Application of Fengyun-4 Satellite to Flood Disaster Monitoring through a Rapid Multi-Temporal Synthesis Approach

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ABSTRACT

Fengyun-4A (FY-4A) belongs to the second generation of geostationary meteorological satellite series in China. Its observations with high frequency and resolution provide a better data basis for monitoring of extreme weather such as sudden flood disasters. In this study, the flood disasters occurred in Bangladesh, India, and some other areas of South Asia in August 2018 were investigated by using a rapid multi-temporal synthesis approach for the first time for removal of thick clouds in FY-4A images. The maximum between-class variance algorithm (OTSU; developed by Otsu in 2007) and linear spectral unmixing methods are used to extract the water area of flood disasters. The accuracy verification shows that the water area of flood disasters extracted from FY-4A is highly correlated with that from the high-resolution satellite datasets Gaofen-1 (GF-1) and Sentinel-1A, with the square correlation coefficient $R^2$ reaching 0.9966. The average extraction accuracy of FY-4A is over 90%. With the rapid multi-temporal synthesis approach used in flood disaster monitoring with FY-4A satellite data, advantages of the wide coverage, fast acquisition, and strong timeliness with geostationary meteorological satellites are effectively combined. Through the synthesis of multi-temporal images of the flood water body, the influence of clouds is effectively eliminated, which is of great significance for the real-time flood monitoring. This also provides an important service guarantee for the disaster prevention and reduction as well as economic and social development in China and the Asia–Pacific region.

Key words: flood disaster monitoring, maximum between-class variance algorithm (OTSU), Fengyun-4A (FY-4A), multi-temporal, rapid synthesis

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1. Introduction

Since the 20th century, the frequency of catastrophic floods has increased significantly around the world (Milly et al., 2002). Flood is one of the most common and harmful natural disasters, which causes great losses to the local economy. The flood disasters mainly take place in the areas with frequent typhoons and rainstorms. Most of the flood events are characterized by abruptness, short duration, and easy identification on the location. However, it is always a long-term process to prevent and control flood disasters (Zhou, 1993). The satellite remote sensing technology has been developed since the 1960s, with advantages of wide coverage, fast speed, and strong timeliness and independence from ground monitoring conditions, which has been more and more widely used in flood disaster monitoring.

The polar orbiting satellite data have been commonly used in traditional satellite-based monitoring of flood disasters. However, it presents the characteristic of long revisit period, and as it is affected by the cloud, availability of the data acquired is relatively low. Even the Synthetic Aperture Radar (SAR) satellite that can realize the all-weather observation has the problem of insufficient coverage to the disaster area. Both the polar orbiting and SAR satellites are inadequate to deal with the flood disasters with abruptness and meet the demand of timeliness in monitoring. Since the launch of geostationary...
meteorological satellites, continuous observations at the one-hour interval can be obtained in the disaster area, which makes up for the problem of long revisit period of polar orbiting satellites. However, compared with the polar orbiting satellites, the monitoring accuracy of geostationary satellites is relatively low due to the limitation in spatial resolution. With the successful launch of the second-generation geostationary meteorological satellite Fengyun-4A (FY-4A) in 2016, the high spatial (0.5 km) and temporal resolution (15 min) can well satisfy the demand for continuous monitoring on widespread flooding to the greatest extent (Dong, 2016; Zhang et al., 2019).

The essence of flood monitoring is to accurately extract the spatial distribution information of water body, and more specifically, it distinguishes the information of water body from that of other ground objects based on the spectral characteristics and spatial position of water body. Traditional extraction methods mainly include the single-band threshold method (Lu and Li, 1992; Shao et al., 2015), spectrum-photometric method (Ding et al., 2006), exponential model method (McFeeters, 1996; Xu, 2005; Wang et al., 2015), spectral classification method (Du et al., 2002), etc. These methods are relatively simple to implement, but repeated tests are needed in the extraction process to determine the optimal threshold for land and water segmentation (Yang et al., 2011), which will consume a large amount of artificial time. This is obviously not applicable to the water body extraction of FY-4A data with high temporal resolution and large amount, and the same threshold is difficult to meet requirements of the large-scale water body extraction.

