Data Processing, Information Extraction and Object Recognition based on SAR Imagery

– Studies on GF-3 Satellite

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Outline

1、Introduction of GF-3 and Our Tasks

2、GF-3 data processing and analysis

3、Applications of GF-3 products

4、Summary

1.1 GF-3 Satellite

- ☐ **GF-3 Imaging mode**
  - ✓ **Sliding Spotlight**
  - ✓ **Strip (Dual-beam)**
  - ✓ **Fully polarized strip**
  - ✓ **ScanSAR**
- ☐ **Polarimetric :**
  - ✓ **Polarization Isolation : ≥35 dB**
  - ✓ **amplitude Unbalance : ≤ ±0.5dB**
  - ✓ **phase Unbalance : ≤ ±10°**
- ☐ **Radiometric accuracy : 2.0dB**

Working Mode of GF-3 Satellite

Index	Imaging mode	Resolution（m）			Imaging Swath（km）		Incidence angle（°）	look Number A×R	Polarization mode
		Nominal	Azimuth	Range	Nominal	Real			
1	Sliding Spotlight	1	1.0~1.5	0.9~2.5	10×10	10×10	20~50	1×1	single
2	Ultra-fine strip Azimuth double beam	3	3	2.5~5	30	30	20~50	1×1	single
3	Fine strip 1	5	5	4~6	50	50	19~50	1×1	Dual
4	Fine strip 2	10	10	8~12	100	95~110	19~50	1×2	Dual
5	Standard strip	25	25	15~30	130	95~150	17~50	3×2	Dual
6	Narrow Scan 1	50	50~60	30~60	300	300	17~50	2×3	Dual
7	Narrow Scan 2	100	100	50~110	500	500	17~50	2×4	Dual
8	**Fully polarized strip 1**	**8**	**8**	**6~9**	**30**	**20~35**	**20~41**	**1×1**	**Full**
9	**Fully polarized strip 2**	**25**	**25**	**15~30**	**40**	**35~50**	**20~38**	**3×2**	**Full**
10	**Wave imaging mode**	**10**	**10**	**8~12**	**5×5**	**5×5**	**20~41**	**1×2**	**Full**
11	Global observing mode	500	500	350~700	650	650	17~53	4×2	Dual
12	Extended Low incidence angle	25	25	15~30	130	120~150	10~20	3×2	Dual
	High incidence angle	25	25	20~30	80	70~90	50~60	3×2	Dual

1.2 Tasks of Our Laboratory

- Tasks from China Centre For Resources Satellite Data and Application
    - GF-3 Satellite product generation software
    - GF-3 Satellite echo simulation software
    - GF-3 Satellite calibration software

- Research projects from
    - GF-3 Satellite Polarization Data Processing and Analysis（Leader）
    - Ground parameter inversion using GF-3 Data（participant）
    - Quality enhancing of GF-3 Satellite ocean images （participant ）

Most of our work focuses on the raw data processing or the post-processing, which aims to provide high quality images for further applications

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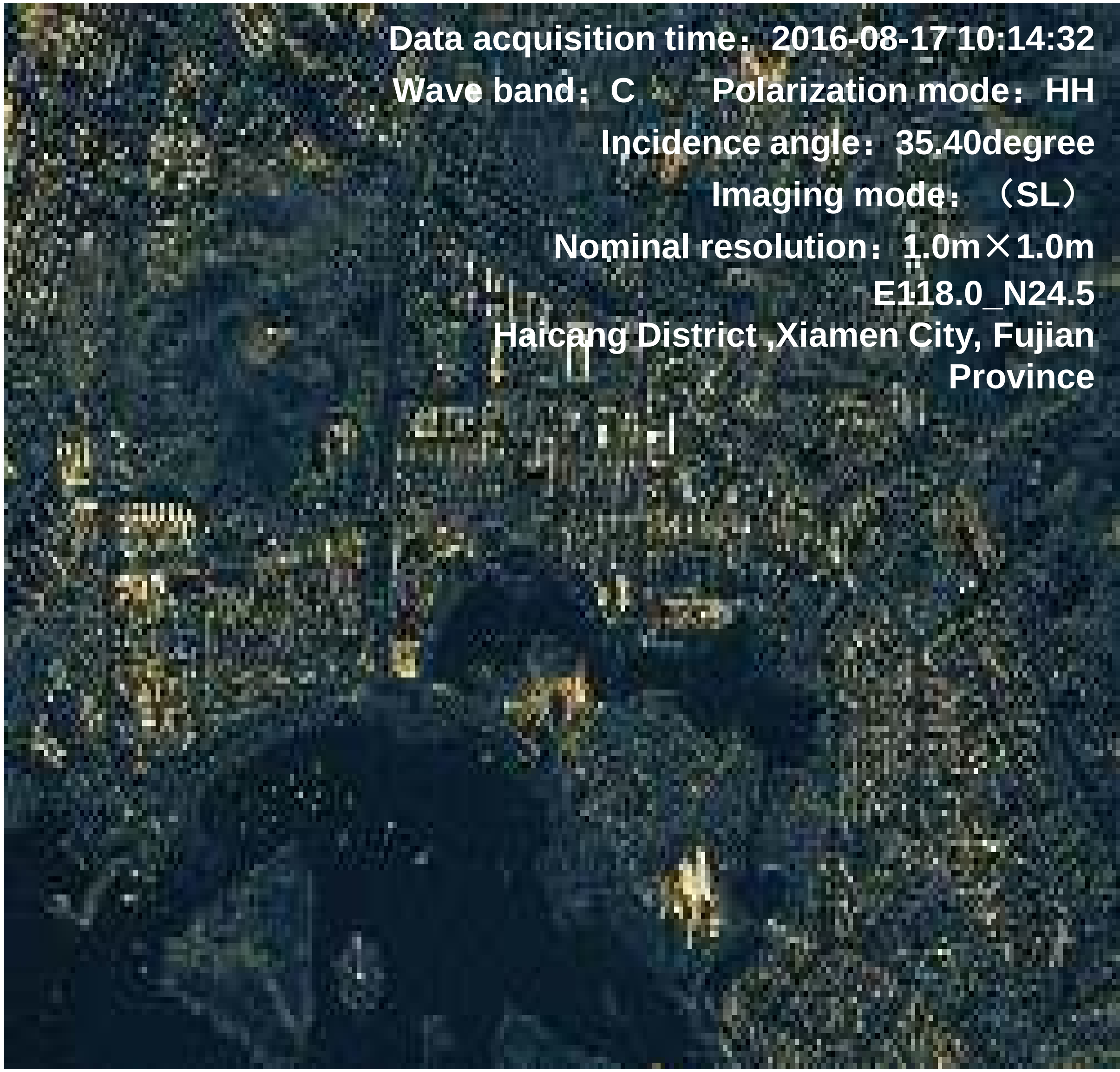
2.1 Sliding spotlight mode

