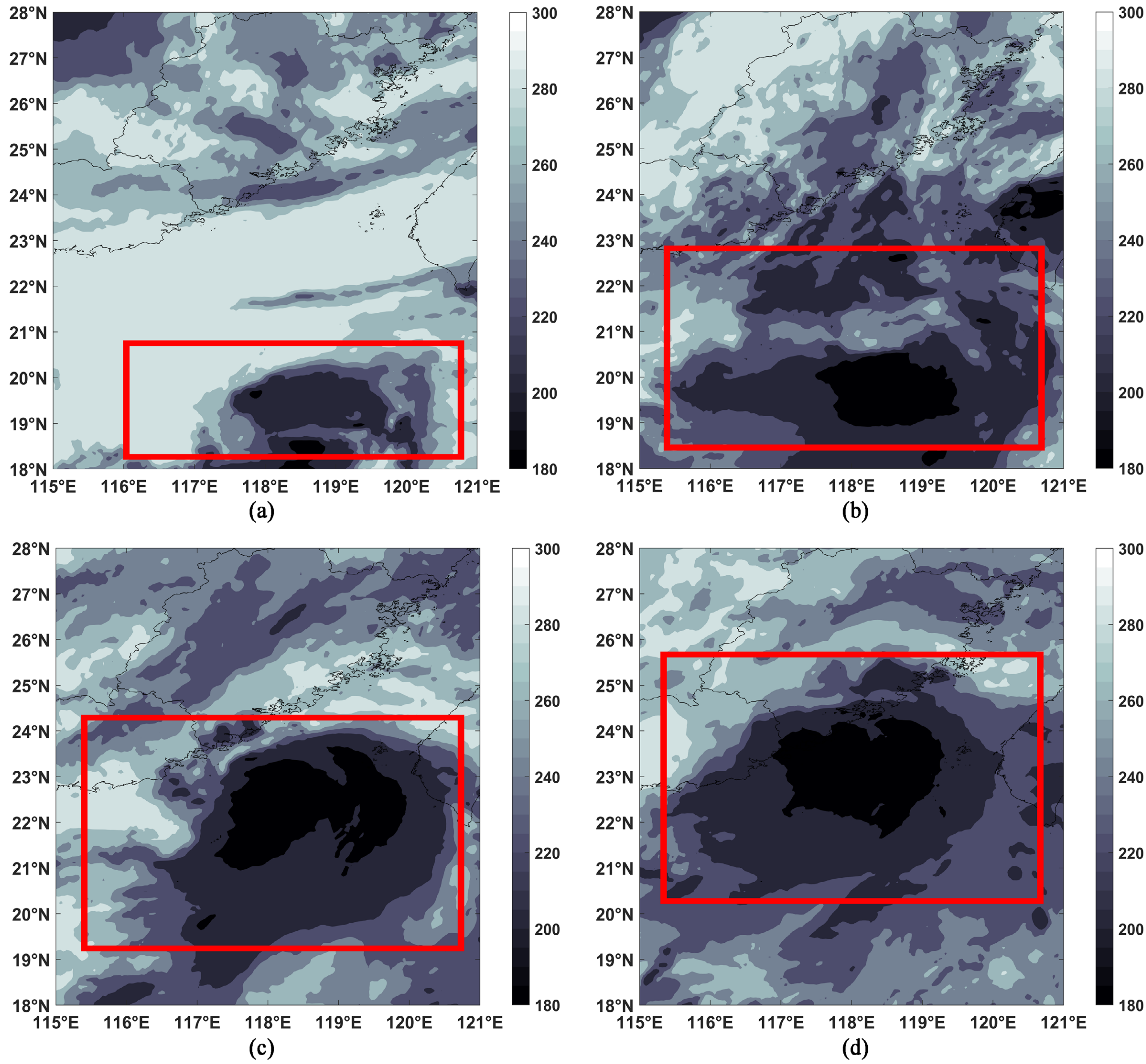

Figure 2. Bright temperature of 10.3 - 11.3 μm band at the developing stage of typhoon "Mekkhala": (a) tropical depression stage; (b) tropical storm stage; (c) strong tropical storm stage; (d) typhoon stage.

overall low value area is more obvious than the tropical depression stage. As shown in Figure 2(c) (in the black box), when "Mekkhala" was in a strong tropical storm at 02:00 on August 11, the distribution of the cloud system showed that the distance between the spiral trend structure and the center of the storm decreased, and the spiral structure became more obvious. The central brightness temperature value is around 190 K, and the range of the overall low-value area has been significantly expanded. As shown in Figure 2(d) (in the red box), when "Mekkhala" was at typhoon intensity at 07:00 on August 11, the spiral distribution of the cloud system was more obvious. The brightness temperature at the center of the storm is around 190 K, and there is no obvious change, but the overall cloud system has a trend of further expansion.