As one of the areas with most precipitation in the world, South Asia is located in the vast area between the central and western Himalayas and Indian Ocean. Flood disasters in South Asia occur frequently during the period of June to October. Although South Asia is not the region with the most floods, the flood-related deaths are often higher than those in other areas in most instances (Yang et al., 2013). The flood dataset collected from Emergency Events Database [EM-DAT; the Office of Foreign Disaster Assistance/Centre for Research on the Epidemiology of Disasters (OFDA/CRED) International Disaster Database] shows that 772 large-scale floods have occurred in South Asia since the records began in 1926, with 163,581 people died, 130 million people being affected and economic loss of 110.2 billion pounds. Therefore, it is of great significance to monitor the flood disasters in this area.

This study focuses on a typical flood event occurring in a wide area of South Asia (Bangladesh and northeastern India) in 2018. Based on FY-4A meteorological satellite data, a rapid multi-temporal combination method is proposed to synthesize the daily remote sensing images during the disaster process. The water body information in the research area is automatically extracted by the maximum between-class variance algorithm (OTSU; Otsu, 2007) and linear spectral unmixing method (Adams et al., 1986; Chen et al., 2016). The influence of mixed pixels on the accuracy of water body is considered in this method, through which the range and area of water body can be quickly and automatically obtained, thus reducing the workload of human–computer interaction. The spatial distribution of flood disasters in the area of concern can be quantitatively determined by comparing with the background water information in 2015. Meanwhile, accuracy of the multi-temporal combination method is verified and evaluated by comparing the flood results of overlapping areas extracted from high-resolution remote sensing images of Gaofen-1 (GF-1) and Sentinel-1A.

2. Date and methodology

2.1 Study region

The study domain of interest (Fig. 1) is located in Bangladesh, Northeast India, and South Asia (22°–27°N, 88°–94°E). This region subjects to the subtropical monsoon climate and monsoon savanna climate. This area is one of the most densely fluvial areas in the world, with an altitude of 12–30 m. The annual monsoon period (June–October) has a significant impact on the climate and hydrological conditions. Three quarters of rainfall is concentrated in these five months. The rainy season is very easy to floods, and tropical hurricanes often appear. Floods become a part of life in the area, with major floods occurring every few years. In this paper, a large-scale flood disaster in the study area in August 2018 is taken as an example to perform the flood disaster monitoring research.

2.2 Satellite data

Two types of satellite data, which are obtained from the FY-4A geostationary meteorological satellite and high-resolution earth observation satellites (GF-1 and Sentinel-1A) respectively, are adopted in this paper, where the former is used for research on the flood disaster monitoring, and the latter is for the accuracy verification on the monitoring results acquired from FY-4A. FY-4A is the second generation of geostationary orbit meteorological satellites in China, which adopts a three-axis stabilized attitude control scheme, whose continuous and stable operation can greatly improve the detection techniques of geostationary meteorological satellites in
China. The FY-4A multi-channel scanning radiation imager of Advanced Geosynchronous Radiation Imager (AGRI) possesses 14 spectral channels, covering the visible short-wave, medium-wave, and long-wave infrared. The technique parameters are as follows: the accuracy of on-board radiometric calibration is 0.5 K, the sensitivity is 0.2 K, the spatial resolution of visible band is up to 0.5 km, and the temporal resolution is 5 min (China region) or 15 min (complete full disk). As the first launch satellite of the second-generation meteorological satellite series in China, FY-4A was successfully launched on 11 December 2016, and officially delivered to users on 25 September 2017 (Lu et al., 2017).

GF-1 satellite is the first sun-synchronous orbit satellite of China's high-resolution earth observation system. GF-1 carries two cameras providing 2-m-resolution panchromatic images and 8-m-resolution multi-spectral images, and also four cameras providing 16 m-resolution multi-spectral images (Li, 2015). We use the 16-m multi-spectral image data in this study. Sentinel-1A, launched on 3 April 2014, is the first SAR satellite developed by European Space Agency as part of the European Union Copernicus Program (Potin et al., 2016). The Sentinel-1A SAR instrument operates at 5.405 GHz (C-band, corresponding to a radar wavelength of about 5.6 cm), four exclusive imaging modes providing different resolutions and coverages are supported: Interferometric Wide Swath (IW), Extra Wide Swath (EW), Strip Map (SM), and Wave (WV; Schubert et al., 2015). The data used in this study are the ground-distance multi-view products under the Terrain Observation by Progressive Scans (TOPS) SAR mode. Channel settings for the two types of satellite data are shown in Table 1.

The flood disasters occurred in Bangladesh, India, and South Asia on 18 August 2018, are taken as the research object in this paper. FY-4A meteorological satellite images can completely cover the study area. The spatial distribution of GF-1 and Sentinel-1A orbital data on the day is shown in Fig. 1, which is used for the accuracy evaluation on the monitoring results of flood disasters obtained from the FY-4A geostationary meteorological satellite.