- There are only a few orders of this mode (totally 127 scenes, about 0.243% of all orders）
- Radiometric quality of this mode, which we observed, is quite good

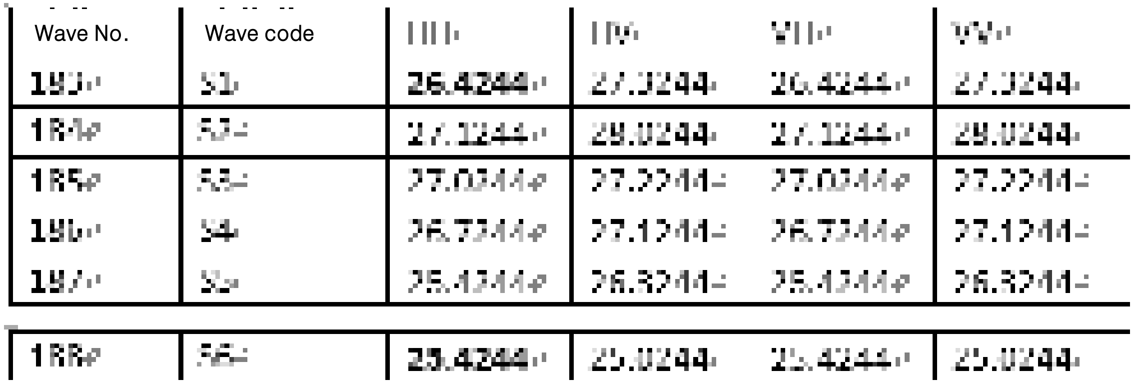


Data acquisition time：2016-08-17 10:14:32
Wave band：C　Polarization mode：HH
Incidence angle：35.40degree
Imaging mode：（SL）
Nominal resolution：1.0m×1.0m
E118.0_N24.5
Haicang District ,Xiamen City, Fujian Province

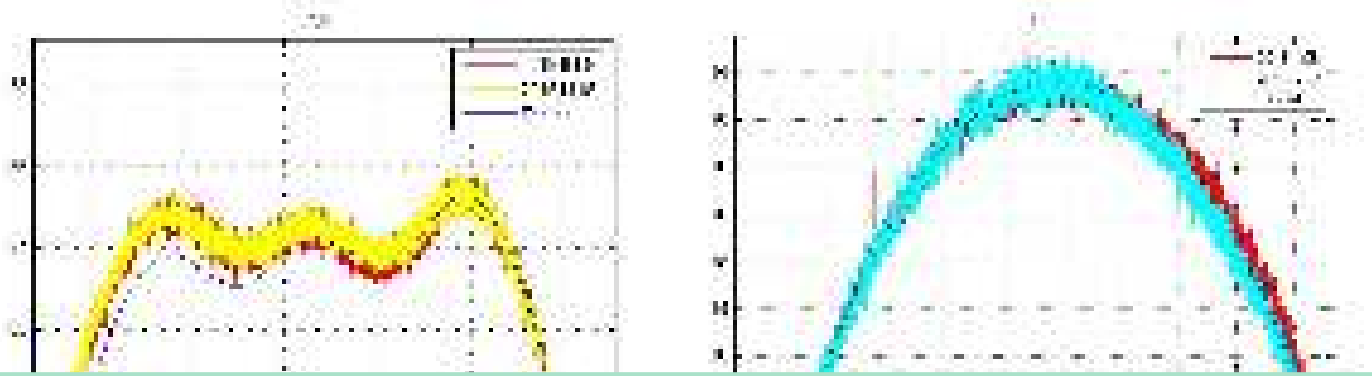
2.2 Standard strip mode

- **This mode is frequently used**

Calibration constant



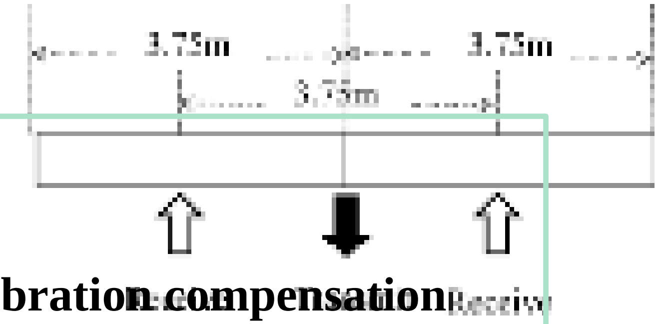
Wave No.	Wave code	HH	HV	VH	VV
183	S1	26.4244	27.3244	26.4244	27.3244
184	S2	27.1244	28.0244	27.1244	28.0244
185	S3	27.0244	27.2244	27.0244	27.2244
186	S4	26.7244	27.1244	26.7244	27.1244
187	S5	25.4244	26.3244	25.4244	26.3244
188	S6	25.4244	25.0244	25.4244	25.0244