4.1.2. Cloud Top Height

The cloud top height distribution characteristics of typhoon "Mekkhala" at various stages were analyzed using the FY-4A satellite cloud top height product.

As shown in Figure 3(a), when the "Mekkhala" is in a tropical depression state, there are areas of high cloud top height in two latitude and longitude ranges near (18.1˚N, 118.6˚E), and the main interval is roughly 16 - 17 km, but the local in a small area, it can reach 19 km. As shown in Figure 3(b), when "Mekkhala" was in the state of tropical storm, the range of the high-value area of cloud top height in the center of the storm expanded, the main interval was roughly 17 - 17.5 km, and the cloud top height increased slightly. As shown in Figure 3(c), when "Mekkhala" was in the state of a strong tropical storm, the range of the maximum value area of cloud top height increased, and the maximum value increased

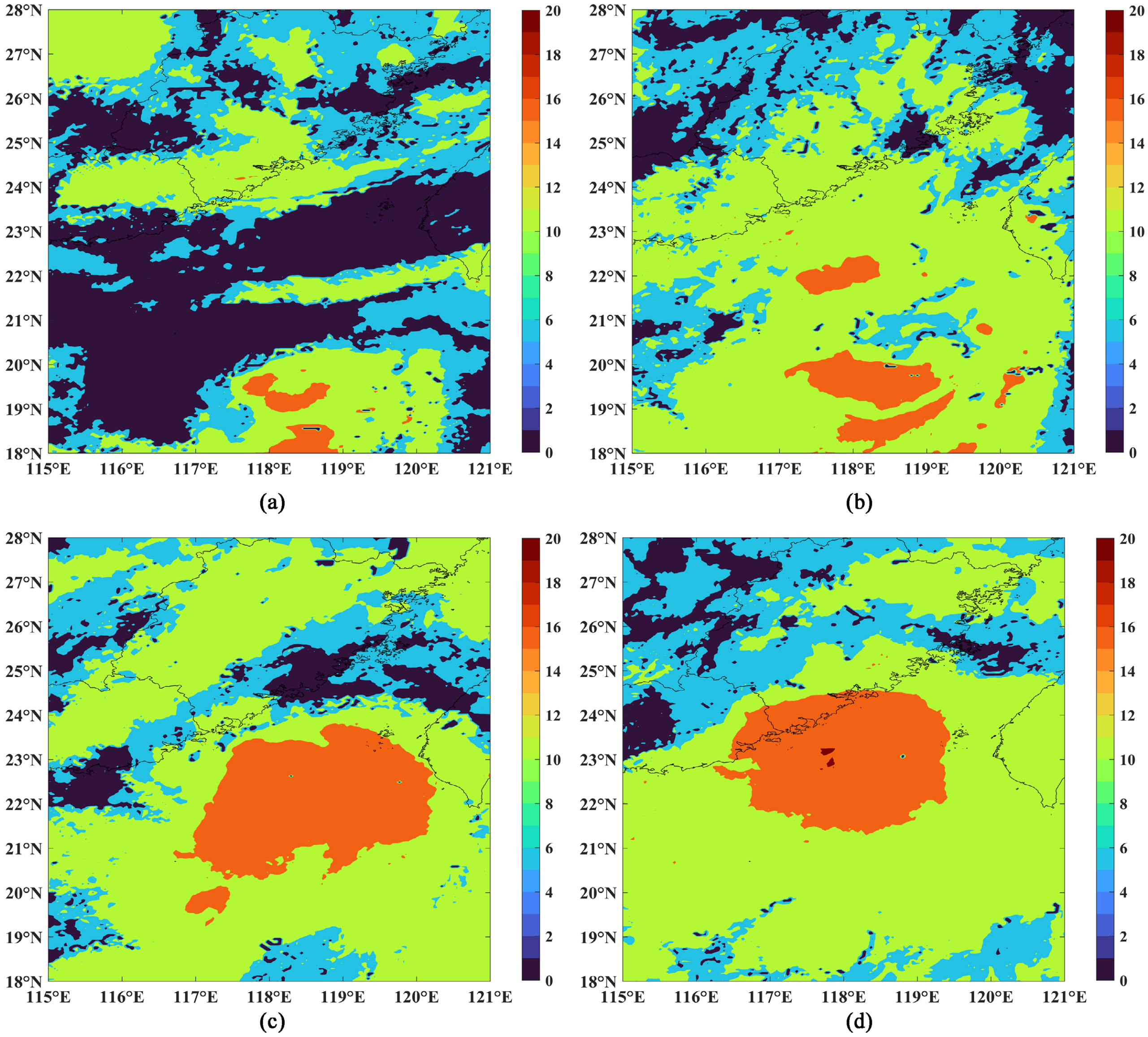

Figure 3. Cloud top height at the developing stage of typhoon "Mekkhala": (a) tropical depression stage; (b) tropical storm stage; (c) strong tropical storm stage; (d) typhoon stage.

to 18 - 18.5 km, and the large value area was mainly located on the south side of the storm center. As shown in **Figure 3(d)**, when "Mekkhala" is at typhoon intensity, on the cloud top height map, although there is no obvious typhoon eye, the cloud top height near the typhoon center is roughly 19 km, and the local area exceeds 20 km.

4.2. Structural Characteristics of Typhoon Precipitation

Based on the precipitation rate products retrieved from the microwave radiometer data of the FY3-D polar orbiting satellite and the GCOM-W1 satellite, the precipitation structure of "Mekkhala" is analyzed, and the precipitation structure of "Mekkhala" in the state of tropical storm and typhoon is analyzed. When "Mekkhala" was in a tropical storm state (**Figure 4(a)**, **Figure 4(c)**), the precipitation

