A cloud-removal method based on image fusion using local indexes

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Abstract

For optical images, cloud and cloud shadow is always a problem during image processing and interpretation. Landsat ETM+ images, as a kind of optical images, are affected by cloud too. On the other hand, microwave images such as ALOS PALSAR images, which depend on microwave, is not affected by cloud, thus they are cloud-free. The aim of this study is to develop a semi-automatic method for removing cloud and cloud shadow in Landsat ETM+ images based on fusion of Landsat ETM+ image and ALOS PALSAR image. The key point of this method is to develop a cloud and cloud shadow mask based on which Landsat ETM+ and ALOS PALSAR images can be fused. To accurately define cloud and cloud shadow area, we first approximately draw the area of interest containing cloud and cloud shadow manually, and the resulted AOI image greatly reduce the number of ground objects and the confusion between objects as well. By analysing the spectral and the grey value of the AOI image, we then define LCI (local cloud index), LSI (local shadow index), and LGI (local ground index) to accurately identify cloud and cloud shadow area in Landsat ETM+ images. Finally, a combination mask of cloud and cloud shadow is developed. Based on this mask, Landsat ETM+ image and ALOS PALSAR image are merged. The fused image is cloud free, at the same time; it keeps the spectral feature and the integrity of Landsat ETM+ image.

Keywords: Cloud-removal, AOI, Landsat ETM+, ALOS PALSAR, LCI, LSI, LGI

1 Introduction

The Landsat series have long provided users high resolution and multi-spectral remote sensing data for scientific research and earth observation for almost 40 years since its first launch. It's one of the most widely used satellites [1]. However, its imaging greatly depends on sunlight. Clouds are common features of images collected from many tropical, humid, mountainous, and coastal regions of the world [2]. The existence of cloud and cloud shadow will influence the processing and observation of ground objects. Therefore, during the pre-processing stage, both clouds and cloud shadows should be removed. Mainly, there are the following three kinds of methods for cloud-removal appearing in documents.

(1) Cloud-removal methods based on multi-spectral images. Tasselled cap transformation [3] is an often used method. Ritcher found that the fourth component of tasselled cap transformation is related to noise (cloud). It can be removed first, and then apply reverse tasselled cap transformation on the remaining components to produce a cloud-free image [4]. Tasselled cap transformation is highly dependent on sensors. It is only fit to MSS and TM (ETM) images. Besides, it will result in band information loss [5].

(2) Cloud-removal methods based on single image by using homomorphic filtering [6] or wavelet transformation [7]. Zhao and Zhu used homomorphic filtering method to remove thin clouds [8]. They first classified the cloud area, and then used interpolation method to restore the cloud area. Homomorphic filtering may acquire a good cloud removal result, but it can remove some useful information of the images. Moreover, once the area is covered by clouds and cloud shadows, we can hardly guess the true objects underneath the clouds and shadows through only one single image.

(3) Cloud-removal methods based on multi images. Use other images to complement the images to be processed. One method is time averaging. The idea is taking the pixel with smallest value from several images for the same area to produce a final image. Its precondition is that the shooting time of these images is near and the cloud area of each image is not overlapped, otherwise, the result is not ideal [9]. Another way is image fusion [10], which takes the corresponding part of a cloud-free image to replace the cloud and cloud shadow area of the image with clouds. Compared to multispectral and single image-based cloud removal methods, multi image-based cloud removal methods can achieve higher quality cloud-free images. On the other hand, as this method involves several images, the pre-processing of images is more complicated. Accurate registration and histogram matching is necessary.

When using multi images for cloud-removal, the key is to define cloud and cloud shadow area. In present, the

