

# FY-3D MERSI-II Cloud Detection and Clear Sky Product Production

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## ABSTRACT

At the present stage, satellite remote sensing images often have the problem of cloud obscuration, which causes difficulties in the subsequent image processing and further research. In this paper, using the Moderate Resolution Spectral Imager II (MERSI-II) data from the domestic Fengyun-3D satellite as the data source, we study how to use the threshold method to detect clouds on the obtained data, and use the multi-temporal image superposition method to produce clear-sky products according to the results of the cloud detection, to eliminate the problem of cloud occlusion, and restore the real information of the features. Comparing the obtained cloud detection products with the actual true-color images and the official cloud detection products of Fengyun Satellite, it is found that the effect is still good. At the same time, the production results of the clear sky products can also clearly see the real features and better realize the de-cloud operation.

## KEYWORDS

FY3D; Threshold method; Cloud detection; Clear sky products.

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## 1. INTRODUCTION

At the current stage of research, when the satellite acquires the ground feature data, due to the influence of cloud cover, the remote sensing image generated by the satellite will always have a large area of cloud cover, resulting in the later use of the image to produce thematic images of the accuracy and completeness of the information being insufficient, which will make the data in some areas of the use of the obstacles caused by the data, for example, it is usually considered that the data cloud coverage of more than 10-15%, then the image cannot be utilized for research in geosciences and other areas [1]. Therefore, how to achieve cloud removal through the detection of clouds becomes the key to the efficient use of remote sensing images.

There are many scholars at home and abroad studying how to realize the image de-cloud operation, such as using the cloud point algorithm [2], the improved homomorphic filter algorithm [3], the dark channel a priori de-cloud algorithm [4], and so on. From the proposal and application of these methods, we can see that, so far, the removal of the cloud layer is still a relatively difficult aspect for remote sensing, and each method inevitably has its own limitations.

For the domestic Fengyun 3D satellite, there is a lack of existing mature products officially provided for clear-sky products after cloud detection, and with the increasing demand for the use of remote sensing data in China, the study of clear-sky product images for the whole country has a wide range of application value.

In this paper, cloud detection and cloud removal of remote sensing images are investigated, and finally cloud detection is carried out using the threshold method, and clear sky products are realized according to the results of cloud detection.

## 2. METHODOLOGY

### 2.1. FY3D MERSI-II PWV

Here the threshold method is used for cloud detection:

(1) Radiation calibration. The calibrated reflectance Ref can be obtained according to the following formula, where Cal\_0, Cal\_1 and Cal\_2 are the calibration coefficients for the corresponding channels, respectively.

$$dn = DN * Slope + Intercept \quad (1)$$

$$Ref = Cal\_2 * dn^2 + Cal\_1 * dn + Cal\_0 \quad (2)$$

The conversion of visible calibration reflectance to incident pupil irradiance can then be accomplished according to the following equation. Where  $L_i$  is the incident pupil irradiance.

$$L_i = Ref * E_0 / \pi \quad (3)$$

(2) Atmospheric correction. The 6s atmospheric correction is performed according to the following equation, where,  $\rho$  is the corrected albedo,  $X_a$ ,  $X_b$ , and  $X_c$  are the atmospheric correction parameters, and  $L_i$  can be obtained from the results of the radiometric calibration.

$$\rho = y / (1 + X_c \times y) \quad (4)$$

$$y = X_a \times L_i - X_b \quad (5)$$

(3) Calculation of channel bright temperature:

Step 1: List the equations of Plank inverse conversion for bright temperature:

$$t(v, L) = \frac{c_2 v}{\ln(c_1 v^3 / (L + 1))} \quad (6)$$

Where  $t$  is the blackbody temperature in K,  $L$  is the blackbody irradiance in  $mW/(m^2 - sr - cm^{-1})$ ,  $c_1: 1.191042 \times 10^{-5} (mW/(m^2 - sr - cm^{-1}))$ ,  $c_2: 1.4387752 (K cm)$ ,  $v$  is the wave number in  $cm^{-1}$ .

Step 2: Obtain the equivalent blackbody brightness temperature ( $T_e$ ) by taking the channel radiant brightness value of the 24th band after radiative calibration and by bringing the equivalent center wave number (MERSI\_EquivMid\_wn) of the 24th band queried from the description file into Eq.

