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Water Body Extraction Research Based on S Band SAR Satellite of HJ-1-C

Liu Liang[1,2,3], Zhang Wei[2,3], Jiang Xiaoguang[1], Li Xianbin[4], Huo Hongyuan[5], and Zhang Xuehua[2,3]

[1]University of Chinese Academy of Sciences, Beijing, China
[2]National Disaster Reduction Center of China, MCA, Beijing, China
[3]Satellite Application Center for Disaster Reduction, MCA, Beijing, China
[4]Institute of Optics and Electronics, Chinese Academy of Sciences, Chengdu, China
[5]College of Urban and Environmental Sciences, Tianjin Normal University, Tianjin, China

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Abstract The C Satellite of Environment and Disaster Monitoring and Forecasting Small Satellite Constellation (HJ-1-C) was launched successfully on 19 November 2012. It is the first Synthetic Aperture Radar (SAR) satellite for civil use in China and the only S-band SAR satellite on orbit in the world at present. One of its applications is to extract water body, which can be used for assessing the severity of floods or drought. As the user of the S Band SAR Satellite of HJ-1-C, the National Disaster Reduction Center of China (NDRCC) has the responsibility to assess its water body extraction capability and precision. This study validates the water extraction precision using the HJ-1-C by means of comparison with water body delineation using optical images of the HJ-1-B and ZY-3. The result shows that, the C Satellite has a prominent advantage in extracting details of water bodies as compared with the HJ-1-A and HJ-1-B.
Keywords *HJ-1; SAR; S-Band; Water Body*

1. Introduction

Environment and Disaster Monitoring and Forecasting Small Satellite Constellation (HJ-1) is the first small satellite constellation that is specifically used on environment and disaster monitoring and forecasting, and the first civilian earth observation system with multiple satellites and multiple payloads in China. The “2+1” constellation consists of two small optical satellites (HJ-1-A, HJ-1-B) and one small radar satellite (HJ-1-C) [1]. HJ-1-A carries optical payloads and HJ-1-B carries multi-spectral camera (CCD), super-spectral camera (HSI), and infrared camera (IRS). After more than seven years’ operation, HJ-1-A and HJ-1-B have become irreplaceable data resources in the Chinese comprehensive disaster prevention and reduction operation system.

On 19 November 2012, the HJ-1-C was launched successfully in Taiyuan (Performance index as shown in Table 1). HJ-1-C is the first SAR satellite for civil use in China and currently the only on-orbit operation S-band SAR satellite in the world [2, 3]. At present, HJ-1-A, HJ-1-B, and HJ-1-C, the three state-owned satellites that are specialized in Chinese disaster management work, stably operate on-orbit. This marks the establishment of environmental and disaster reduction satellite "2+1" constellation, which continuously provides remotely, sensed data in these fields.

Table 1: *Performance Index of HJ-1-C*

Index	Performance
Polarization Mode	VV Polarization
Frequency	S-band
Spatial Resolution/Width	Scan：20 m/100 km Strip：5 m/40 km
Radiation Resolution	3 dB
Observation Mode	Right side looking. Visual Angle: 25°–47°

Flood disaster is one of the most important natural disasters in China. Flooding and waterlogging are the two main types of flood disasters. Flooding is caused by excessive water volume in rivers, lakes and coastal areas and water level rise and flashfloods due to heavy rains, snow and ice melting, dam bursts, storm surges, and other reasons. Waterlogging is due to excessive water and insufficient drainage, which is caused by heavy rains, rainstorms, or long-term concentrated water accumulation [4].

In order to assess the water monitoring capability of HJ-1-C, the Poyang Lake region in China is chosen as the study area in this study [5]. The Poyang Lake region is a typical flood-afflicted area. The lake is in the northern part of Jiangxi Province, on the southern bank of the middle and lower reaches of the Yangtze River. The lake is connected with the Ganjiang River, Fu River, Xinjiang River, Rao River, and Xiu River, receiving inflow from these five rivers and discharge water to the Yangtze River.