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general way is to define some kinds of cloud index(CI) to determine cloud, and then according to the shape of cloud and the distance between shadow and cloud to determine shadow area. Combination of Total Reflectance Radiance Index (TRRI) and Cloud-Soil Index (CSI) is used to define cloud by Nguyen Thanh Hoan when removing clouds of optical images [11]. However, various CIs proposed are defined globally, that's, they are based on the overall images. As we know, for a remote sensing image, there are a great number of ground objects. Due to the phenomenon of "same objects having different spectrum or same spectrum corresponding to different objects", CI is very difficult to be defined. Even though it is determined, some non-cloud area may be extracted, while some cloud area may be omitted. To alleviate this problem, based on human vision [12], we first approximately draws the area of interest (AOI) including cloud and cloud shadow so as to reduce the number of ground objects at a minimum level. The resulted AOI image is mainly composed of cloud, cloud shadow and ground area. Then we define Local Cloud Index (LCI), Local Cloud Shadow Index (LSI), and Local Ground Index (LGI) by analysing the spectral feature of the AOI image. As there are fewer objects appearing in the AOI image, there is less confusion between objects, and it is much easier to define LCI, LSI, and LGI. Finally, we use LCI, LSI, and LGI to accurately produce the combination mask of cloud and cloud shadow area, based on which Landsat ETM+ image with cloud and cloud-free ALOS PALSAR HH image are merged together to produce cloud-free Landsat ETM+ image. This method can help to make a series of free cloud multi-temporal images for change detection studies, land cover classification studies, environmental monitoring studies and so on.

2 Data

2.1 LANDSAT ETM+ DATA

In the present study, Landsat ETM+ image (Path 122, Row 39) dated on August 19, 2008 has been used (see table 1). Landsat ETM+ image data consist of eight spectral bands, with a spatial resolution of 30 meters for bands 1 to 5 and band 7. The resolution for band 6H/6L (thermal infrared) is 60 meters or 30 meters. The resolution for band 8 (panchromatic) is 15 meters. The approximate scene size is 170 km north-south by 183 km east-west (106 mi by 114 mi). Figure 1 shows the false colour composite image of band4, band3 and band2 of image1.

TABLE 1 Landsat ETM+ data specifications

Acquired time	Path/row	Landsat sensor	Cloud cover (%)	Used band
2008-08-19	122/39	ETM+(SLC-off)	5.35	1,2,3,4,5,6,7

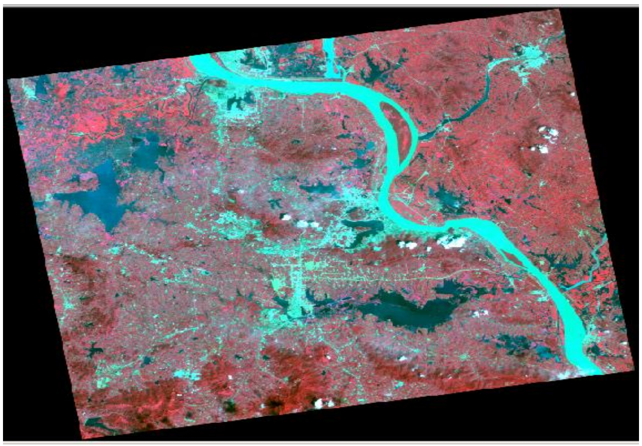


FIGURE 1 Landsat ETM+ 432 false colour composite image (20080819)

2.2 ALOS PALSAR DATA

ALOS PALSAR data is a Japanese Earth observation satellite carrying a cloud-piercing L-band radar, which is designed to acquire fully polarimetric images. The resolution is 12.5 meters. In the present study, the HH polarization image dated on July 3, 2008 is mainly used (table 2). As shown in figure 2, there is no cloud at all.

TABLE 2 ALOS PALSAR Data Specifications

Track/ Frame	Date	Mode (Polarization)	Incidence angle	orbit
454/590	2008-07-03	FBD(HH)	34.3	ascending

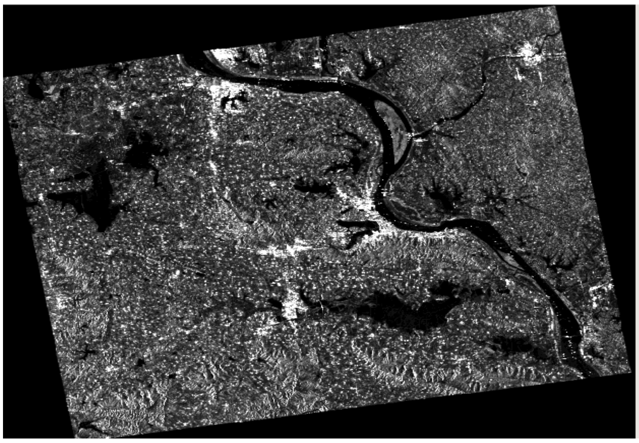


FIGURE 2 ALOS PALSAR HH image (20080703)

3 Methodologies

Figure 3 shows the whole processing framework.

