Evaluation of FY-4A Temperature Profile Products and Application to Winter Precipitation Type Diagnosis in Southern China

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Abstract: FY-4A GIIRS temperature profile products have provided unprecedented information for studying the atmospheric characteristics of thermal structures since 2020. The main objective of this paper is to evaluate GIIRS temperature profile products by using radiosonde observations and then apply them to the diagnosis of winter precipitation types in southern China. GIIRS temperature profile products for four types (clear sky perfect quality, cloudy sky perfect quality, cloudy sky good quality and cloudy sky bad quality) show different performances. Relatively, the cloud can affect the quality and quantity of GIIRS products. At different pressure levels, the perfect flagged data under the clear or cloudy sky show the best agreement with radiosonde observations, yielding the highest Pearson correlation coefficient and lowest mean bias as well as root mean square error. The good flagged data have a slight deviation from the perfect data. The impact on the quantity of the GIIRS temperature data is greater than that on the quality with an increase in cloud top height. A case investigation was carried out to analyze the performance of GIIRS temperature profiles for the diagnosis of precipitation types in a winter storm of 2022. The GIIRS temperature profiles represent the reasonable atmospheric thermal structures in the rain and snow in Hubei and Hunan provinces. The GIIRS temperature below 700 hPa is an important indicator to precipitation type diagnosis. Furthermore, two critical thresholds for GIIRS temperatures, which are below $-2 \degree C$ at 850 hPa and below $0 \degree C$ at 925 hPa, respectively, are proposed for the occurrence of snowfall in this winter storm. In addition, the distribution of GIIRS temperature at different pressure levels is consistent with radiosonde observations in a freezing rain event in Guiyang, all of which show the warm rain mechanism by combining the cloud top information.

Keywords: GIIRS temperature profile; winter precipitation types; evaluation; application

1. Introduction

The discrimination of winter precipitation types has always been a significant challenge for weather forecasters. Common types of precipitation in winter, such as rain, snow, freezing rain, and sleet, can have very different impacts on human activities. For instance, snowfall has a greater impact than rainfall. The time of the rain and snow phase transformation, as well as its geographical location, directly affect the amount of snow, which is related to road safety. Compared to rain and snow, freezing rain is a severe weather phenomenon that can strain the transport infrastructures and energy networks. Therefore, the accurate diagnosis of winter precipitation types can provide important information to meteorological services and decision makers. The diagnostic method is an important way to determine precipitation types, which derive statistical relationships between some threshold indicators and precipitation types. Some studies showed that related atmospheric parameters can be used to determine precipitation types, including surface temperature and pressure [1,2], vertical temperature profile [3–6], relative humidity [7–9], wet-bulb temperature [10–12]. In recent years, many researchers have also proposed discrimination...
thresholds and diagnostic methods to determine winter precipitation types in southern China. Xu et al., 2006 [13] indicated that a temperature below 925 hPa is the key to the phase of precipitation in southern China. Qi and Zhang 2012 [14] showed that a set of discrimination criteria is proposed according to a temperature below 700 hPa and geopotential thickness for different precipitation types. Ding et al., 2014 [15] pointed out that there are significant differences in the temperature thresholds of the rain and snow phase transition at different altitudes. Our previous diagnostic studies indicated that the temperature at 700 hPa is greater than $4\degree C$, while being less than $0\degree C$ between 1000 and 850 hPa, which is conductive to the occurrence of freezing rain [16,17]. These studies all point out that the atmospheric vertical temperature is one of the critical indicators used to determine precipitation types.