2. Method and Evaluation Standard of Water Extraction Accuracy Analysis

2.1. Water Extraction and Accuracy Analysis Method

The flow chart of the water extraction accuracy test is shown in Figure 1.

The specific method and process are as follows:

2.1.1. Image Processing

- **Speckle Noise Suppression**

Use speckle noise suppression algorithm based on the image features to suppress speckle noises in the images and improve the identification of targets.

- **Geometric Correction and Registration**

Use 1:50,000 topographic map, ground control points (GCP), or the same type of remote sensing data after geometric correction to correct geometric precision of HJ-1-C. GCP of each image should be uniformly distributed. Re-sample images of strip mode or scan mode to specify projection, directing and resolution.

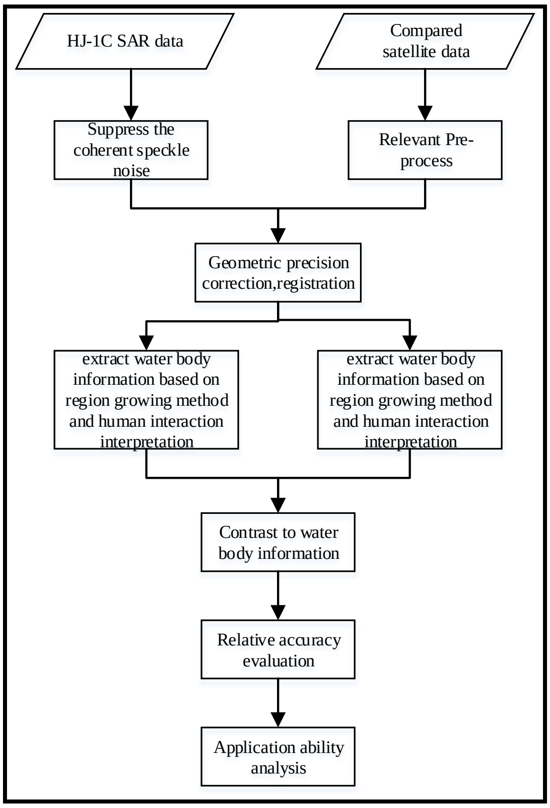

Figure 1: *Flow Chart of Water Extraction Accuracy Analysis*

2.1.2. Extraction of Water Body

Interpreting the data and extracting water bodies based on the region-growing method and threshold value method or interactive interpretation

2.1.3. Accuracy Analysis and Result Evaluation

Select monitoring results of HJ-1-B CCD image and ZY-3 optical images to relative precision analysis and result evaluation according to the situation actual damage, satellite transit and data quality. The overlapping area of water bodies extracted through the test data and in the reference data is drawn. Through comparison analysis, the relative precision of water extraction using HJ-1-C is evaluated.

2.1.4. Application Capability Analysis

Applicability of flood water extraction using HJ-1-C data for disaster monitoring and assessment is analyzed in the final step.

2.2. Evaluation Standard

Integrity rate, accuracy rate, false rate and missing rate are selected as evaluation standard in this study.

2.2.1. Test Data

(A) Scan Mode

Parameters of the test data of HJ-1-C in scan mode is shown in Table 2. The data used for precision validation of the extraction result is HJ-1-B CCD optical image with 30 m spatial resolution, which were obtained on 8 March 8 2013, when the most recent cloud-free HJ-1-C data for the study area were acquired.

Table 2: *Test Data Parameters, HJ-1-C (Scan Mode)*

Parameter Type	Value
Imaging time	2013-03-11 18:12:18
Imaging mode	Scan
Incidence angle (degrees)	34.0616,36.1216,37.8016,39.3716
Orbital direction	Rising Orbital
Equivalent number	2.081
Radiation resolution(dB)	3.879
Dynamic range (dB)	24.984

(B) Strip Mode

Parameters of the test data of HJ-1-C (strip mode) is shown in Table 3. The data used for precision validation of the extraction result is ZY-3 optical image with 5.8 m spatial resolution, which were obtained on 18 January 2013, when the most recent cloud-free HJ-1-C data for the study area were acquired.