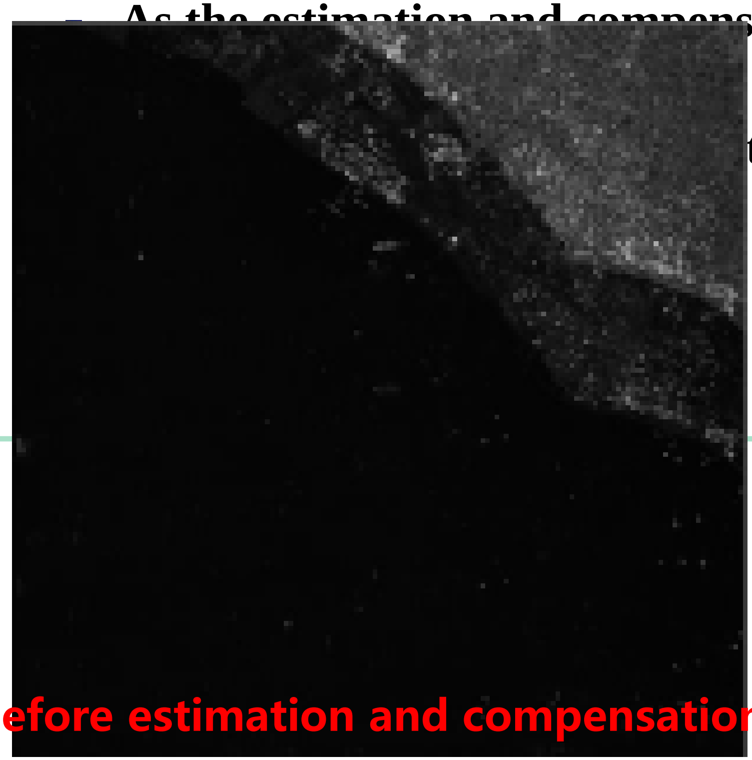
1.The system is stable, but there is a deviation between the ground test antenna pattern and the actual antenna pattern.
2."Rainforest Estimation" correction produced a better image.

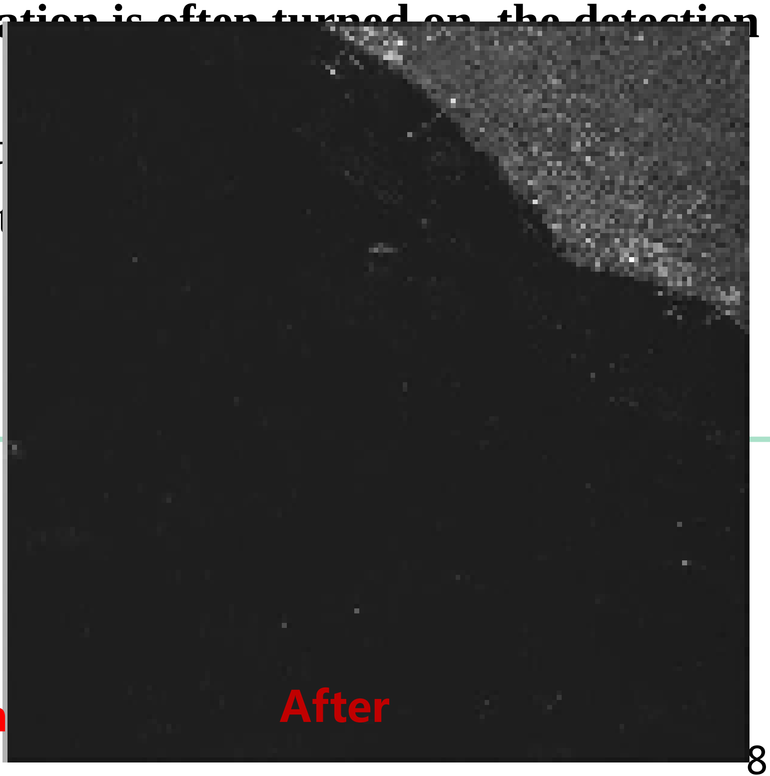
2.3 Ultra-fine strip (dual-beam)

- **Difficulty：Dual channel error compensation**



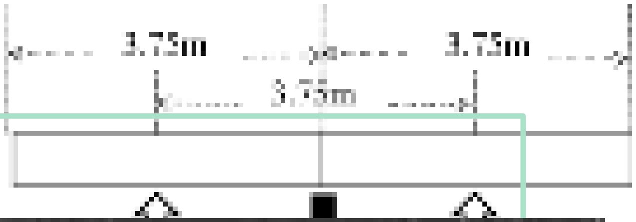
- **Processing and results**
  - **External calibration is not done**
  - **There is residual error after the internal calibration compensation**
  - **As the estimation and compensation is often turned on, the detection**