Table 1. Parameters for the remote sensing data

| Parameter             | FY-4A | GF-1 | Sentinel-1A |
|-----------------------|-------|------|-------------|
| Optical satellite     |       |      |             |
| Blue band             | 0.45–0.49 μm | 0.45–0.52 μm | Acquire mode |
| Green band            | 0.52–0.59 μm |       | Product type |
| Red band              | 0.55–0.75 μm | 0.63–0.69 μm | Polarity     |
| Near infrared band    | 0.75–0.90 μm | 0.77–0.89 μm | HH + HV, VV+VH |
| Spatial resolution    | 0.5 m, 1 km | 16 m  | Range resolution |
| Revisit period        | 15 min/full disk | 2 days | Azimuth resolution |
|                       |       |      | 20 m        |

Note: HH—horizontal transmit/horizontal receive, HV—horizontal transmit/vertical receive, VV—vertical transmit/vertical receive, and VH—vertical transmit/horizontal receive.
2.3 Methodology

The method and calculation procedure adopted in this study are shown in Fig. 2. FY-4A satellite data are used to generate daily monitoring images for the flood area extraction. The calculation process includes the disaster area selection, cloud removal, and automatic extraction of the flood water body. The cloud extracted from multi-scene images at adjacent time within a day is removed based on the recognition of cloud movement in successive periods, which is defined as the rapid multi-temporal synthesis approach in this paper. This method is adopted for the first time to generate the daily cloudless (less cloudy) product from FY-4A satellite data. The water body information in the study area is automatically extracted with the OTSU algorithm and linear spectral unmixing method. By comparing the background information of water body in the period of non-flood disasters, the results with quantitative information of the flood location and area could be obtained. Finally, accuracy of the results of flood disaster coverage is verified by using GF-1 and Sentinel-1A data.

2.3.1 Rapid multi-temporal synthesis approach

The rationale of rapid multi-temporal synthesis approach is to replace ground information of the cloud covered region by information of the cloud-free region at different time of the day for the same area. Based on the method of mosaicing multi-temporal cloud-free pixels into cloud regions proposed by Li et al. (2003), the method of cloud detection in this paper has been improved by the mathematical morphology theory.

First, in order to eliminate differences of the radiation and location among multi-temporal images, radiometric correction and image registration are done for FY-4A multi-scene images within one day. Secondly, through the cloud detection and classification, the images are divided into two categories of cloud and cloud-free surfaces. Take the image with minimum cloud amount in the multi-scene images as the base image of this composite image, and then the cloud pixels in the base image are replaced by cloud-free pixels in adjacent images. Finally, a cloudless (or partly cloudy) image is synthesized.

The key step of this method is the cloud detection, through which the cloud boundary is initially determined based on the characteristic of high reflectivity at 0.645 μm in the visible band with the cloud region. Errors will occur due to strong reflection over snow-covered or ice-covered areas, or the instance with aerosol scattering. So firstly, the threshold method is used to make a rough
judgment.

\[ R_{\text{red}} > T_0, \quad (1) \]

where \( R_{\text{red}} \) represents the reflectivity of red band, and \( T_0 \) is the selected threshold. This study is aimed at cloud detection applications in middle and low latitude areas. After repeated tests, when the value of \( T_0 \) is 0.18, the effect is better.

Then, the morphological closing operation is adopted to extract the cloud boundary (Cao et al., 2009). The advantage of closing operation is that it can fill the tiny holes in the cloud, connect the disconnected adjacent clouds, and smooth the boundary without significant changes to the cloud area. The closing operation includes the expansion and corrosion algorithm. After the rough judgment, let the binary image set of cloud detection be \( A_0 \), the structure element set be \( B_0 \), while symbol for the expansion algorithm is \( \oplus \), \( \ominus \) is for the corrosion algorithm, and \( \circledast \) for the closing operation. The closing operation is defined as follows:

\[ A_0 \oplus B_0 = U \{ A_0 + b_0 : b_0 \in B_0 \}, \quad (2) \]

\[ A_0 \ominus B_0 = I \{ A_0 + b_0 : b_0 \in B_0 \}, \quad (3) \]

\[ A_0 \circledast B_0 = (A_0 \oplus B_0) \ominus B_0. \quad (4) \]

The structural element \( B_0 \) is set to be a \( 5 \times 5 \) matrix in

\[
\begin{bmatrix}
0 & 0 & 1 & 0 & 0 \\
0 & 1 & 1 & 1 & 0 \\
1 & 1 & 1 & 1 & 0 \\
0 & 1 & 1 & 1 & 0 \\
0 & 0 & 1 & 0 & 0
\end{bmatrix}
\]

This paper, which is as below:

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2.3.2 Automatic extraction of water body

The OTSU method is adopted in this paper to automatically select the best threshold for water body extraction. Meanwhile, the linear spectral unmixing method (Chen et al., 2016) is also introduced to further improve the accuracy of water extraction from the perspective of spatial resolution.