Table 3: *Test Data Parameters, HJ-1-C (Strip Mode)*

Parameter Type	Value
Imaging time	2013-01-22 06:15:46
Imaging mode	Strip
Incidence angle (degrees)	37.2712
Orbital direction	Falling Orbital
Equivalent number	0.768
Radiation resolution(dB)	2.733
Dynamic range (dB)	108.165

2.2.2. Test Results

(A) Scan Mode

Remote sensing monitoring of the HJ-1 constellation for the Poyang Lake test area (scan mode) is shown in Figure 2. Comparison of the SAR and CCD extraction results and analysis are shown in Figure 3. Statistics of water extraction result is shown in Table 4. Error result is shown in Table 5.

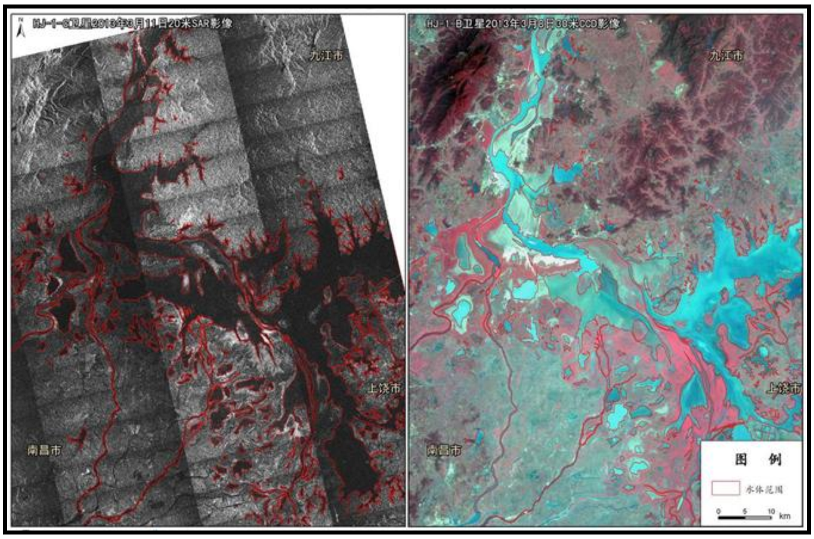

Figure 2: *Remote Sensing Monitoring of Water Bodies in the Poyang Lake Area – Scan Mode*
(Left: Water Body Extraction Result of HJ-1-C SAR Image; Right: Water Body Extraction Result of False Color Composite Image of HJ-1-B CCD with Red: Band4, Green: Band3, Blue: Band2)