Radiosonde observations can provide atmospheric temperature data at different pressure layers. However, the distribution of radiosonde stations is sparse. Comparatively, satellites have the characteristics of high temporal and spatial resolution, which can effectively make up for the lack of radiosonde observations. The three-axis stabilized FY-4A represents a new generation of Chinese geostationary meteorological satellite and was launched on 11 December 2016. It carries the Geostationary Interferometric Infrared Sounder (GIIRS) which is the first high-spectral resolution advanced IR sounder on board a geostationary weather satellite [18]. Thus, the FY-4A GIIRS is expected to provide unprecedented measurements for studying the atmospheric characteristics of dynamic and thermodynamic structures. Recently, several studies significant improvement on spectrum calibration of GIIRS were proposed and operationally implemented since November 2019 [19], and retrieval methods of temperature profiles and humidity profiles have been carried out and verified [20–25]. A few studies were also performed that used GIIRS data for weather event applications. Ma et al., 2021 [26] found that four-dimensional wind fields can be derived from FY4A GIIRS data, and that they can provide dynamic information during Typhoon Maria. In addition, some results demonstrated that the track and coastal precipitation forecasts for typhoons from assimilating GIIRS data on numerical models are better [27–29]. Huang et al. [30,31] found that, relative to observation, the detection and performance of GIIRS temperature products vary with the intensities of typhoon. Maier and Knuteson 2022 [32] pointed out that GIIRS profile products are able to capture the rapid transition from a stable to an unstable atmosphere in a case study.

However, due to its short time in operation, the attempts to apply GIIRS profile products to weather events are relatively limited. To our knowledge, research on the application of GIIRS temperature profiles to winter precipitation type diagnosis in southern China has not been carried out. High temporal and spatial resolution temperature profiles can not only capture changes in the thermodynamic structure of atmosphere, but also provide unprecedented information for the diagnosing and monitoring of winter precipitation types in southern China. Therefore, the first objective of this study is to evaluate the suitability and limitation of GIIRS temperature profile product in southern China. The second objective is to illustrate the availability of GIIRS temperature profiles in winter precipitation type diagnosis. It is the first attempt to use temperature profiles from the FY-4A GIIRS to diagnose and monitor winter precipitation types in southern China, which can provide new support for weather forecasters.

This paper is arranged as follows. In Section 2, brief descriptions of FY-4A GIIRS temperature profile data and the methodology used are presented. In Section 3, the evaluation results and their application to winter precipitation types are discussed, while in Section 4, the conclusions and discussion are presented.

2. Data and Methodology

An important instrument on board the FY-4A for atmospheric temperature measurements is the GIIRS. The GIIRS temperature profile products have 2-h temporal resolution at 101 pressure levels from 1100 hPa to 0.005 hPa, with a horizontal resolution of 16 km. In this paper, we used FY-4A GIIRS level 2 temperature profile products during the winter
(December–February) of 2021–2022. The level 2 GIIRS temperature products are processed by the retrieval algorithm based on the level 1 data, which are the calibrated and navigation data from GIIRS onboard the FY-4A. The GIIRS temperature products consist of latitude, longitude, pressure level, temperature profile, quality flags and cloud mask. The quality flags represent the retrieval accuracy of temperature data, which are classified into four categories: perfect (QFlag = 0), good (QFlag = 1), bad (QFlag = 2) and very bad or do not use (QFlag = 3 and QFlag = 4). When the QFlag is equal to 4, it indicates that the level 1 data from GIIRS is invalid. Each vertical point of every profile is marked by a quality flag. In addition, the cloud masks are classified into clear sky and cloudy sky.

The radiosonde observations were collected from 18 stations in southern China, which are provided by the National Meteorological Information Center, China Meteorological Administration. The temporal resolution is twice a day (00:00 UTC and 12:00 UTC), and the temperature profiles are at 10 levels from 925 hPa to 100 hPa. The study in this paper evaluates the GIIRS data above 925 hPa, because the altitude of the radiosonde stations in southwestern China is higher due to the local topography.

The hourly surface observations of precipitation types and 2 m temperature were obtained from 583 ground-based stations in southern China, which are also provided by the National Meteorological Information Center, China Meteorological Administration.

Figure 1 shows the spatial distribution of radiosonde stations and ground-based stations. Taking into account the resolution of GIIRS product, we set the pairing criterion that GIIRS grid matches with a radiosonde station or ground-based station at better than 0.16° in both latitude and longitude. On the other hand, if a radiosonde station or ground-based station matches with more than one GIIRS grid, the nearest profile data are selected.

![Figure 1](image_url)  
**Figure 1.** The distribution of radiosonde stations (top panel, red dots) and ground-based stations (bottom panel, blue dots) in southern China.
The cloud top information used in this study comes from the Advanced Geosynchronous Radiation Imager (AGRI), which is another important instrument on board the FY-4A. The horizontal resolution of cloud top product is 4 km, and the temporal interval is 5 min.