First, the Normalized Difference Vegetation Index (NDVI) is calculated based on the \( FY-4A \) images, which can further expand the difference between the water body and background to make the water body in the images clearer.

\[ \text{NDVI} = \frac{R_{\text{Nir}} - R_{\text{red}}}{R_{\text{Nir}} + R_{\text{red}}}, \quad (5) \]

where \( R_{\text{Nir}} \) and \( R_{\text{red}} \) represent the reflectance of near infrared and red bands, respectively.

Second, since the existence of clouds and terrain shadows is the main interference factor to the accuracy of water extraction, the rapid multi-temporal synthesis approach is used for cloud removal. Moreover, considering that the terrain shadows are similar to the water body in

the spectral characteristic, while the slope of water surface is generally less than 10° (Lu et al., 2011), some of the terrain shadows could be removed by the Shuttle Radar Topography Mission (SRTM) slope (90M) data (Feng et al., 2016), through which part of the background land that affects the extraction of water body can also be removed.

Then, the OTSU method is adopted to extract the water body information in this paper. The advantage of this method is that the optimal threshold can be determined by adaptive algorithm to extract water automatically. In this paper, calculation processes of the OTSU method are as follows. For Image \( I(x, y) \), this paper is based on the NDVI gray image after removing the interference factors. The segmentation threshold between the foreground (water) and background (land) is \( T_b \), which is the optimal threshold when the square difference between the two groups reaches the maximum. The proportion of foreground pixel that points to the whole image is \( w_0 \), the average gray level is \( \mu_0 \); the proportion of background pixel that points to the whole image is \( w_1 \), the average gray level of the image is \( \mu_1 \); and the total average gray level of the image is \( \mu_T \). The optimal threshold is defined as follows:

\[ T_b = \arg \max \left\{ w_0(\mu_0 - \mu_T)^2 + w_1(\mu_1 - \mu_T)^2 \right\}. \quad (6) \]

Finally, to further improve the accuracy of water extraction, the linear spectral unmixing method (Adams et al., 1986) is used to calculate the percentage of water body in each pixel, through which the endmember in the pixel is divided into two categories (water and land). The percentage of water body area is \( P_w \), which is defined as follows:

\[ P_w = \frac{(R_L - R_M) / (R_L - R_W)}, \quad (7) \]

\[ \Delta S_w = P_w \times \Delta S. \quad (8) \]

In this paper, according to the NDVI gray value of water and land pixels after identification, \( R_w \) is the NDVI gray value of pure water pixel, \( R_L \) denotes the NDVI gray value of pure land pixel, and \( R_M \) represents the NDVI gray value of image pixel to be calculated. \( P_w \) is the calculated water area percentage. \( \Delta S_w \) is the water area of the pixel to be calculated, and \( \Delta S \) is the pixel area.

In summary, compared with the previous studies, there are two advantages to the method used in this paper. First, in data preprocessing before the water area extraction, the rapid multi-temporal synthesis approach is used in \( FY-4A \) data for the first time, which could largely eliminate the cloud influence, leading to an improvement in the accuracy of water extraction. Second, the influence of mixed pixels is comprehensively considered in
the calculation of water area extraction, which is also a factor rarely considered in the calculation of water body extraction in the past. Therefore, the algorithm proposed in this study improves the calculation accuracy of water body area from a different perspective, which makes an effective usage of FY-4A data with high temporal resolution and continuous observation, leading to the improvement in the capability of flood monitoring.

3. Results

3.1 Analysis of cloud eliminating results from multi-temporal synthesis

From the continuous images of FY-4A observation at visible band from 0900 to 1700 BT (Beijing time) 18 August 2018 (Fig. 3), it shows that the surface cloud coverage over the study area is about 60%, and convective clouds exist in some areas. Composite images obtained by using the rapid multi-temporal synthesis approach are shown in Fig. 4a.