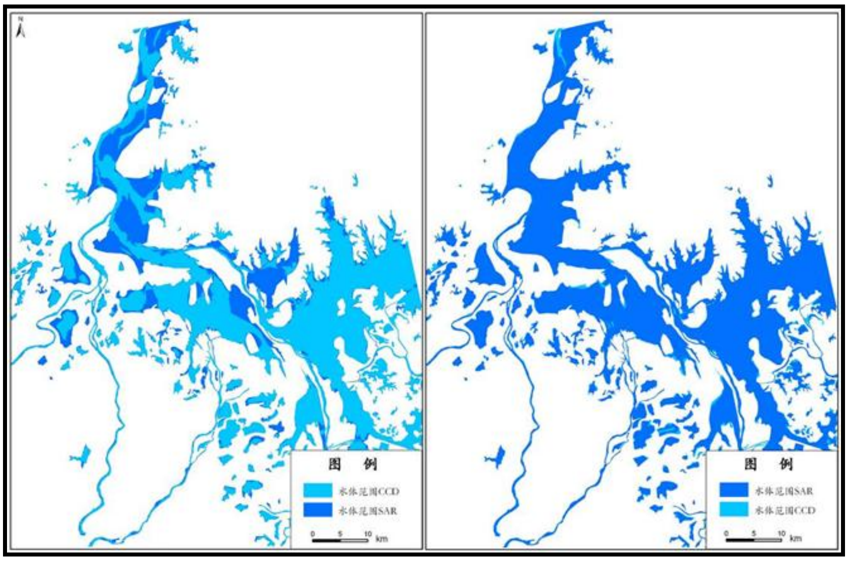

Figure 3: *Water Range of the Poyang Lake Area – Scan Mode*

Table 4: *Water Extraction Result Statistical Table – Scan Mode (Unit: km^2)*

	HJ-1-C 2013-03-11	HJ-1-B 2013-03-08
Extracted water record (number)	218	306
Water area (km^2)	1591.79	1286.88
Minimum effective water area (m^2)	14909	269
Accurate extracted area (km^2)	1150.54	

Table 5: *Error Table – Scan Mode*

Integrity Rate	Accuracy Rate	False Rate	Missing Rate
=1150.54/1286.88 =89.41%	=1150.54/1591.79 =72.28%	=1-72.28% =27.72%	=1-89.41% =10.59%

The acquisition time of the HJ-1-C SAR data was three days after the HJ-1-B CCD. Assuming the change of water scope in the test area over these three days was negligible, the water body extraction result of the HJ-1-B CCD was used as reference for comparison/validation. Through contrasting the extracted water bodies from the HJ-1-C SAR and HJ-1-B CCD, two types of errors in the result of the HJ-1-C SAR are identified.

The first type of error of extraction is false information, which indicated no water in the water body extraction result of CCD but water in the extraction result of SAR. In the SAR image, these areas are the flood plains or the margin of the water bodies without very clear water and land boundary. These two types of areas both have higher soil moisture, which are dark in the SAR image, so they are falsely interpreted as water area (Figure 4).

The second type of error of extraction is missing information, which indicated water in the extraction result of CCD, but no water in the extraction result of SAR. In the CCD image, these areas are shows as narrow river channels, small water areas, or the area of poor image SNR are regarded as water area, which cannot be identified by image intensity contrast difference of beam adjacent area of scan mode image. These areas are misinterpreted in the SAR image as no water (Figure 5). So it can be inferred that in this test area, under the data quality of the test image (HJ-1-C SAR of 20 m spatial resolution with scan mode) and by using the region-growing method, threshold value method, or interactive interpretation, the extracted water area is slightly smaller than the HJ-1 constellation CCD image of 30 m spatial resolution.

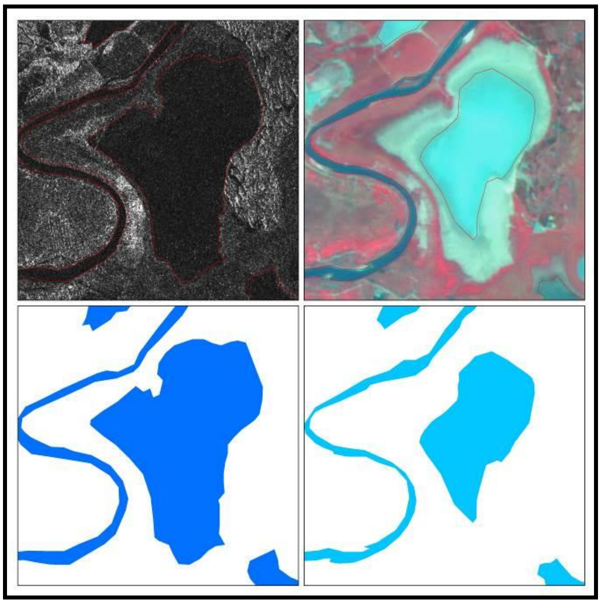

Figure 4: *Extraction Error: False Information – Scan Mode*

(Upper Left: SAR Image; Upper Right: Optical Image; Lower Left: Extraction Result of SAR Image; Lower Right: Extraction Result of Optical Image)