Step 3: Convert the equivalent blackbody bright temperature to the channel blackbody bright temperature ( $T_{bb}$ ) based on the channel bright temperature revision factor ( $T_{bb}Corr\_Coeff$ ). The formula is as follows:

$$T_{bb} = A \times T_e + B \quad (7)$$

where  $A$  represents the slope of the brightness conversion factor and  $B$  represents the intercept of the brightness conversion factor. Once the brightness temperature is obtained, it can be calculated for different bands to realize the detection of clouds.

(4) Detection of cold clouds. In the region with cold clouds, since one of the main differences between cold clouds and the subsurface is that cold clouds have lower bright temperatures, the difference in bright temperatures can be used for the detection of cold clouds, and since the radiation received by the Stormy 3D MERSI data on  $10.8 \mu m$ , i.e., the 24-band, mainly comes from the subsurface, the

bright temperatures can be computed based on the above differences first, and then a threshold can be found, through which the detection of high-level cold clouds can occur.

(5) Detection of high clouds. The CO<sub>2</sub> thin slice method is used to set the threshold for detection. The 25th band of the wind and cloud 3D MERSI, the wavelength of the band is 12 μm, for the monitoring of cold clouds has a strong sensitivity; for the radiation flux density of the channel observation, only 500 Pa above the cloud layer has a contribution, so we can use the channel to detect high clouds. There are clouds in the region of the bright temperature that are low, and the undercushion surface temperature is much higher than the cloud layer. Based on this principle, we can set a threshold detection of high cloud cover.

(6) Detection of mesoclouds. The visible light single-channel reflectivity detection method is used to set the threshold for detection, and the 3rd band with a wavelength of 0.65 μm is selected in the wind and cloud 3D MERSI for judgment, because land features such as bodies of water have a small reflectivity in this band, while the reflectivity of thick clouds is large, which makes it easy for clouds to be detected, and the detection of the middle clouds is based on this principle.

(7) Detection of low clouds. The bright temperature difference method is used to detect the low clouds. In this paper, the 20th band image data with a wavelength of 3.8 μm, which is in the mid-infrared window of 3.5-4.0 μm, and the 24th band image data with a wavelength of 10.8 μm are selected. The bright temperature difference is obtained by subtracting the bright temperature of the 20th band from the bright temperature of the 24th band, and the threshold is set according to the bright temperature difference. When clouds appear in the field of view, the bright temperature difference will increase, and in the daytime, together with the effect of solar radiation on the mid-infrared, this difference will become further larger, and low clouds can be detected according to this principle.

## **2.2. Principles and methods of making clear sky products**

### **2.2.1. Principles of making clear sky products**

When the cloud layer reaches a certain thickness, it is difficult for electromagnetic waves to penetrate the cloud layer, so it is almost impossible to realize cloud removal based on the obtained one-scene image [5], so this paper adopts a combination of the multi-temporal phase method and the spatial superposition analysis method to produce cloud-free clear sky products. The general steps to achieve cloud removal are as follows: firstly, a color image is synthesized by selecting the red, green, and blue multispectral single-band data on the original data file, then geometrically corrected, and the cloudy image of the desired area is cropped by the provincial boundary, and the cloudy content is eliminated to obtain the residual cloud-free image, and this process is repeated to obtain multiple residual cloud-free images at different times, and then the clear-sky product containing complete feature information is obtained by the superposition analysis.

### **2.2.2. Methods of making clear-sky products**

(1) Color image production. In the HDF5 file of the Fengyun satellite, the extracted 1, 2, and 3 bands, which will be written as B, G, and R into a new he5 file, borrowed ENVI and other auxiliary software to open, can be displayed and viewed as color images.

(2) Geometric correction. Based on the GLT method, domestic satellite image geometry correction, the he5 file written in (1) is geometrically corrected, and the tiff file is output.

(3) Splicing and cropping the required regional images. Firstly, the geometrically corrected images were spliced using ENVI software, and then the TIFF file output from the splicing was cropped with the provincial boundaries to produce the cloud-containing image of Xinjiang using ArcGIS software, and then the data were exported and made into a TIFF file.

(4) De-cloud operation. Step 1: Obtain the red, green, and blue waveband data through the TIFF file in (3). Step 2: Simple cloud detection of the three bands under visual judgment, respectively, set

appropriate thresholds, set the value to 0 for those above the threshold, and make no change for those below the threshold, and output the TIFF image.

(5) Multi-temporal cloud-free image superposition. Using the method of multi-temporal cloud-free image superposition, several cloud-free images obtained at different times after the de-clouding process are superimposed to obtain cloud-free products.