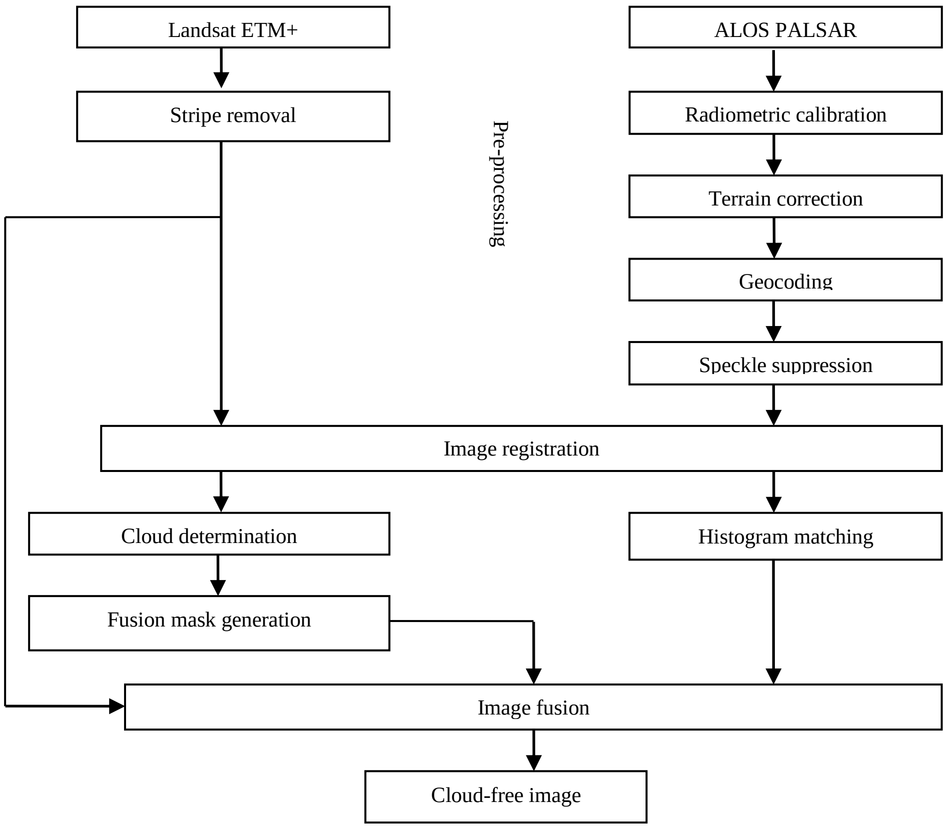


FIGURE 3 The whole processing framework of cloud removal

3.1 PREPROCESSING OF LANDSAT ETM+ DATA

The Landsat ETM+ data were acquired from http://datamirror.csdb.cn/ with stripes. For each band, the strip was successfully removed by multi image adaptive local regression method (RGF) provided on http://datamirror.csdb.cn/.

3.2 PREPROCESSING OF ALOS PALSAR DATA

The ALOS PALSAR images were provided by Alaska Satellite Facility at 1.5 level format. It was pre-processed through ASF MapReady 3.0 software package developed by the Engineering group at the Alaska Satellite Facility. Pre-processing included radiometric calibration using Sigma calibration coefficients, terrain correction based on DEM information, topographic normalization as well as geocoding to 30m pixel resolution (WGS84, UTM 50N).

An obvious disadvantage of ALOS PALSAR image is its speckles which greatly degrades image quality and influences land cover classification and interpretation. Here, a 3*3 local region adapter was adopted to reduce speckles of ALOS PALSAR images.

As Landsat ETM+ and ALOS PALSAR are taken from different sensors, and have different sizes, co-registration is necessary. ALOS PALSAR image was rectified to the coordinates of the Landsat ETM+ image using 12 ground control points (GCPs) defined from a topographic map of the study area. For the transformation, a second-order transformation and nearest-neighbour resampling approach were applied and the related root mean square error was 0.5 pixels.