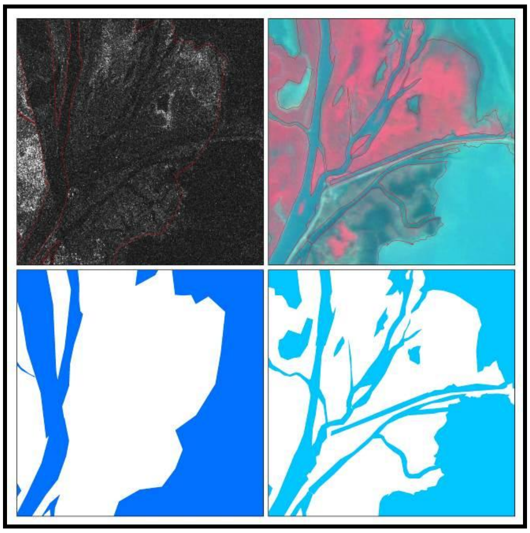

Figure 5: *Extraction Error: Missing Information – Scan Mode*
(Upper Left: SAR Image; Upper Right: Optical Image; Lower Left: Extraction Result of SAR Image; Lower Right: Extract Result of Optical Image)

(B) Strip Mode

Remote sensing monitoring of HJ-1 constellation for the Poyang Lake test area (strip mode) is shown in Figure 6. We compared and analyzed the extraction results of the SAR and multispectral image. Contrast analysis of the extraction results of water range is shown in Figure 7. Statistics of water extraction result is shown in Table 6. Error result is shown in Table 7.

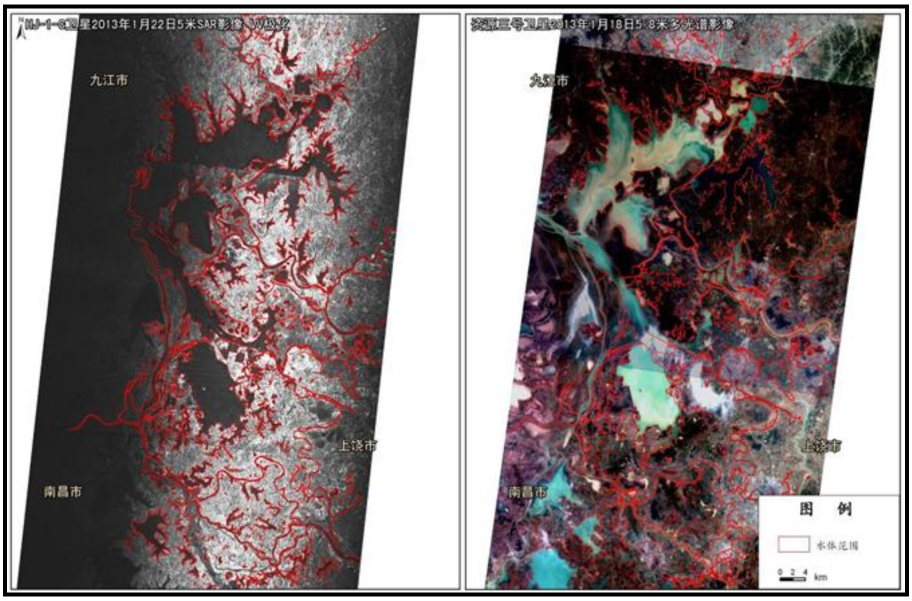

Figure 6: *Remote Sensing Monitoring of Water Bodies in the Poyang Lake Area – Strip Mode*
(Left: Water Body Extraction Result of HJ-1-C SAR Image; Right: Water Body Extraction Result of True Color Composite Image of ZY-3 with Red: Band3, Green: Band2, Blue: Band1)