Before estimation and compensation

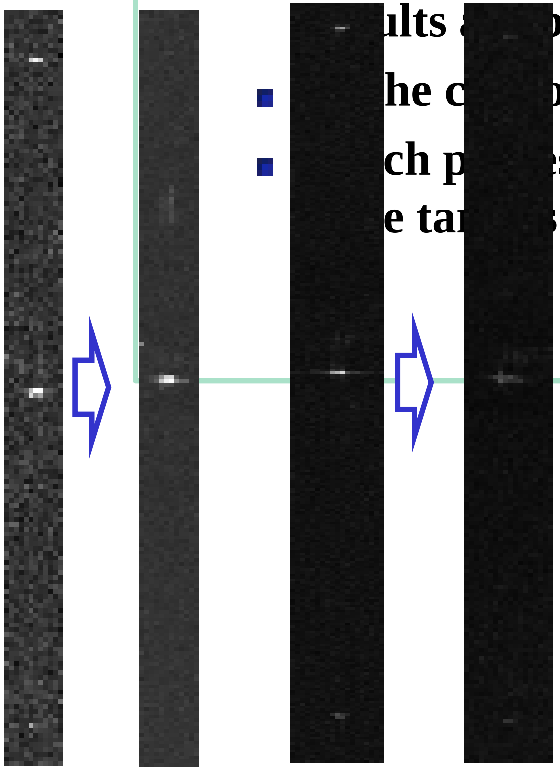

After

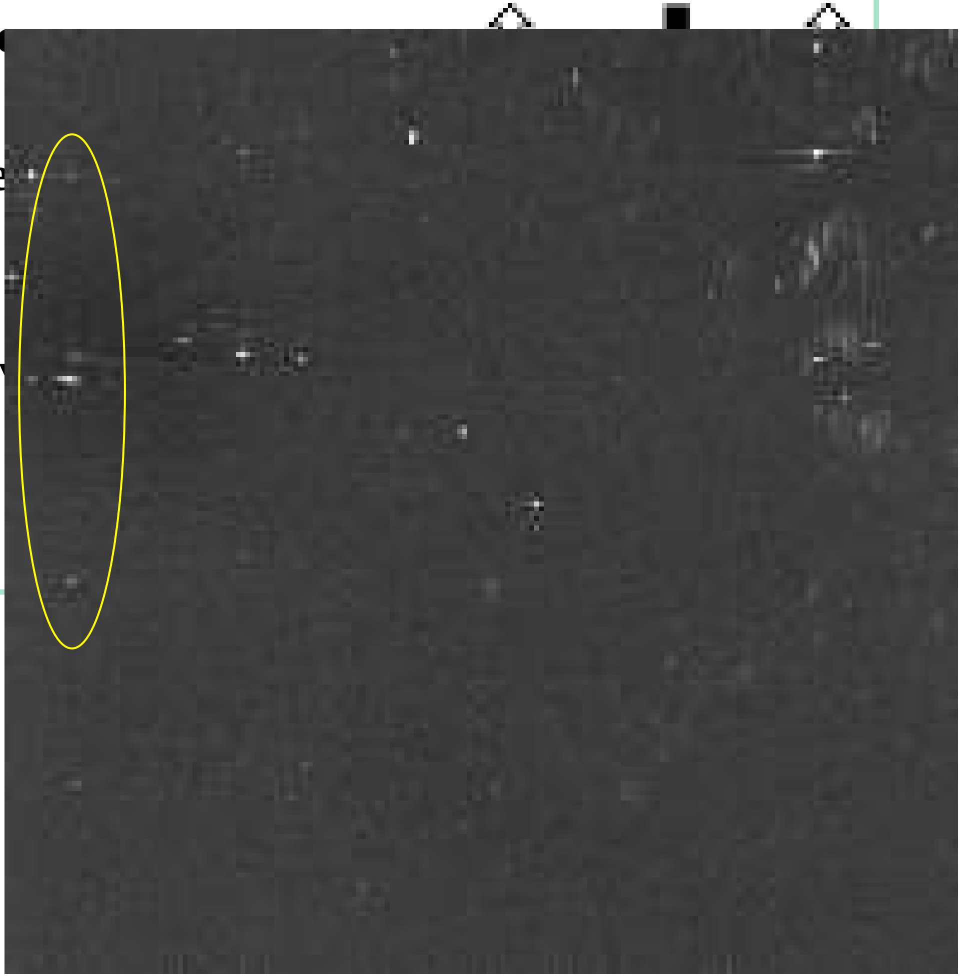
2.3 Ultra-fine strip (dual-beam)

- **Difficulty：Dual channel error compensation**



- **Processing and results**
  - **External calibration is not de**
  - **There is residual error after**
  - **As the estimation and compe ults a basically stable**
  - **he c of low SNR, the**
  - **ch p essing can not solv e tar s**





2.4 Fully polarized strip mode

- **Processing and results：**
  - **External calibration——limited (only 4 times): high isolation, but its amplitude and phase unbalance is not constant (different in each beam) .**
  - **We use the method of amplitude and phase error estimation based on distribution target, analyzing and monitor the amplitude and phase error of each beam, find out the error sources**

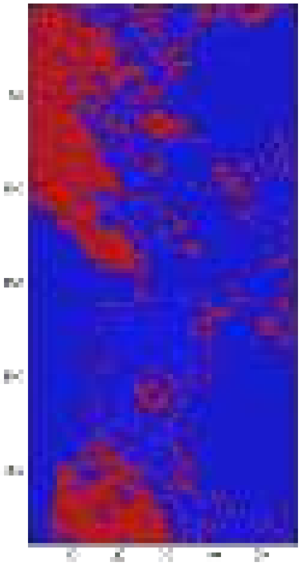
Calibrated RadarSAT-2 image

Amplitude estimation ⇨ Looking for ground objects

$$\text{if}\begin{cases}|hh|_L - |vv|_L \approx 0\\ |hv|_L - |vh|_L \approx 0\end{cases}$$

Phase estimation ⇨ Looking for ground objects

$$\begin{cases}phase\left(\left\langle S_{HV}S_{VH}^{*}\right\rangle\right) \approx 0\\ phase\left(\left\langle S_{HH}S_{VV}^{*}\right\rangle\right) \approx 0\end{cases}$$