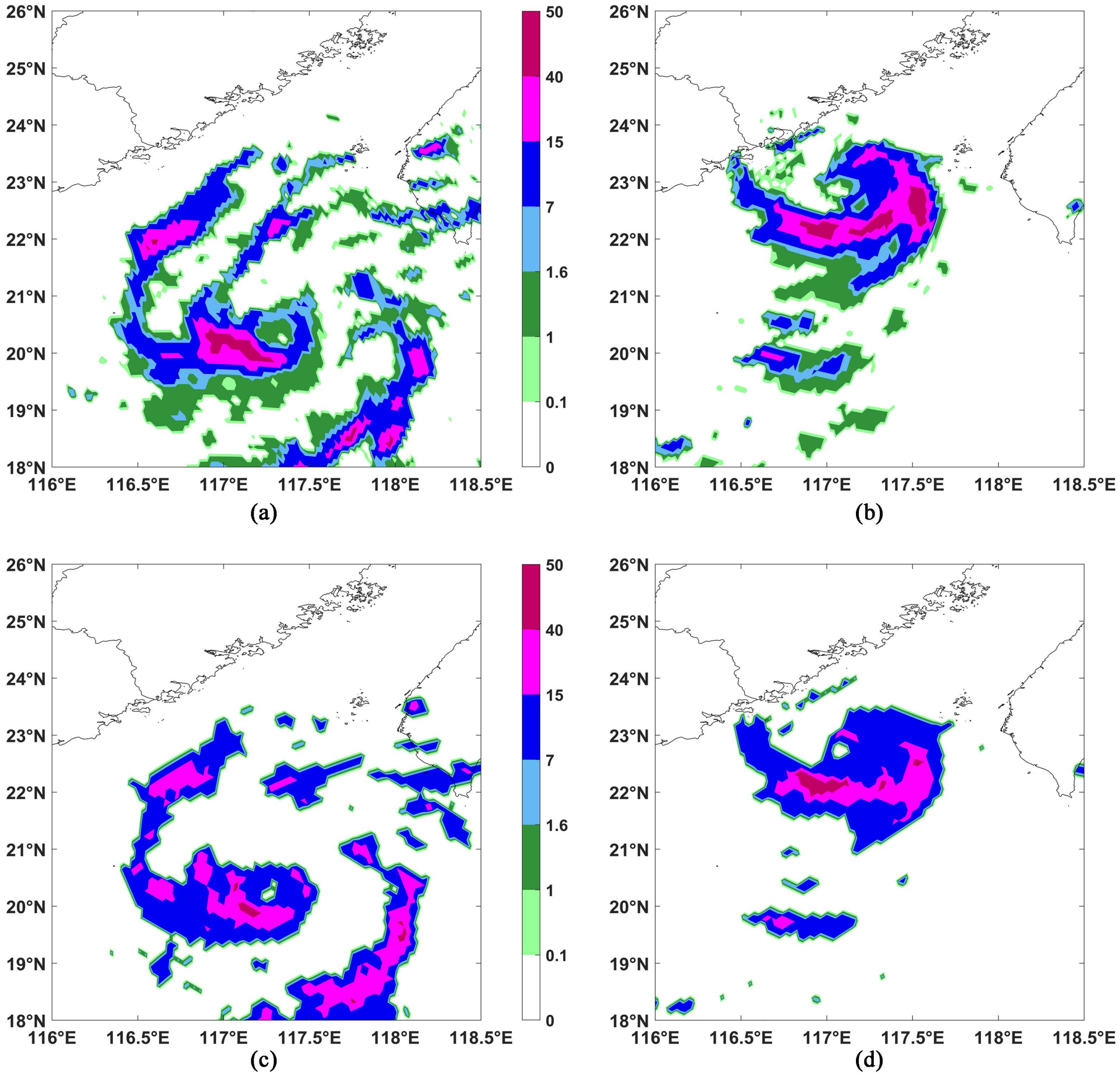

Figure 4. The precipitation rate products of FY3-D polar orbiting satellite ((c), (d)) and GCOM-W1 polar orbiting satellite ((a), (b)).

rate products retrieved by the two satellites were roughly the same.

The typhoon core area and the outer rainband were separated by a certain distance, showing two band-shaped rainbands. The precipitation area above 40 mm was slightly less. It is mainly concentrated in 20 - 30 mm. In contrast, the magnitude of the precipitation rate retrieved by the GCOM-W1 satellite is slightly larger than that of FY3-D, and the area where the precipitation greater than 0.1 mm is retrieved is also relatively larger. When "Mekkhala" is in a typhoon state (**Figure 4(b)**, **Figure 4(d)**), there is no precipitation in the center of the typhoon, and precipitation begins to appear from the center to the outside. The main precipitation areas are distributed on the east and south sides of the typhoon center. The precipitation area is roughly distributed around the typhoon center. The distribution of the species is basically consistent with the spiral distribution of the "Mekkhala" typhoon cloud system. The near-surface precipitation rate increases gradually from the center to the outside, and then gradually decreases, and the precipitation area above 40 mm increases significantly, which is a typical typhoon rain belt precipitation characteristic. On the east and south sides of the typhoon center, there are 3 areas with heavy precipitation above 40 mm/h. On the distribution ring belt, the 3 heavy precipitation locations are all within the cloud area of the typhoon spiral cloud belt. The characteristics of the two satellite products are consistent with tropical storm status. Finally, judging from the small-scale precipitation inversion of the precipitation rate products of the FY3-D polar-orbiting satellite and the GCOM-W1 satellite, the precipitation rate products of the GCOM-W1 satellite respond better to small-scale precipitation.