### **3. PRE-PROCESSING**

#### **3.1. Data**

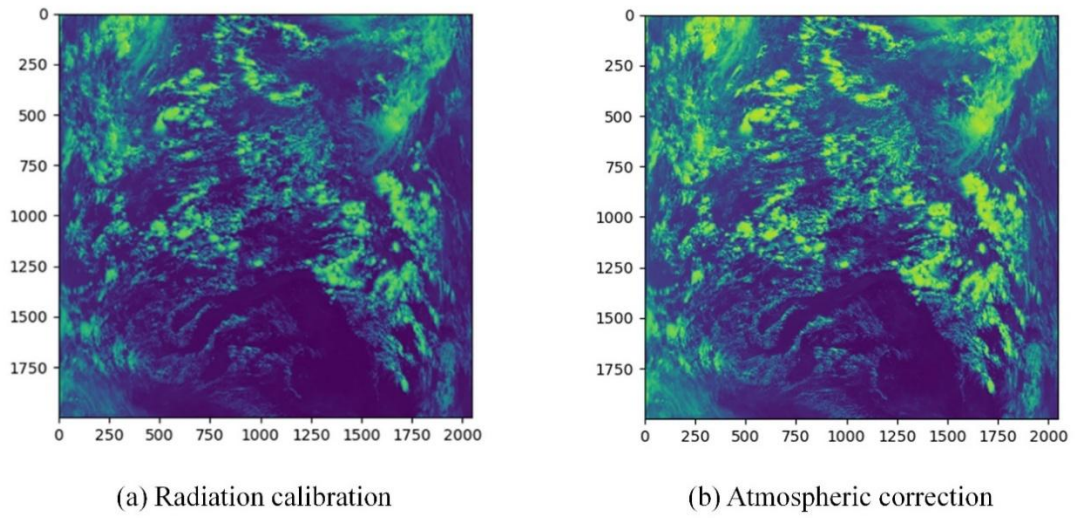
(1) Introduction to satellites and sensors. The Fengyun-3 (FY-3) meteorological satellite is the second generation of polar-orbiting meteorological satellites in China, and the goal of producing FY-3 meteorological satellites is to realize the three-dimensional observation of global atmospheric and geophysical elements and to provide observation data to medium-term numerical weather prediction so as to realize the monitoring and control of the ecological environment and large-scale natural disasters. The satellite carries a total of 11 different detectors, including the visible infrared scanning radiometer (VIRR), microwave thermometer (MWTS), infrared spectrometer (IRAS), medium resolution spectral imager (MERSI), and microwave hygrometer (MWHM), and so on, and each kind of detector has its own unique performance and function. The VIRR sensor, for example, has a spectral range of 0.43 to 12.5  $\mu\text{m}$ , 10 channels, and can be used to detect cloud maps, vegetation, and more. It is the existence of these fully functional sensors that makes Fengyun satellites have a wide range of applications in different fields.

(2) Introduction of MERSI-II Sensor. As one of the main payloads of Fengyun-3D, the Moderate Resolution Spectral Imager II (MERSI-II) is equipped with a total of 25 channels, of which 16 are visible-near-infrared (VNIR) channels, 3 are short-wave infrared (SWIR) channels, and 6 are mid- and long-wave infrared (MWIR) channels; among the 25 channels, 6 channels, 1, 2, 3, 4, 24, and 25, have a ground resolution of 250 meters, and the remaining 19 have a ground resolution of 1000 meters. Of the 25 channels, 1, 2, 3, 4, 24, 25, 6 channels have a ground resolution of 250 meters, and the remaining 19 channels have a ground resolution of 1000 meters. It not only inherits the mature technology from its previous product FY-3A/B/C satellites, but also improves on it. Compared with MERSI on FY-3C satellites, MERSI-II improves its calibration accuracy and sensitivity, and is recognized as one of the most advanced wide-area imagers [6].

The bands used in this paper are 1, 2, 3, 20, 24 and 25, and the center waves of the six bands are 0.47, 0.55, 0.65, 3.8, 10.8, and 12  $\mu\text{m}$ , of which the spatial resolution of the images in the 1, 2, 3, 24 and 25 bands is 250 m, and that of the 20 band is 1000 m. The center waves of the six bands are 0.47, 0.55, 0.65, 3.8, 10.8 and 12  $\mu\text{m}$ .