3.3 FUSION MASK DETERMINATION

Generally one image often contains a great number of objects, due to the phenomenon of “same objects having different spectrum and same spectrum corresponding to different objects”; they tend to be confused with each other. As figure 4 shows, the spectrum of cloud shadow and lake can hardly be distinguished for band 1 to 7, and the spectrum of thin cloud and building can be easily confused as showing in figure 5. Therefore, when extracting a particular object based on a predefined rule, some parts not belonging to the object may be extracted, while some parts belonging to it may be omitted.

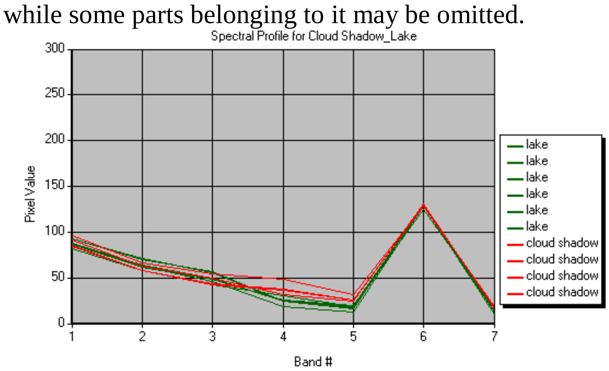


FIGURE 4 The spectral profile of cloud shadow and lake

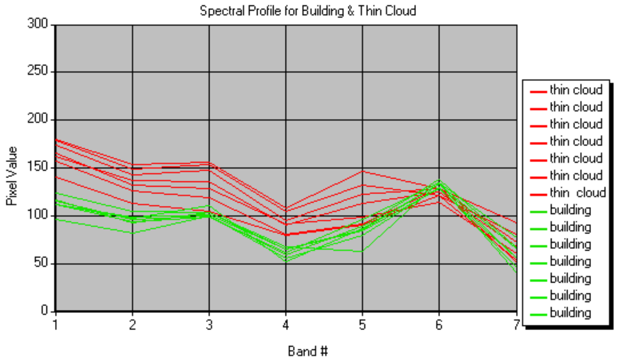


FIGURE 5 The spectral profile of building and thin cloud

In practical application, we often focus on one particular object instead of all objects. As shown in figure 1(432 false colour composite image), there are three objects relevant to cloud: (1) thick cloud, with white colour; (2) thin cloud, with light blue colour, easy to be confused with buildings; (3) cloud shadow, with black colour, easy to be confused with water(lake). We can first approximately separate the cloud area manually so that there are fewer objects involved and thus reducing the confusion at a great scale.

Figure 6 shows the processing flow.

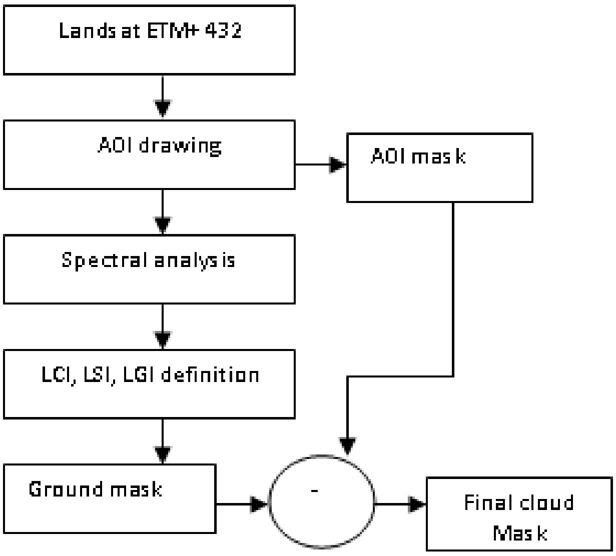


FIGURE 6 The processing flow of cloud and cloud shadow mask generation

(1) AOI drawing

In "Towards cognitive image fusion" [12], based on human visual system, dozens of observers are invited to draw the outline of ground objects. As human vision is sensitive to different objects, and has good ability of macro control over objects, we can first draw the approximate outline of cloud and cloud shadow area based on eyes' observation so as to greatly reduce the number of objects in the image. Here, we first draw a block of cloud area, as shown in figure 7. In figure 7, there are only three classes of objects: cloud (white thick cloud, light blue thin cloud), cloud shadow (dark black), and ground (red, in 432, it is vegetation).

(2) LCI, LGI, LSI definition

For each class, we take 10-12 samples from different parts to draw their spectral curves. Figure 8 gives the spectrum of thick cloud, thin cloud, cloud shadow, and ground. We found that for each class, the spectral curves of the sampled points are almost the same; for different classes, there is great difference between them. This feature can help us more easily to classify them.