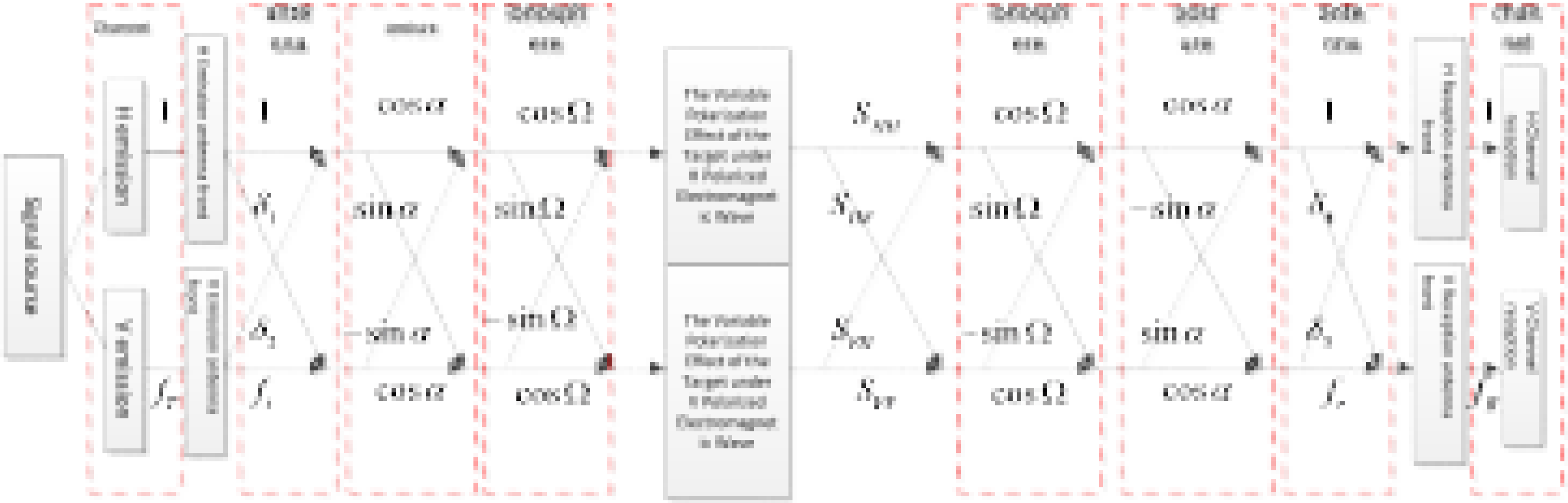
Limitation factors

Amplitude：<0.3dB

Phase：<4degree

2.4 Fully polarized strip mode

Error model



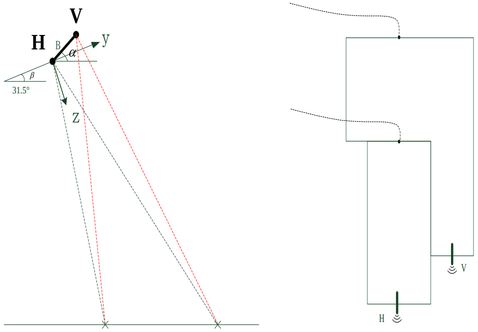
$$\begin{bmatrix} M_{hh} & M_{hv} \\ M_{vh} & M_{vv} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & f_R \end{bmatrix} \begin{bmatrix} 1 & \delta_3 \\ \delta_4 & f_r \end{bmatrix} \begin{bmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{bmatrix} \begin{bmatrix} \cos\varphi & \sin\varphi \\ -\sin\varphi & \cos\varphi \end{bmatrix}$$

$$\times \begin{bmatrix} S_{HH}(t-\tau) & S_{HV}(t+t_3-\tau) \\ S_{VH}(t+t_2-\tau) & S_{VV}(t+t_4-\tau) \end{bmatrix}$$

$$\times \begin{bmatrix} \cos\varphi & -\sin\varphi \\ \sin\varphi & \cos\varphi \end{bmatrix} \begin{bmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{bmatrix} \begin{bmatrix} 1 & \delta_1 \\ \delta_2 & f_t \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & f_T \end{bmatrix}$$

2.4 Fully polarized strip mode

- **Through in-depth analysis on the SAR payload and the antennas, we solved the problem of phase center deviation and channel delay inconsistency**



$$\begin{cases} \theta_{r,1} = \dfrac{2\pi B \sin(\alpha - \phi)}{\lambda} \\ \theta_{t,1} = \dfrac{2\pi B \sin(\alpha - \phi)}{\lambda} \end{cases}$$

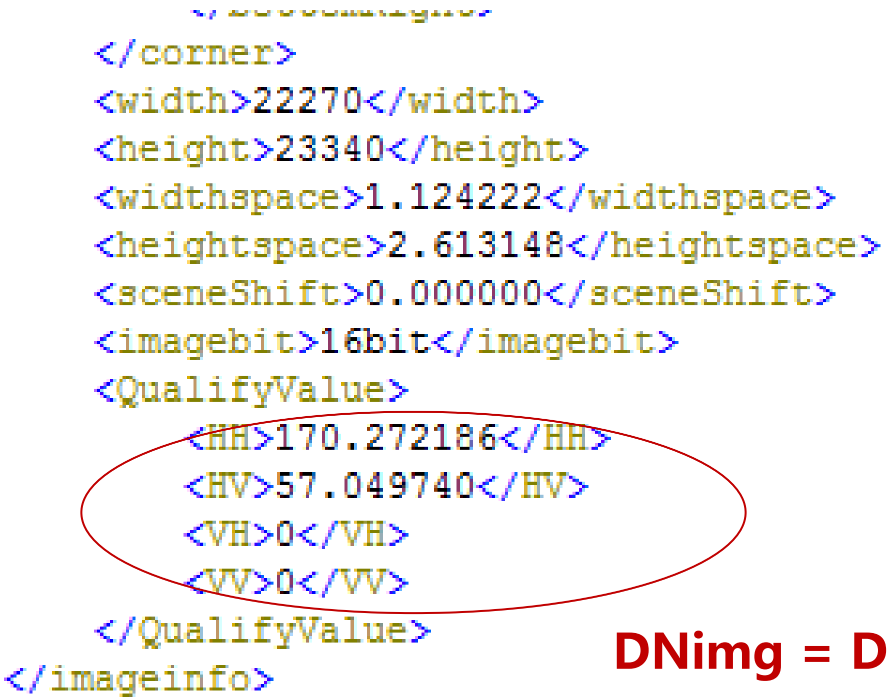
$$\begin{bmatrix} M_{HH} & M_{VH} \\ M_{HV} & M_{VV} \end{bmatrix} = \begin{bmatrix} S_{HH}(t,\tau) & S_{VH}(t - \Delta t_2, \ \tau) \\ S_{HV}(t - \Delta t_3, \ \tau) & S_{VV}(t - \Delta t_4, \ \tau) \end{bmatrix}$$

- **By March 30, 2017, we have updated the system and the quality of the polarized products are guaranteed**

Parameter	Requirements	GF-3 Data
Polarization isolation	>35dB	OK
Amplitude imbalance	<0.5dB	OK
Phase imbalance	<10°	OK

2.4 Fully polarized strip mode

- ***Notice：Different polarized channel data are quantized using different quantization peaks (see xml), see the manual for use.***