In order to compare GIIRS products and sounding observations, three widely used statistical metrics were applied to evaluate the GIIRS temperature profile, the Pearson correlation coefficient (CC), root mean square error (RMSE) and mean bias (MB). The equations of the indicators are as follows:

\[
CC = \frac{\sum_{i=1}^{n} (S_{i} - \bar{S})(R_{i} - \bar{R})}{\sqrt{\sum_{i=1}^{n} (S_{i} - \bar{S})^{2} \sum_{i=1}^{n} (R_{i} - \bar{R})^{2}}}
\]

\[
RMSE = \sqrt{\frac{\sum_{i=1}^{n} (S_{i} - R_{i})^{2}}{n}}
\]

\[
MB = \frac{\sum_{i=1}^{n} (S_{i} - R_{i})}{n}
\]

where \(n\) is the number of matched samples, \(S_{i}\) is the FY-4A GIIRS temperature profile, \(R_{i}\) represents radiosonde temperature profile, and \(\bar{S}\) and \(\bar{R}\) are their mean values, respectively.

3. Results

3.1. Evaluation of GIIRS Temperature Profiles under Clear and Cloudy Sky

In order to demonstrate whether the atmospheric temperature profile product retrieved by GIIRS can be applied to diagnose and monitor winter precipitation types in southern China, detailed evaluation is the basis of their application.

As mentioned above, based on the cloud mask results of GIIRS temperature profile product, all of the matched samples are divided into “clear sky” and “cloudy sky” to evaluate the product with different quality flags. Figure 2 shows the frequency distribution of the matched samples. The occurrence frequency of missing data is 1% under clear sky, while it is almost 22.5% under cloudy sky. The frequencies of perfect flagged data under clear sky and cloudy sky are 95.7% and 22.6%, respectively. Meanwhile, the temperature data has 16.8% of good samples and 14.3% of bad samples under the cloudy sky. Thus, the amount and quality of GIIRS temperature data will be affected by the cloud. Under the clear sky, the data only have two kinds of quality flags, which represent perfect data (QFlag = 0) and unavailable data (QFlag = 4). Therefore, this study focuses on four types of data, such as the perfect data (QFlag = 0) under clear sky, the data under cloudy sky whose qualities are perfect (QFlag = 0), good (QFlag = 1) and bad (QFlag = 2).

Figure 3 illustrates the density scatterplots for the GIIRS temperature products and radiosonde observations. The perfect flagged samples perform better than good and bad samples, with perfect data having a higher percentage of points near the 1:1 line than others. The distribution of perfect data under cloudy sky is similar to that of perfect data under the clear sky, and the RMSE is 1.81 °C and 1.82 °C, respectively. As shown in Figure 3, the deviation of GIIRS temperature data from radiosonde observation increases with the degradation of data quality. The RMSE of good data or bad data is higher, even if the CC is very close to that of perfect data. A deeper statistical analysis is conducted with respect to different pressure levels. In Figure 4a–c, all perfect flagged data show a higher CC and smaller MB as well as RMSE at different pressure levels. The CC of good data is slightly lower than that of perfect data, while the RMSE is obviously larger. Comparatively, the RMSE of perfect data is around 2 °C below 500 hPa, while the RMSE of good data is above 3 °C. The MB of good and bad data has a noticeable change from...
positive to negative between 100–250 hPa. This phenomenon is mainly caused by the fact that the number of outliers and uncertainty of the temperature are greater in the tropopause layer (100–300 hPa) than the troposphere layer due to the instrument sensitivity [18,25]. With decreasing pressure level, the MB of good and bad data changes from negative to positive between 500 and 700 hPa. This fact is related to the cloud top height in winter, which can reach to 4–6 km in southern China. The retrieval of vertical profile is affected by cloud height, resulting in the variation of MB above and below cloud. Comparatively, the MB of perfect flagged data under cloudy sky also has a similar positive and negative change. However, the smaller variation in perfect flagged data is attributed to the higher accuracy. Meanwhile, the MB of good data at 850 hPa and 925 hPa is below 1.5 °C, which is very close to that of perfect data. The bad flagged data of different levels obtain a larger deviation not only in RMSE but also in MB.