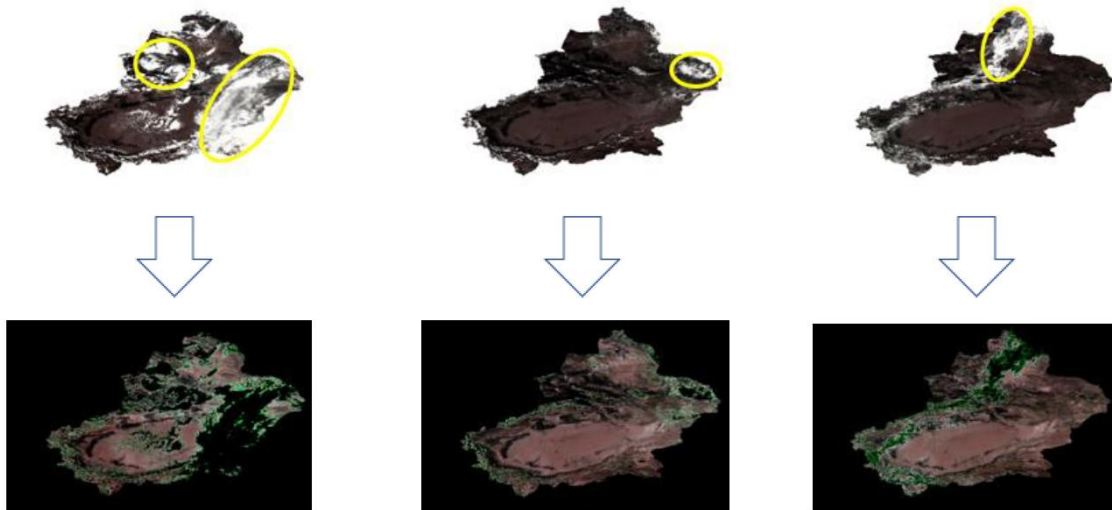
#### **3.2. Data processing**

As far as the cloud detection part is concerned, it is firstly necessary to pre-process the acquired raw data of Feng Yun satellite for radiation calibration (see Fig. 1 (a)), atmospheric correction (see Fig. 1 (b)), etc., and then bright temperature calculation is carried out after obtaining the reflectivity, and finally the detection is carried out for the different clouds according to the aforementioned principle, and it is measured by the experiments that the threshold value of the cold cloud is 267 K; the threshold value of the high cloud is 285.5 K; and the threshold value of the reflectivity of the middle cloud is 0.75; The bright temperature difference threshold for low clouds is -30K [7].

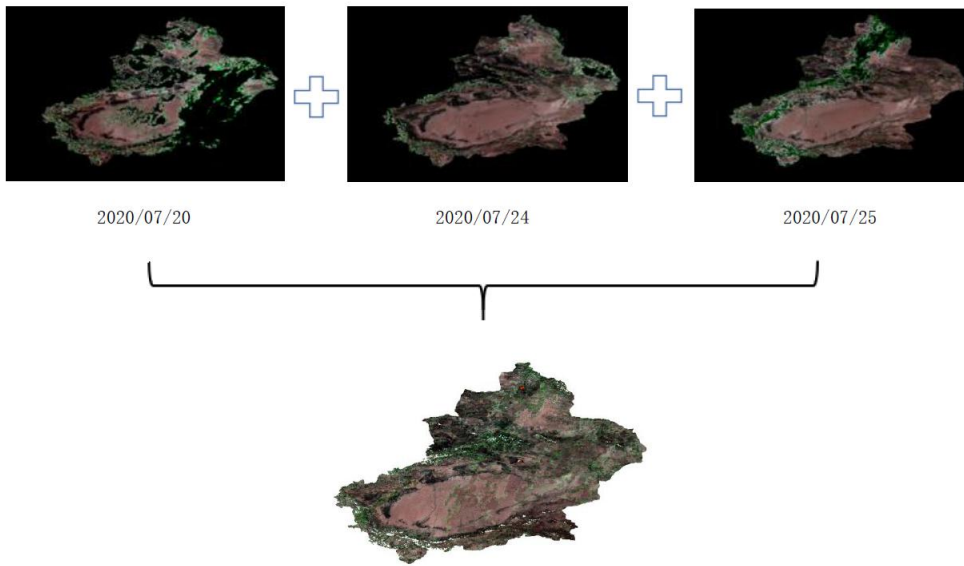


**Fig. 1** Pre-processing results

For the production part of the clear-sky product, the data processing consists of multiple geometric corrections, cropping, de-clouding (see Fig. 2), and overlay analysis (see Fig. 3) steps.