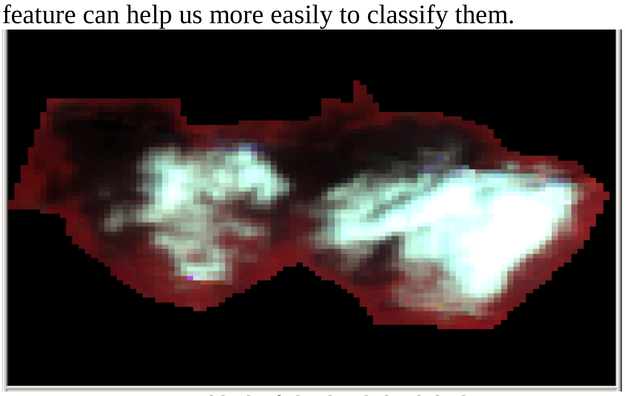


FIGURE 7 A block of cloud and cloud shadow area

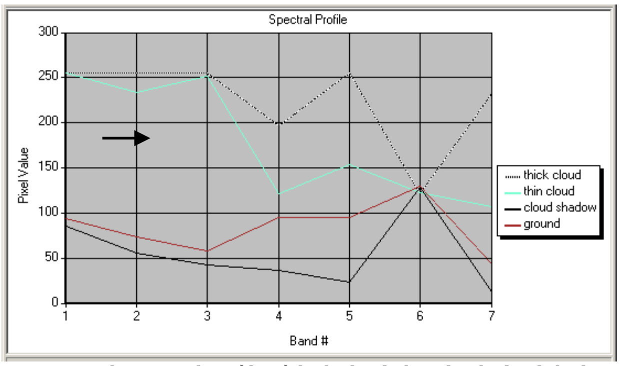


FIGURE 8 the spectral profile of thick cloud, thin cloud, cloud shadow and ground

Table 3 gives the grey value range of sampled pixels for each class.

TABLE 3 the grey value range of sampled pixels for each class

Class band	Thick cloud	Thin cloud	Cloud shadow	Ground
Band1	255-255	175-242	78-84	**87-110**
Band2	227-255	147-212	50-56	**65-83**
Band3	243-255	154-234	37-44	**47-72**
Band4	144-200	103-133	28-38	**64-89**
Band5	211-255	120-201	16-26	**61-101**
Band6	121-123	124-126	128-131	**129-132**
Band7	**73-136**	**73-136**	**9-16**	**28-50**

1) LCI definition

Based on the above spectral curves and the gray value range of sampled pixels, we concluded that the gray value of cloud(no matter thick cloud or thin cloud) in band1, band2, and band3 is much higher than that of cloud shadow and ground, thus the rule to extract cloud can be written as:

$$band1 > 130 \ And \ band2 > 100 \ And \ band3 > 100 . \quad (1)$$

2) LSI and LGI definition

The grey value of both cloud shadow and ground is almost less than 100 in band2, band3, band4, band5, and band7. However, from the spectral curve and gray range of sampled pixels, we can see the difference between cloud shadow and ground. The gray value of ground in each band is greater than that of cloud shadow, besides, for cloud shadow, the gray value displays such a relation: band5<band4<band3; while for ground, the relation is like this: band5>band4>band3. After dozens of times experiments, we built the following rules for cloud shadow and ground:

LSI for cloud shadow:

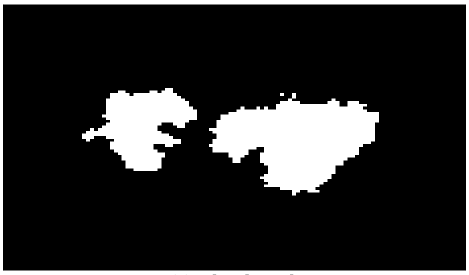
$$\frac{band\,5 - band\,3}{band\,5 + band\,3} < 0 \; (band\,2 < 100 \; And \; band\,3 < 100) \, , \quad (2)$$

LGI for Ground:

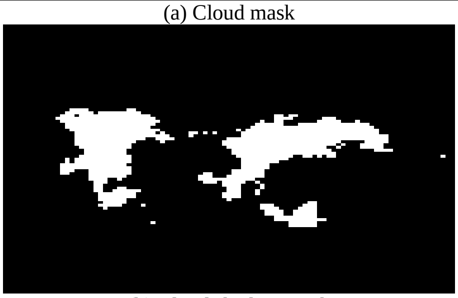
$$\frac{band\,5 - band\,3}{band\,5 + band\,3} > 0 \; (band\,2 < 110 \; And \; band\,3 < 110) \, . \quad (3)$$

(3) Cloud mask determination

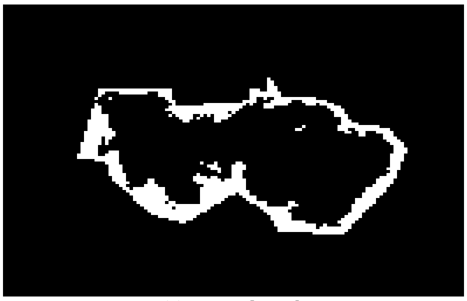
Based on the above LCI, LSI, and LGI, the following cloud mask (figure 9(a)), cloud shadow mask (figure 9(b)), and ground mask (figure 9(c)) are obtained. As considering, only the spectral feature of ground is much simpler, and it does not involve the transitional area between cloud and cloud shadow, we can first obtain the ground mask, and then use the AOI to subtract the ground mask to get the final mask. Doing this is less time-consuming, and the resulted final mask is intact, as shown in figure 9 (d) and (e).



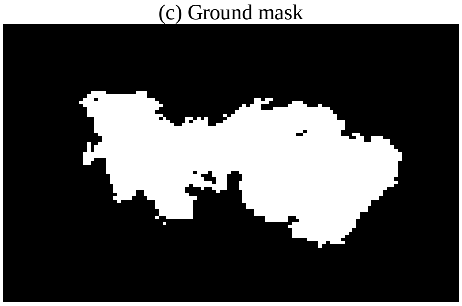
(a) Cloud mask



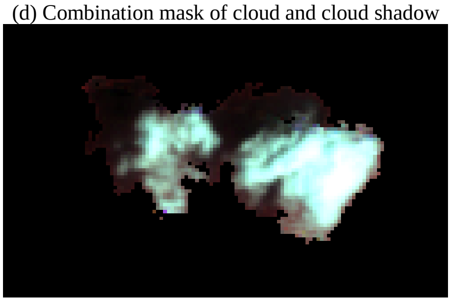
(b) Cloud shadow mask



(c) Ground mask



(d) Combination mask of cloud and cloud shadow



(e) Cloud and cloud shadow area extraction

FIGURE 9 Cloud, cloud shadow, ground, and combination mask

4 Cloud-free image generation

4.1 CLOUD AND CLOUD SHADOW MASK GENERATION

Based on the above method, we first draw out AOI to produce the approximate outline of cloud and cloud shadow. When drawing AOI, the shooting time, the direction of cloud shadow, and corresponding relation between the shape of cloud and cloud shadow should be taken into full consideration. At the same time, it would be better to use colour composite image instead of single band image because single band image is a kind of greyscale image, cloud, cloud shadow and other objects can be easily confused with each other. In this paper, the 432 false colour composite image is used, in which, the thick cloud (white colour), cloud shadow (dark black), and ground (dark red) can be clearly distinguished. Moreover, during this process, some image processing experts' advices should be adopted.

The combination mask of cloud and cloud shadow is shown as figure 10.

FIGURE 10 The combination mask of cloud and cloud shadow (cloud_mask)

4.2 CLOUD-FREE IMAGE GENERATION BASED ON IMAGE FUSION

Here, we take Landsat ETM+ band5 image (image1) and ALOS PALSAR HH image (image2) as an example. The former one has clouds, while the latter one has no cloud at all. Figure 11 shows the former one, and figure 2 shows the latter one. Both of them are well pre-processed for later image fusion.

As these two images are taken at different time and under different environment, there colour is not uniform. Before fusion, histogram matching is necessary. Based on the combination mask and the following rule, the above two images are merged. The final fused image is shown as figure 12. There is no cloud in the fused image at all.

$$F(x,y)=\begin{cases} image1(x,y) & cloud\_mask(x,y)=0 \\ image2(x,y) & cloud\_mask(x,y)=1 \end{cases}, \quad (4)$$

where F(x,y) refers to the final fused image.