Figure 2. The occurrence frequency (%) with different quality flags (QFlag) from FY-4A GIIRS temperature profile product. The frequency is calculated under the cloudy sky (red bar) and clear sky (blue bar) separately.

Figure 5 shows the occurrence frequency of bias for GIIRS temperature products in comparison with radiosonde observations. The perfect flagged data have the smallest systematic deviation under the clear and cloudy sky, the percentage frequency of occurrence peaked around a bias of −1 °C, and the occurrence frequency is above 20%. The peak frequencies of good flagged data occur at biases around 2 °C and −3 °C, whereas the peak frequencies for bad flagged data occur at biases around 4 °C and −5 °C. Therefore, they all indicate the characteristics of double peaks.

3.2. Evaluation of GIIRS Temperature Profiles at Different Cloud Top Height

As mentioned above, cloudy sky, when compared against clear sky, not only had an impact on the amount of GIIRS temperature profile but also exhibited more bad flagged data. Considering the spectral characteristics of GIIRS instrument, we continue to study the relationship between GIIRS temperature profiles and cloud top height. In Figure 6, four types of data illustrate a similar distribution that the frequencies of occurrence peaked around a cloud top height of 4 km, and the occurrence frequency is above 8%. This phenomenon is mainly due to the climatic characteristics of winter in southern China, which is dominated by middle and low level clouds. However, the occurrence frequency of missing data reaches 11% when the cloud top height is 6 km. With increasing cloud top height, the trend of missing data lags behind the other four types of data, which shows the
cloud top height having a more significant impact on the data quantity than quality. In other words, it will directly lead to the failure of retrieval with an increase in the cloud top height, showing more missing values under the cloud. These missing values are due to the fact that high thick clouds can block the infrared sounder from observing the atmosphere under the cloud.

Figure 3. Density scatterplots for G1IRS atmospheric temperature profile products vs. the radiosonde observations. (a) the perfect flagged samples under the clear sky; (b) the perfect flagged samples under the cloudy sky; (c) the good flagged samples under the cloudy sky; (d) the bad flagged samples under the cloudy sky. The occurrence frequency represents the percentage with respect to the total samples of the number (perfect flagged samples under the clear sky, good flagged samples and bad flagged samples under the cloudy sky) lying in each grid area with an interval of 0.5 °C. The color bar indicates the occurrence frequency (%) lying with in each grid area. The black line is the 1:1 line.

Our statistical analysis suggests that the occurrence frequency of perfect flagged data under the cloud sky is significantly lower than that under the clear sky. However, the perfect flagged data under the cloudy sky still show the best agreement with radiosonde observations, and the good flagged data have a slight deviation from the perfect data. On the whole, the MB of perfect data is between −1 °C and 1 °C, whereas the MB of good data is between −2 °C and 2 °C. Considering that the cloud top height of winter in southern China is mainly below 6 km, only perfect and good flagged data below 500 hPa are considered in the next part of this study. For instance, if a vertical temperature profile does not contain missing values below 500 hPa, and the quality flags are perfect or good below 500 hPa, this profile is considered to be reliable. This kind of profile can be used for the diagnosis of rain and snow events.
3.3. Application of Winter Precipitation Type Diagnosis in Southern China

The advantage of GIIRS temperature profile is that it has high temporal and spatial resolution, which is useful to diagnose the precipitation types in some areas without radiosonde observations. In 2022, a winter storm occurred in southern China, this weather event persisted from 25 to 29 January. With the cold air moving to the southeast, the transformation of rain and snow occurred in many provinces in southern China. In addition, some areas also experienced freezing rain in Guizhou province. Figure 7 shows two atmospheric temperature profiles from GIIRS in Yichang in this winter storm. It features that the temperature throughout the atmospheric column is below freezing at 20:00 on 27 January, which is propitious for the formation of snow. However, the temperature profile below 700 hPa is greater than 0 °C at 12:00 on 25 January, so the diagnosis of the precipitation type should be rain. Compared with surface observations, there was agreement between the GIIRS temperature profiles and precipitation types. Therefore, the transition of rain and snow events in Yichang was described by a GIIRS temperature below 700 hPa. When rainfall occurs, a warm layer with the temperature above 0 °C below 700 hPa is important.
Figure 5. The occurrence frequency (%) of bias for GIIRS temperature profile products in comparison with radiosonde observations. The interval of bias is 1.0°C on the horizontal axis. The four types of GIIRS data are the perfect flagged under the clear sky (red line), the perfect flagged under the cloudy sky (orange line), the good (purple line) as well as bad (blue line) flagged under the cloudy sky.