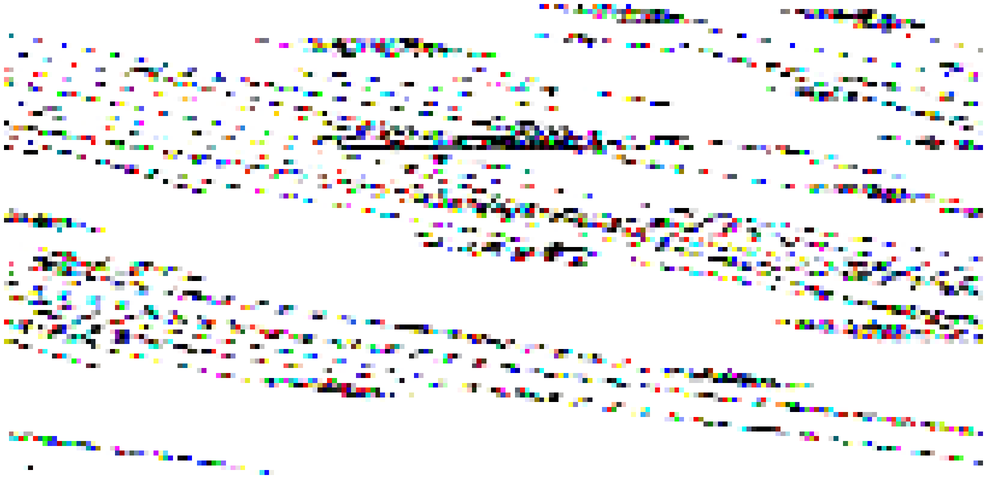


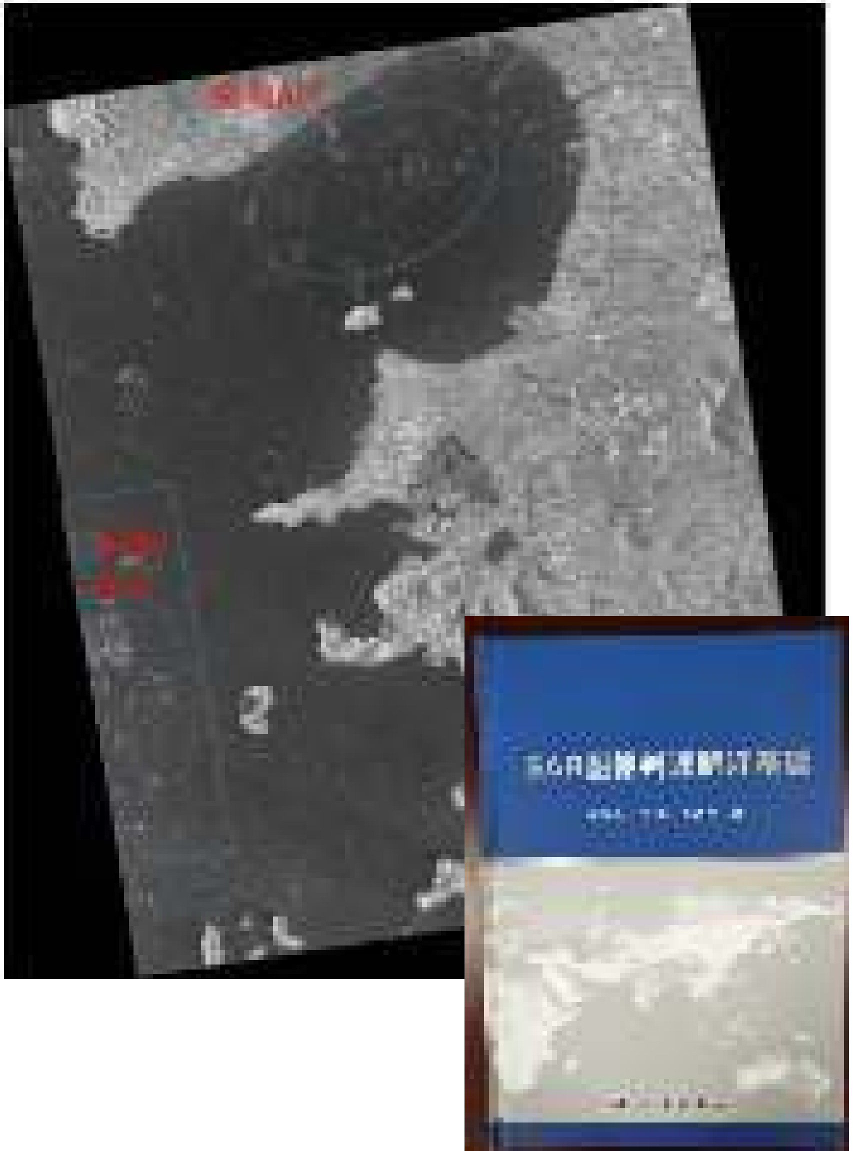
```
    </corner>
    <width>22270</width>
    <height>23340</height>
    <widthspace>1.124222</widthspace>
    <heightspace>2.613148</heightspace>
    <sceneShift>0.000000</sceneShift>
    <imagebit>16bit</imagebit>
    <QualifyValue>
        <HH>170.272186</HH>
        <HV>57.049740</HV>
        <VH>0</VH>
        <VV>0</VV>
    </QualifyValue>
</imageinfo>
```