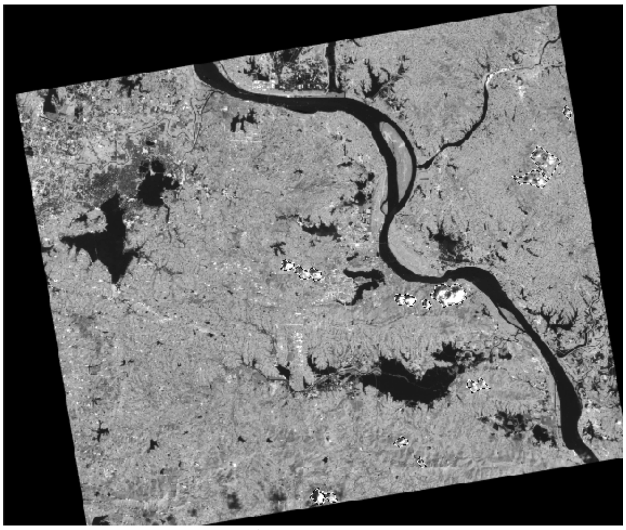


FIGURE 11 band5 of 2008-08-19 with clouds (image1)

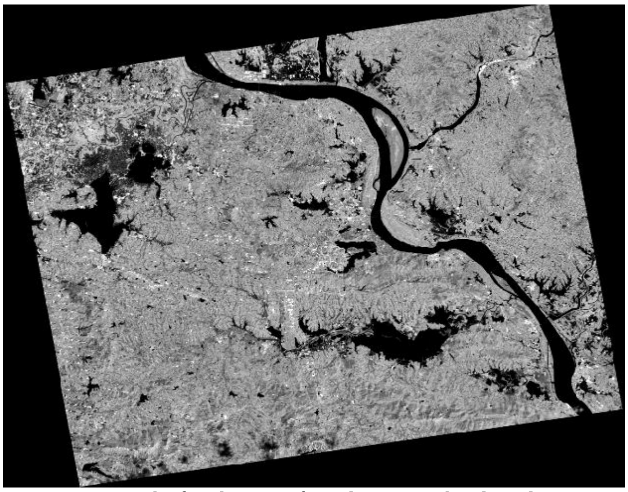


FIGURE 12 The fused image of Landsat ETM+ band5 and ALOS PALSAR HH

5 Conclusions

Due to the phenomenon of "same objects having different spectrum and same spectrum corresponding to different objects", if there are a great number of ground objects in an image, they tend to be confused with each other. When classifying land types, according to the actual situation, we can do it locally instead of globally so that the number of land types can be greatly reduced, thus decreasing confusion between different land types.

For cloud-removal, the focus is cloud and cloud shadow area classification, therefore, taking human vision into consideration, we first approximately drew the interest area related to cloud to reduce the number of ground objects at a minimum scale. The AOI mainly contains three land type classes: cloud, cloud shadow, and ground. Based on the AOI, by analysing the spectral feature and grey value of these three classes, we then defined LCI, LSI, and LGI, which can correctly extract cloud, cloud shadow and ground area without confusion or omission.

When generating the combination mask of cloud and cloud shadow, we first obtained the ground mask, and then used the AOI mask to subtract the ground mask to produce the final combination mask of cloud and cloud shadow. This method is simple and not time consuming, and since the transitional zone between cloud and cloud shadow is not involved in the processing, there are no holes left in the final mask.

For image fusion, a very important point is not to destroy the original images, but to combine the good points of the original images. Landsat ETM+ images can better reflect land cover types, but they are affected by whether and clouds, while ALOS PALSAR images are not affected by whether and clouds, however, they have speckles, and are not good for interpretation. Therefore, we can use ALOS PALSAR images to complement Landsat ETM+ images to remove the cloud and cloud shadow area of Landsat ETM+ images, and at the same time retain the multispectral feature and the integrity of

Landsat ETM+ at a maximum extent.

After pre-processing of cloud-free ALOS PALSAR HH image, we merged Landsat ETM+ band5 image with ALOS PALSAR HH image, and got a cloud-free image to a good effect.

The method proposed in this paper is suitable for removing closely tied big clouds but not scattered small clouds. Removing scattered small clouds would be more time-consuming.

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