Figure 6. The occurrence frequency of GIIRS temperature profile products with the different cloud top heights under the cloudy sky. The black line represents the missing data. The different quality flags are as follows: perfect (orange line), good (purple line), bad (blue line), very bad or do not use (green line).
Figure 7. GIIRS temperature profiles in Yichang, Hubei province. The purple line was the GIIRS profile at 12:00 (Beijing time) on 25 January 2022. The black line was the GIIRS profile at 20:00 (Beijing time) on 27 January. The surface observation of the precipitation type was rain at 12:00 on 25 January, while it was snow at 20:00 on 27 January. The quality flags of purple profile are 3 (100 hPa), 3 (150 hPa), 0 (200 hPa), 1 (250 hPa), 2 (300 hPa), 0 (500 hPa), 0 (700 hPa), 1 (850 hPa), 1 (925 hPa), 0 (1000 hPa). The quality flags of black profile are 3 (100 hPa), 3 (150 hPa), 2 (200 hPa), 1 (250 hPa), 3 (300 hPa), 0 (400 hPa), 0 (500 hPa), 1 (700 hPa), 0 (850 hPa), 0 (925 hPa), 0 (1000 hPa). The quality flags are 0, 1, 2 and 3, which represent perfect data, good data, bad data and very bad data.

Figure 8a illustrates the temperature profile in Xiangyang, Hubei province at 08:00 on 28 January. The atmospheric temperature of the whole layer of Xiangyang is relatively low, at less than 0 °C, which can lead to the occurrence of snowfall. Meanwhile, the ground-based observation shows that the precipitation type is snow in Xiangyang. The temperature profile in Xiangtan is shown in Figure 8b, there is an inversion layer, warm air with the temperature above 0 °C between 700 hPa and 925 hPa. In addition, a layer colder than 0 °C exists below 925 hPa. However, this vertical thermal structure over Xiangtan will not lead to freezing rain, because the cold layer in the lower level is relatively shallow and the 2 m temperature is higher than 0 °C, so the liquid water from the deep warm layer falls into the shallow cold layer, they cannot be turned into supercooled water and frozen on the ground. Therefore, although there is an inversion layer over Xiangtan at 08:00 on 28 January, the precipitation type should be rain, which is also consistent with the ground-based observation.

These snow and rain examples in Hubei and Hunan, GIIRS temperature profiles represent the reasonable thermal structures. The precipitation type diagnosis by GIIRS temperature profile is also consistent with the surface observations. In addition, results also show that the GIIRS temperature below 700 hPa is an important indictor to determine rain or snow. This indictor is in agreement with the results obtained by others, who diagnose precipitation types by using radiosonde observations [13,14]. In order to verify which layer of temperature dominates the rainfall and snowfall, more detailed statistics were performed. According to the matched principle, we match the GIIRS temperature below 700 hPa with the surface observation of precipitation types from 25 to 29 January. All precipitation matched samples from this winter storm are divided into snowfall and rainfall (excluding freezing rain) samples, the perfect or good flagged temperature at 700 hPa, 850 hPa, 925 hPa and 1000 hPa are selected to make statistics. Figure 9 shows the perfect or good flagged
GIIRS temperature for different precipitation types. The medians at 700 hPa are 0 °C for rain and −6 °C for snow, respectively, while there is considerable overlap in temperature for snow and rain events. Comparatively, there are fewer overlaps in temperature for snow and rain events at 850 hPa and 925 hPa. When the temperature at 850 hPa is below −2 °C, the probability of snowfall events is greater. In addition, the probability of snowfall events is greater when the temperature is below 0 °C at 925 hPa. Therefore, \( T_{850\text{hPa}} < -2 \degree C \) and \( T_{925\text{hPa}} < 0 \degree C \) are two critical thresholds for the occurrence of snowfall in this winter storm.