5. Conclusion

This paper uses a variety of satellite observation data to analyze the characteristics of the 2020 No. 06 typhoon "Mekkhala" in different stages, focusing on the analysis of the characteristics of the rapid intensification of the typhoon, and draws the following conclusions.

Based on the observation data from the infrared channel of the FY-4A geostationary satellite, the macroscopic characteristics of the clouds in the life process of typhoon "Mekkhala" were analyzed. The area and cloud top height are also constantly changing, and the change in cloud top height is positively correlated with the typhoon intensity. In the rapid enhancement stage of "Mekkhala", its helical structure is the most obvious, and the range of the low-value area of cloud top brightness temperature also reaches the maximum.

According to the precipitation process during the "Mekkhala" tropical storm and typhoon, the precipitation structure characteristics were analyzed based on the inversion precipitation data from polar orbiting satellites. During the precipitation period of the "Mekkhala" tropical storm and typhoon, the near-surface precipitation rate is roughly distributed in a ring shape. From the comparison of the precipitation rates in different periods of "Mekkhala", during the typhoon period, that is, the rapid intensification stage, the typhoon center. The large value area of the nearby precipitation rate is wider and wider, and most of the precipitation area is concentrated near the center of the typhoon, while in the tropical storm stage, the precipitation area is relatively far away from the center of the typhoon; from the FY3-D polar-orbiting satellite and the GCOM-W1 satellite, compared with the precipitation rate products of the GCOM-W1 satellite, the precipitation rate products of the GCOM-W1 satellite are more responsive to low-level precipitation.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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