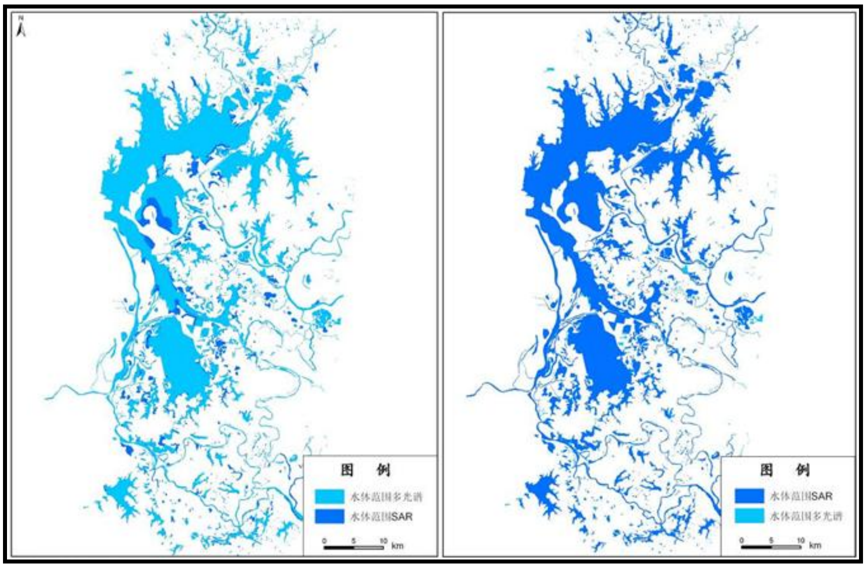

Figure 7: *Water Range of the Poyang Lake Area – Strip Mode*

Table 6: *Water Extraction Result Statistical Table – Strip Mode (Unit: km^2)*

	HJ-1-C 2013-01-22	ZY-3 2013-01-18
Extracted water record (number)	1077	1645
Water area (km^2)	879.29	779.40
Minimum effective water area(m^2)	734	296
Accurate extracted area(km^2)	746.20	

Table 7: *Error Table – Strip Mode*

Integrity Rate	Accuracy Rate	False Rate	Missing Rate
=746.20/779.40 =95.74%	=746.20/879.29 =84.86%	=1-84.86% =15.14%	=1-95.74% =4.26%

The acquisition time of the HJ-1-C SAR was four days later than the optical image from ZY-3. Disregarding the change of water scope in the test area over these four days and misinterpretation of water information because of cloud cover for small areas in the ZY-3 optical image, the extraction result of ZY-3 optical image was considered more accurate. Through the comparison of water body extraction results of HJ-1-C SAR and ZY-3 optical images, two types of errors in the result of HJ-1-C SAR are identified.

The first type is false information, which indicated no water in the extraction result of the multispectral image, but water in the extraction result of the SAR. In the SAR image, these areas are flood plains or the margin of water bodies without very clear water and land boundary. These areas both have higher soil moisture, which are dark in the SAR image, so they are falsely interpreted as water area (Figure 8).

The second type of error is missing information, which indicates water in the extracting results of multi-spectral image, but indicates no-water in the extracting results of SAR. In multi-spectral image, these area shows as the thin river or small water area, which are missing to be interpreted in SAR image (Figure 9). So it can be inferred, in this test area, under the data quality of this image, by using region-growing method and threshold value method or interactive interpretation, according to water information extracting, the information extraction fine degree of HJ-1-C SAR of 5m spatial resolution of strip mode is slightly less than ZY-3 CCD multi-spectral image of 5.8m spatial resolution.