DNimg = DN / QualifyValue * 32767

2.4 Fully polarized strip mode

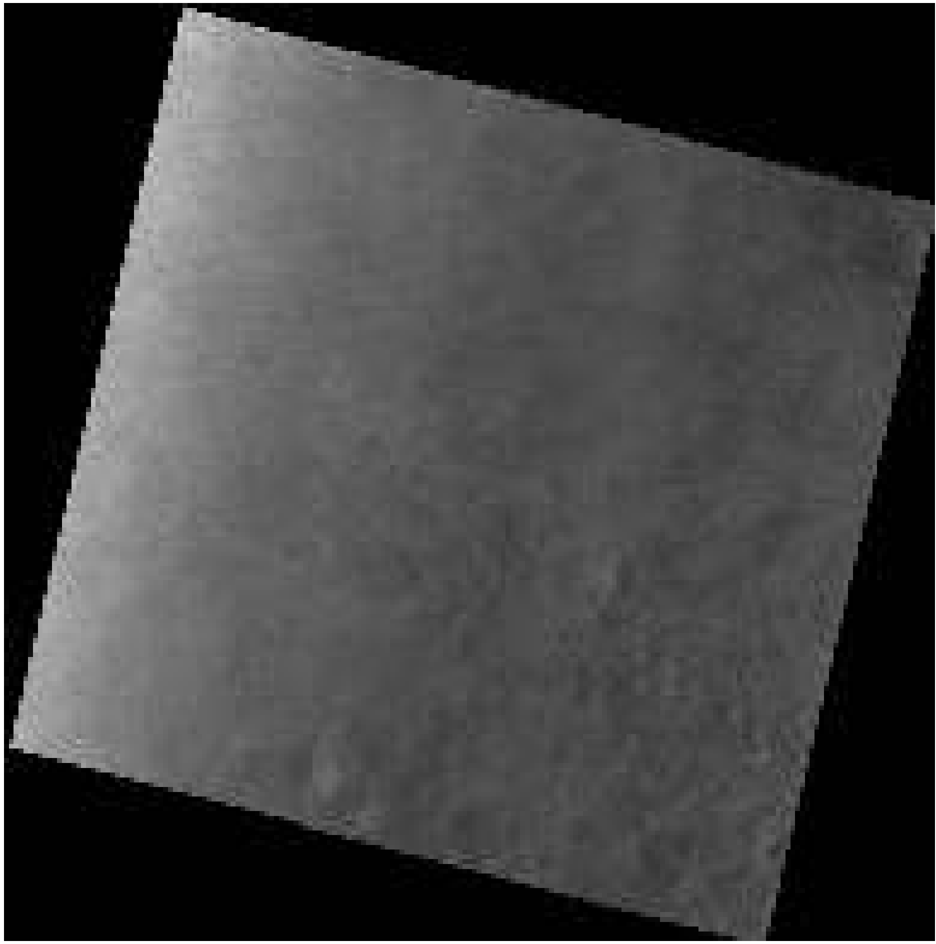
Range ambiguity phenomenon





2.5 ScanSAR mode

- Attitude measurement and beam pointing accuracy are not yet guaranteed that scallops are not visible
- Using the center frequency estimation, in the non-uniform and low SNR region, the estimation accuracy decreases, the scallops exsists
- The noise has a large effect on the correction of the direction map , and the internal calibration has only the center beam data. At present, with the noise estimator works, it shows that the noise difference may be larger in the area where the signal-to-noise ratio changes violently



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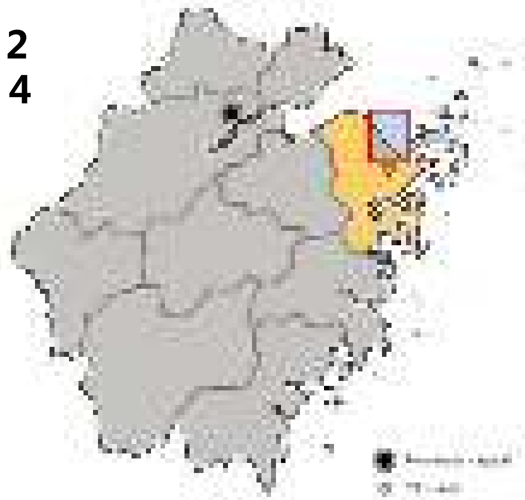
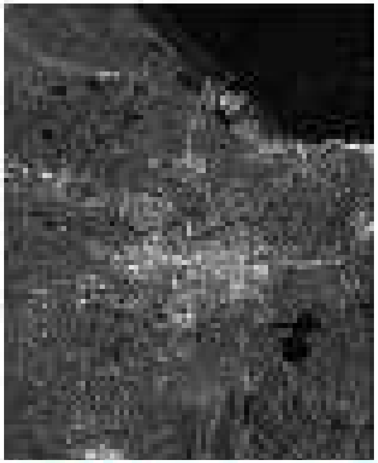
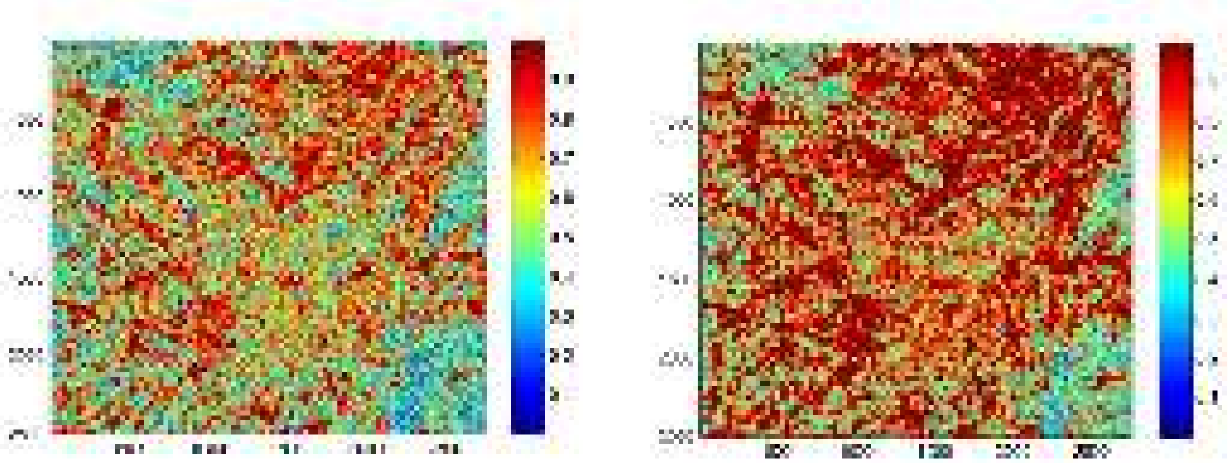
3.1 InSAR/DInSAR Processing

Song Shan ：2
Huang Hua : 4
Ning Bo : 2



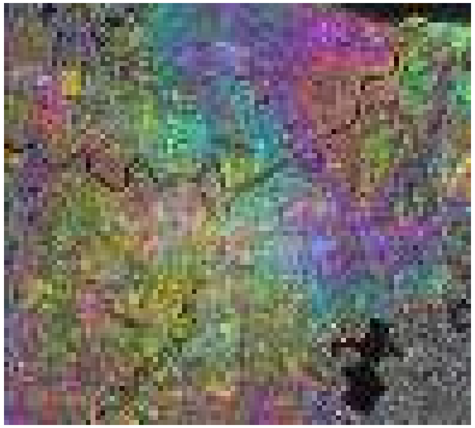




Commercial software **Our research filter algorithm**

Coherence graph

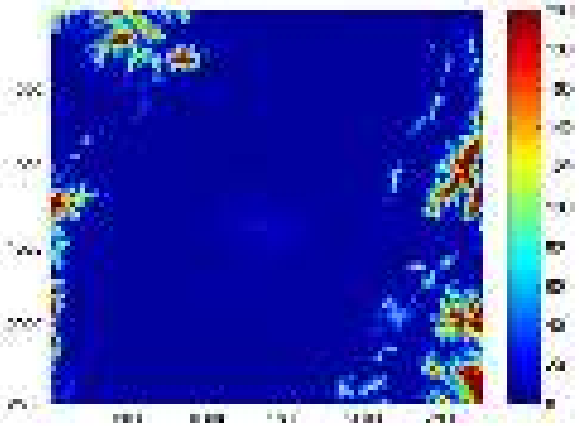
Ground Phase removal by the original orbital data