**Fig. 2** De-cloud processing

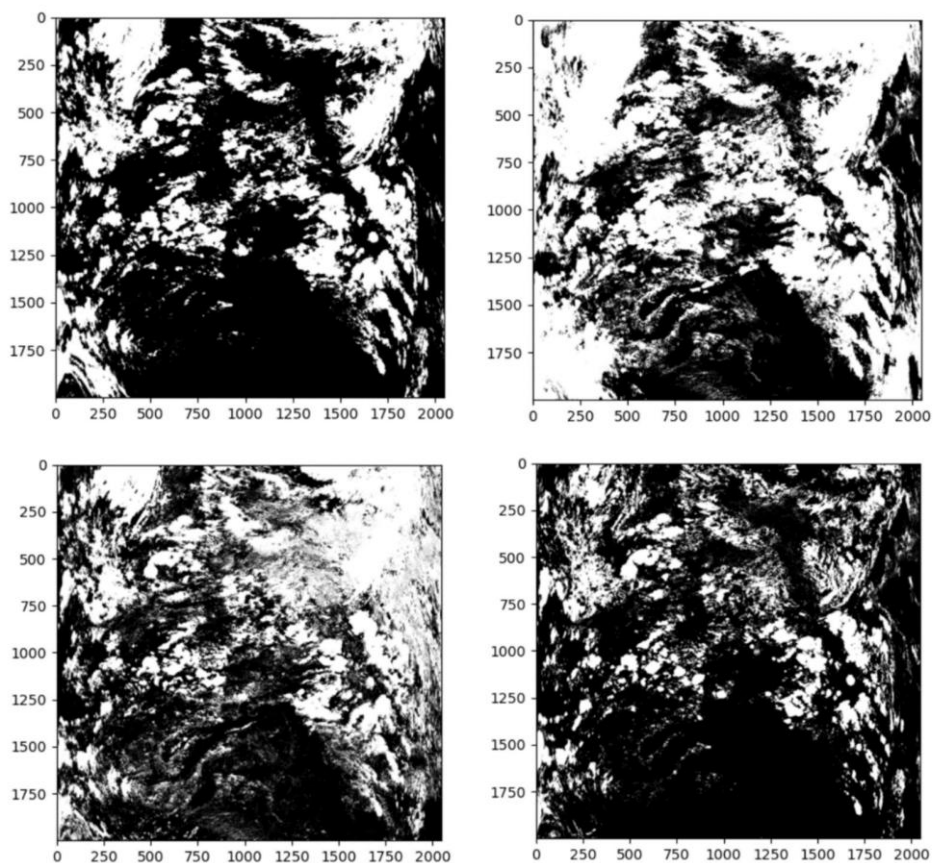


**Fig. 3** Spatial superposition

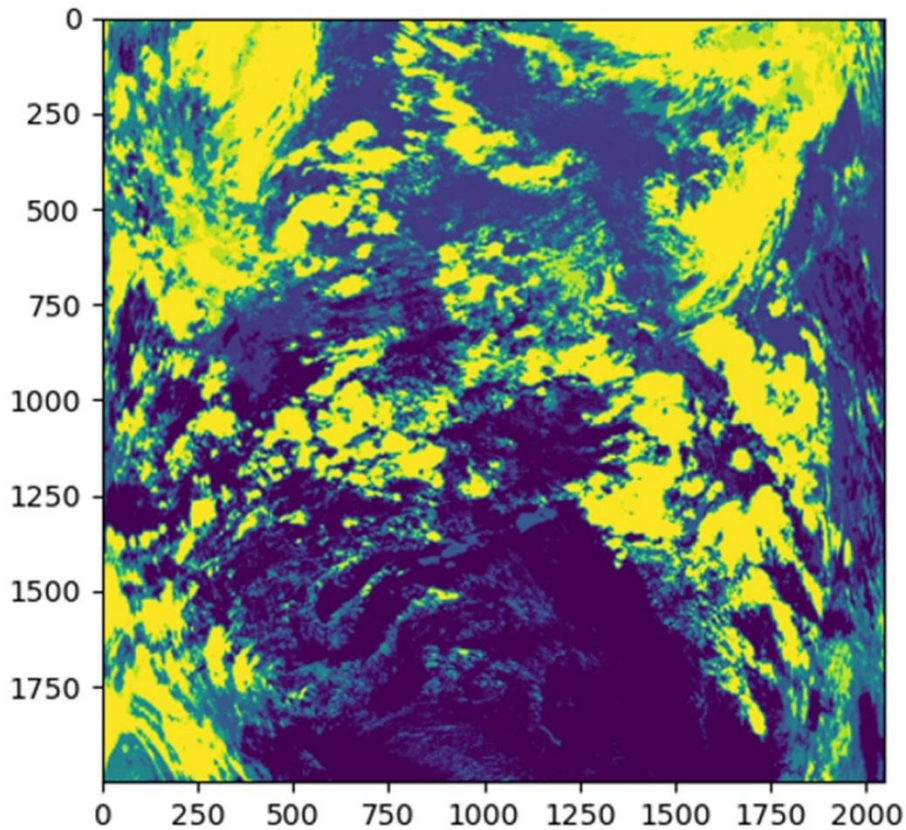
## 4. DISCUSSION AND ANALYSIS

### 4.1. Cloud detection results

As shown in Fig 4, different kinds of clouds are detected according to the threshold method, which contains cold clouds (top left), high clouds (top right), medium clouds (bottom left), and low clouds (bottom right):



**Fig. 4** Threshold method results

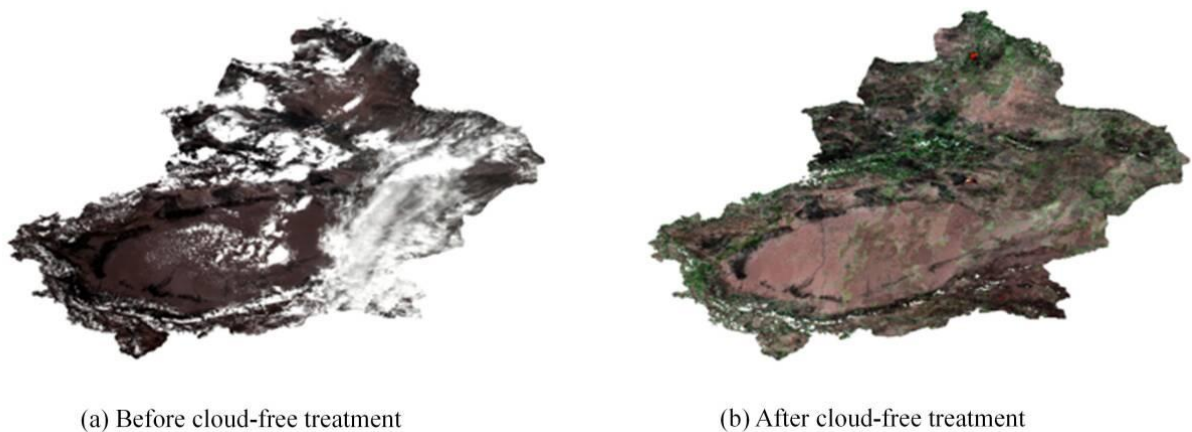


**Fig. 5** Cloud detection results

The cloud detection results obtained by the principle described in this paper (see Fig. 5) can be compared with the fast view of the Feng Yun satellite and the official cloud detection picture to find that the cloud detection success of this paper is still good, compared with the official cloud detection picture, the official cloud detection in the thin clouds is not good, while in contrast, the clouds detected in this paper are more accurate, and the thin clouds underneath can also be detected.

#### 4.2. Clear Sky Product Results

Fig. 6 shows the comparison of the results before and after processing of cloud-free images in Xinjiang in July:



**Fig. 6** Results before and after cloud-free treatment

Comparing the images before and after cloud-free processing, it can be found that the image obtained by the method of multi-temporal superposition analysis described in this paper removes the interference of clouds, and the terrain and landforms under the clouds can be seen more clearly to provide data support for the subsequent research.

## 5. CONCLUSION

In this paper, a total of two results have been obtained: a product containing a complete cloud detection algorithm and a clear-sky product produced using a multi-temporal image overlay method. The cloud detection product can obtain different kinds of clouds and their distribution locations to solve the problem of regional cloud distribution detection. Assuming that we have remote sensing images of the same area for a continuous period of time, we can realize the monitoring of cloud changes in the area, and at the same time, we can provide data reference for predicting the weather changes in the area; the clear sky product can solve the problem of cloud blockage, and we can obtain the information under the clouds that cannot be captured and display the information of the local landforms, rivers, and snow cover, and so on.

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