**Figure 8.** GIIRS temperature profiles at 08:00 (Beijing time) on 28 January 2022, in (a) Xiangyang, Hubei province; (b) Xiangtan, Hunan province. The surface observation of precipitation type was snow in Xiangyang, and the precipitation type was rain in Xiangtan at 08:00 on 28 January 2022. The quality flags of profile in Figure 8a are 3 (100 hPa), 3 (150 hPa), 0 (200 hPa), 3 (250 hPa), 3 (300 hPa), 2 (400 hPa), 1 (500 hPa), 0 (700 hPa), 1 (850 hPa), 1 (925 hPa), 0 (1000 hPa). The quality flags in Figure 8b are 0 (100 hPa), 0 (150 hPa), 0 (200 hPa), 0 (250 hPa), 0 (300 hPa), 0 (400 hPa), 0 (500 hPa), 0 (700 hPa), 0 (850 hPa), 0 (925 hPa), 1 (1000 hPa). The quality flags are 0, 1, 2 and 3, which represent perfect data, good data, bad data and very bad data.

Freezing rain is a more complex weather event, which often occurs in southern China. Freezing rain can be caused by an ice-phase mechanism and warm rain mechanism [33,34]. The ice-phase mechanism is the typical thermal structure: the ice particles fall into a warm layer, and then they can be melted to liquid water, then supercool and freeze up in the lower cold layer where the temperature is below 0 °C. Some studies have found that the warm rain mechanism can also have a warm layer, but the precipitation particles have always existed in form of liquid [35–37]. Therefore, the difference between the ice-phase mechanism and the warm rain mechanism is the process of melting ice particles. Although the vertical temperature profile is most critical indicator, freezing rain diagnosis must take account of related atmospheric parameters, including 2 m temperature and cloud particle information. Therefore, a single threshold of vertical temperature is not suitable to determine the occurrence of freezing rain. On the other hand, freezing rain event only occurs in Guizhou province from 25 to 29 January, so we did not make statistics to explore the GIIRS temperature threshold for freezing rain.

In this winter storm event, freezing rain occurred in central Guizhou at 08:00 on 28 January. Guizhou is a region with a high altitude and complex terrain, the distribution of atmospheric temperature data is above 850 hPa. Therefore, the diagnosis of freezing rain is a significant challenge for weather forecasters. Figure 10 shows the cloud top information and temperature profiles in Guiyang when the precipitation type is freezing rain.
According to the matched principle in Section 2, a GIIRS temperature profile closest to a radiosonde station in Guiyang is selected. The quality flag is perfect at every pressure level on this profile. In Figure 10d, the distribution of the GIIRS temperature profile is very similar to that of radiosonde observation, all showing cold layers with the temperature less than 0 °C above 700 hPa. However, it can be found that there is a shallow warm layer below 700 hPa. The temperature from GIIRS and observation at 700 hPa is 1.45 °C and 1.4 °C, respectively. In Figure 10a–c, the cloud top height in central Guizhou is relatively low, about 3–4 km, the cloud top temperature is around 0 °C and the cloud top phase is mainly supercooled cloud and warm water cloud. In addition, the 2 m temperature is −1.2 °C. This shows that liquid particles fall into a shallow warm layer, then supercooling in the lower cold layer, and eventually freezing up on surface where the 2 m temperature is below 0 °C. By combining the cloud top information, we can see that the phase of precipitation particles did not change. Therefore, in this winter storm, freezing rain in Guiyang on 28 January is caused by warm-rain mechanism.
Figure 10. FY-4A AGRI cloud top information (a) cloud top height (km), (b) cloud top temperature (°C), (c) cloud phase, (d) GIIRS temperature profile vs. radiosonde observation at 08:00 on 28 January 2022 (black dot: the location of Guiyang). The quality flags of GIIRS profile in Figure 10d are 0 (100 hPa), 0 (150 hPa), 0 (200 hPa), 0 (250 hPa), 0 (300 hPa), 0 (400 hPa), 0 (500 hPa), 0 (700 hPa), 0 (850 hPa). The quality flags are 0, 1, 2 and 3, which represent perfect data, good data, bad data and very bad data.

4. Discussion and Conclusions

The discrimination of winter precipitation types in southern China is difficult for weather forecasters, and skills need to be improved. In this study, we first evaluated the FY-4A GIIRS temperature profiles at different pressure levels, using radiosonde observations in southern China. In addition, we also illustrated the availability of GIIRS temperature profiles in winter precipitation type diagnosis for the first time in a winter storm event of 2022.