It shows that the cloud amount in the study area decreases significantly, the surface information is clearer, and the water information is clear and discernible. Comparing with FY-3D/Medium Resolution Spectral Imager (MERSI) polar orbit meteorological satellite image (Fig. 4b) and Earth Observation System/Moderate Resolution Imaging Spectroradiometer (EOS/MODIS) 8-day composite image (Fig. 4c) at the same period, it represents...
that most of the sky above the study area in FY-3D/MERSI image is covered by clouds, and surface information, especially the water information, cannot be clearly displayed. Meanwhile, there are more cloud fragments, and water information is not obvious in the EOS/MODIS 8-day composite image. On the whole, water body information in the images synthesized by the method in this paper is the clearest (Fig. 4), and the cloud classification shows that the elimination rate of thick and high clouds exceeds 90% except for thin clouds with little movement.

Compared with the water monitoring maps synthesized by FY-4A images, the single image of polar orbit meteorological satellite is often covered by clouds, and thus, flood information in the study area cannot be obtained. The multi-day synthetic image of polar orbit meteorological satellite can remove thick clouds to a certain extent. However, there are still more fractostratus in the image, part of the surface is covered by clouds, and the timeliness is also poor. Therefore, the application of FY-4A geostationary meteorological satellite can greatly improve the timeliness of satellite monitoring, which has important practical value for real-time monitoring of flood disasters.

### 3.2 Verification and analysis of flood disaster monitoring capability of FY-4A

From the composite images with clouds removed through the rapid multi-temporal synthesis approach, water body information is automatically extracted by the OTSU method. By comparing the background information of water body in 2015 (Fig. 5), it presents that the areas with serious flooding are mainly located in the middle of study area (A) and at the junction of Jiamuna River and Ganges River (B). The flooding at the central part of study area (A) is the most serious, which has increased significantly with a wide scope. In Region B, water body of the flood has increased obviously in some sections of the river. In Region C, water body of the flood has increased at different extents in the whole section of Brahmaputra reach. The total area of flood water in the study area is about 13,464 km².

Based on images from the high-resolution satellites of GF-1 and Sentinel-1A, the monitoring accuracy of water body is evaluated. GF-1 image data are preprocessed by radiometric and geometric corrections. The Sentinel Application Platform (SNAP) software was used for the pre-

![Variation maps of flood monitoring based on FY-4A data in the study area. The comparison of water monitoring of FY-4A before and after the disaster on 18 August 2018 (background water 300 m) is provided by European Space Agency (ESA) Climate Change Initiative-Land Cover (CCI-LC) project in 2015.](image)
process of Sentinel-1A SAR image, including the preprocess radiometric correction, multi view processing, filtering processing, and geographical correction. Then, the two types of high-resolution data are extracted by the threshold method. The results of high-resolution data are treated as the truth value of water extraction. The accuracy of floodwater monitoring in Regions A, B, and C in Fig. 5 is evaluated and displayed.

In Region A, the spatial distribution of flood water monitored by FY-4A (Fig. 6a) and Sentinel-1A (Fig. 6b) are basically the same. As affected by the revisit period and cloud cover, the monitoring image of Sentinel-1A does not completely cover the study area, and therefore, we selected the corresponding water body of two kinds of data for comparison. The area of mixed pixels extracted by FY-4A is about 2985 km$^2$, which is about 11% less than that from Sentinel-1A (3390 km$^2$). The difference in the area is attributed to the fact that Sentinel-1A SAR image can better distinguish and display small water bodies and rivers because of its higher resolution, while FY-4A geostationary meteorological satellite data have the advantage of wide coverage for comprehensive flood monitoring (Figs. 6c, d). In Region B (Fig. 7), it shows that in the GF-1 image, there are only some clouds, and the water body is basically uncovered. The spatial ranges of water body information monitored by FY-4A (Fig. 7a) and

**Fig. 6.** Typical Region A: monitoring and thematic maps of (a, c) FY-4A composite images at 0900–1700 BT 18 August 2018 and (b, d) Sentinel-1A SAR image at 1204 BT 17 August 2018.
GF-1 (Fig. 7b) in Region B are basically the same, while that of the GF-1 high-resolution satellite is more obvious in details than that of FY-4A geostationary meteorological satellite. The area of mixed pixels of water body extracted from FY-4A is about 270 km², which is about 12% less than that from GF-1 (309 km²; Figs. 7c, d). In Region C (Fig. 8), there are more clouds in the GF-1 satellite image, and the rivers are more delicate (Fig. 8b). The mixed pixel area of water body extracted from FY-4A is about 2354 km², which is about 17% less than that from GF-1 (2850 km²). The FY-4A data exhibit a relatively low accuracy in small rivers (Figs. 8c, d).