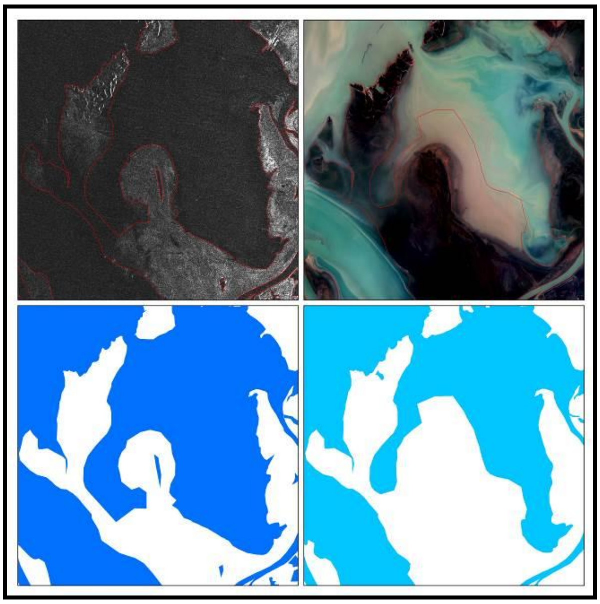

Figure 8: *Extraction Error: False Information – Strip Mode*
(Upper Left: SAR Image; Upper Right: Optical Image; Lower Left: Extraction Result of SAR Image; Lower Right: Extraction Result of Optical Image)

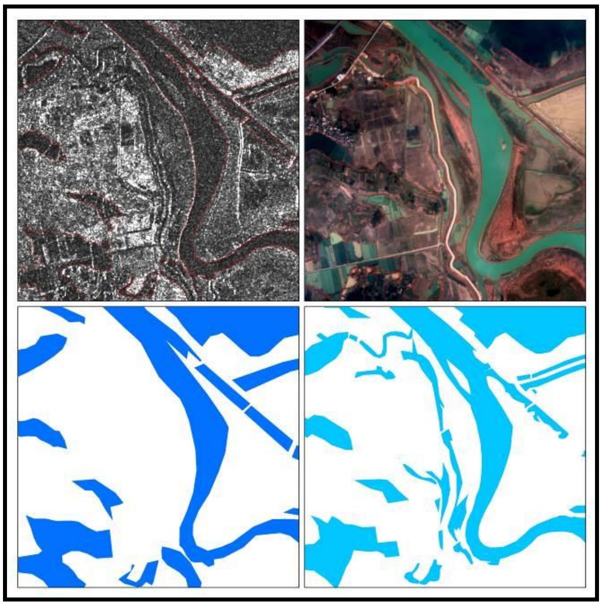

Figure 9: *Extraction Error: Missing Information – Strip Mode*
(Upper Left: SAR Image; Upper Right: Optical Image; Lower Left: Extraction Result of SAR Image; Lower Right: Extract Result of Optical Image)

3. Conclusions and Prospects

In this study, the scan mode and strip mode of HJ-1-C SAR data were both selected to extract water body range in the Poyang Lake area. A HJ-1-B CCD image and a ZY-3 multispectral image were selected to validate the monitoring result of HJ-1-C. The results indicate that the HJ-1-C satellite generally respond well to water bodies, which is shown as dark regions. It can be effectively used for the delineation of water distribution, and can accurately distinguish low soil humidity areas and floodplains, so it has good application potentials in monitoring flood inundated areas. At the same time, areas of relatively high soil humidity or flat floodplains that show the same spectral characteristics as water bodies can easily lead to false judgment, resulting in larger water area than is the actual case. Information extraction from image of the strip mode presents the flooding situation much better than the scan mode.

In the future, we will continue to carry out research in the following areas to further explore the application potential of the S-band SAR satellite in disaster reduction: (1) Field validation and joint interpretation of multiple data sources to examine the false interpretation areas in order to increase the precision of water range extraction; (2) Calculation of soil humidity through analyzing the backscatter coefficient and inference of water area post-flood disaster to fully take advantage of the SAR for disaster reduction and relief applications.

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