In general, the GIIRS temperature products for four types (clear sky perfect quality, cloudy sky perfect quality, cloud sky good quality, and cloudy sky bad quality) show the different performances compared to radiosonde observations. Relatively, the cloud can affect the quality and quantity of GIIRS temperature profile products. Under clear and cloudy skies, the frequencies of missing data are 1% and 22.5%. Meanwhile, the frequencies of perfect flagged data are 95.7% and 22.6%, respectively. The perfect flagged data show the best agreement with radiosonde observations, the RMSE is 1.81 °C and 1.82 °C under clear and cloudy sky, respectively. The perfect flagged data show the best agreement with radiosonde observations, the RMSE is 1.81 °C and 1.82 °C under clear and cloudy sky, respectively. The RMSE of good data and bad data is 3.13 °C and 4.57 °C under the cloudy sky, respectively. At different pressure levels, statistical indicators
always show that the perfect data has the highest CC, lower MB and RMSE. The good data has a slightly lower CC, higher MB and RMSE than perfect data. The MB of good data below 700 hPa is very close to perfect data. On the whole, the perfect flagged data have the smallest systematic deviation under clear or cloudy sky when compare with the other flags of data. We also found that the cloud top height having a more significant impact on the amount of data.

A case study was carried out to analyze FY-4A GIIRS temperature profile’s ability to diagnose precipitation types in a winter storm in southern China. The distribution of GIIRS temperature below 700 hPa can represent the transformation process of rain and snow in Yichang. Furthermore, in the snowfall and rainfall events in Xiangyang and Xiangtan, GIIRS products also show reasonable atmospheric thermal structures. The GIIRS temperature below 700 hPa is an important indicator to precipitation type diagnosis. According to the statistical results of all rain and snow events from 25 to 29 January in southern China, $T_{850\text{hPa}} < -2\, ^\circ\text{C}$ and $T_{925\text{hPa}} < 0\, ^\circ\text{C}$ are two critical thresholds for the occurrence of snowfall.

In the freezing rain event in Guiyang, GIIRS temperature profile performed very well, the temperature distribution at different pressure levels is consistent with radiosonde observation. This shows that freezing rain is a warm rain mechanism by combining the cloud top information of FY-4A AGRI. Therefore, Guizhou is a region with a high altitude in southern China, determined by not only using FY-4A GIIRS temperature profile to diagnose precipitation types but also combined with the cloud top information of FY-4A AGRI. In the future, more freezing rain events are necessary in order to obtain the diagnosis method of freezing rain.

FY-4A GIIRS temperature profiles provide unprecedented measurements for studying the atmospheric characteristics of thermal structure. This study assessed FY-4A GIIRS temperature profile products in southern China. In addition, it is the first attempt to apply GIIRS profiles to the diagnosis of winter precipitation types, and the results can provide a new perspective for weather forecasters. The relative humidity profiles of FY-4A GIIRS after May 2019 are not available due to some contamination effects on its mid-wave infrared measurements [19]. Therefore, we did not analyze the effect of relative humidity on those types in this winter storm. However, FY-4B was launched on 3 June 2021, the GIIRS temperature and relative humidity profile products will be released in the near future. We will combine FY-4B temperature with relative humidity profile to explore the dual threshold methodology of winter precipitation type diagnosis.

Author Contributions: Conceptualization, D.M., D.Q., X.W. and Y.G.; methodology, Y.G.; formal analysis, Y.G.; investigation, Y.G., D.M., X.W. and D.Q.; writing—original draft preparation, Y.G.; writing—review and editing, Y.G., D.M., X.W. and D.Q.; All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Second Tibetan Plateau Scientific Expedition and Research (STEP) program (grant number 2019QZKK0105).

Data Availability Statement: The FY-4A products were downloaded from the FENGYUN Satellite Data Center (http://satellite.nsmc.org.cn/, accessed on 7 April 2022).

Acknowledgments: The authors thank the National Meteorological Information Center of China Meteorological Administration for providing radiosonde and surface observations.

Conflicts of Interest: The authors declare no conflict of interest.

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