In the above typical Regions A, B, and C, we selected FY-4A and high-resolution (GF-1 and Sentinel-1A) data, which are in clear sky, and the water area of sample area at several corresponding positions is adjacent to or on the same day. Those sample data are selected to verify the extraction accuracy of water body area from FY-4A satellite images. Table 2 is the sample area verification statistics, which shows that the mean relative error (MRE) of FY-4A water area is less than 10%, so we came to the conclusion that the monitoring accuracy is greater than 90%. Meanwhile, it should be noted that the water area of mixed pixels extracted from FY-4A is less than that from high-resolution data, which is mainly attributed to the spatial resolution of remote sensing images. The lower the spatial resolution, the larger the area of a single pixel, and the information of water body or linear water body with the small area will be lost, which could result in a smaller area of water body extracted from the same area. As can be seen from Table 2, most of the data from FY-4A are basically consistent with the high-resolution data, but there are still large relative error (RE) in some area due to the limitation in resolution. The large number of small rivers in the region make it difficult for the full extraction of water body from the FY-4A data, resulting in a relatively low value in the overall area.

Figure 9 is a linear fitting of monitoring area of FY-4A and high-resolution data (GF-1 and Sentinel-1A). The result shows that the trend of monitoring area size of the two data has good consistency, reaching more than 99%. FY-4A has high precision in estimating water area monit-
4. Summary

As the first satellite of the second-generation geostationary orbit meteorological satellite series, FY-4A has realized a leap-forward development of geostationary orbit meteorological satellite observation system in China, which exhibits the advantages of faster acquisition speed of information as well as a more powerful function. The high frequency and high resolution observations obtained from FY-4A can meet the important requirement of sudden disaster monitoring.

In this paper, FY-4A satellite data with high time resolution are used to synthesize cloudless (or partly cloudy) images from adjacent multi-temporal images. Quantitative results of the water body are automatically extracted by the OTSU and linear spectral unmixing methods in the study area. The location and area of flood disasters are obtained by comparing the background information of water body in the stable period before the disasters. By using the extraction results from GF-1 and Sentinel-1A images, the results of this method are compared and evaluated in three key areas of the study area. The results are as follows. First, by using FY-4A data, cloudless (or partly cloudy) images can be synthesized with the images in one single day. Compared with the single image of polar orbiting meteorological satellite (FY-3D) and multi-day synthesized images of EOS/MODIS, FY-4A data exhibits the advantages of stronger timeliness and

Fig. 8. As in Fig. 7, but for typical Region C.
fewer cloud fragments, and thus, more obvious land surface information can be revealed. However, limitations of insufficient coverage and poor timeliness exist with high-resolution satellite images (GF-1 and Sentinel-1A) and lower timeliness with EOS/MODIS images. The characteristics of strong timeliness and wide range with FY-4A data make it possible to obtain more surface information in a relatively short time, which is of more practical value for flood disaster monitoring in cloudy and rainy weather, and can provide timely and efficient real-time surface information for decision-making departments. Second, FY-4A is consistent with the high-resolution satellite in the spatial range and area of the extracted water body, and it can better reflect the flood distribution especially in the area where flood disasters larger than normal occur. As affected by the limitation of resolution, FY-4A exhibits the relatively low accuracy in extracting the water area from the regions where there are more small water bodies or small rivers, leading to the result of relatively small extraction of flood water, but it can still meet the needs of flood monitoring in a large area.

In this paper, FY-4A satellite data are utilized for the first time to generate daily cloudless (or partly cloudy) images, which are used in real-time monitoring and analysis on the information of flood water in the study area, where the influence of clouds is eliminated to the greatest extent, and the influence of mixed pixels is also taken into account. The data of geostationary meteorological satellite at the existing resolution are effectively utilized, which has significantly improved the feasibility of flood disaster monitoring with optical satellites in cloudy and rainy weather. It is of great significance for rapid and constant monitoring and evaluation of flood information in a large area.

There is still room for enhancement of the cloud removal method and water extraction algorithm used in this paper. At present, the boundary splicing problem caused by the pixel reconstruction in the multi-temporal cloud removal method is being improved. Further research will be continued with the improvement in details of the algorithm proposed in this paper, and moreover to enhance the quality of image processing and accuracy of flood monitoring eventually.

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