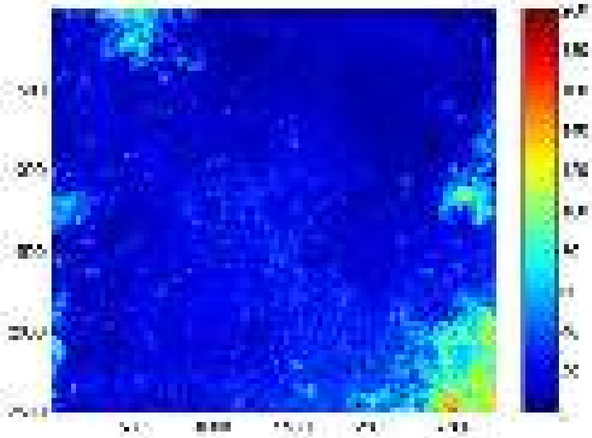
Phase results using the processed Orbital data

rough DEM is used to remove the flat ground phase

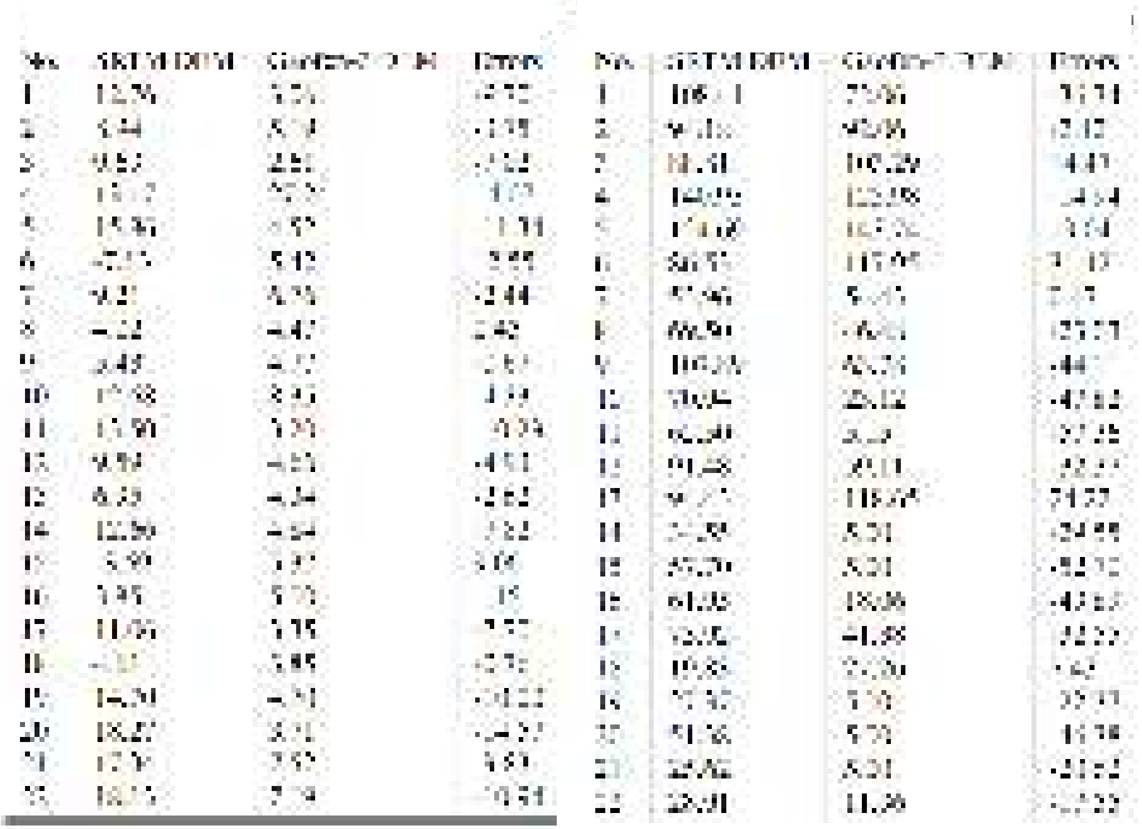
3.1 InSAR /DInSAR Processing



SRTM's DEM



GF3 InSAR DEM



Comparison: average elevation error is 4 meters in flat area, the average height error is about 30 meters in mountain area.

3.1 InSAR/DInSAR Processing

Songshan area results: using the proposed method, get a good coherent results, observed some areas of the deformation, as shown below

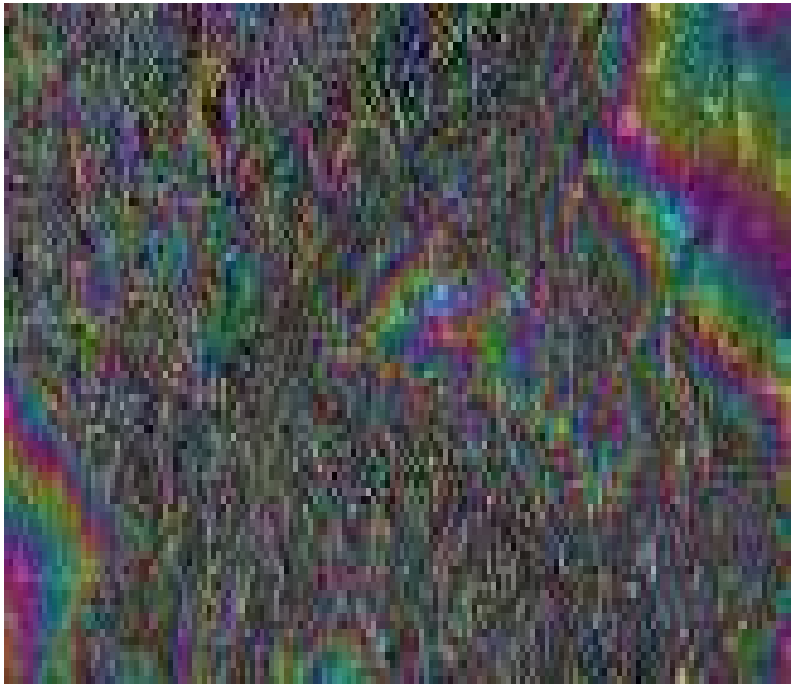


Figure1

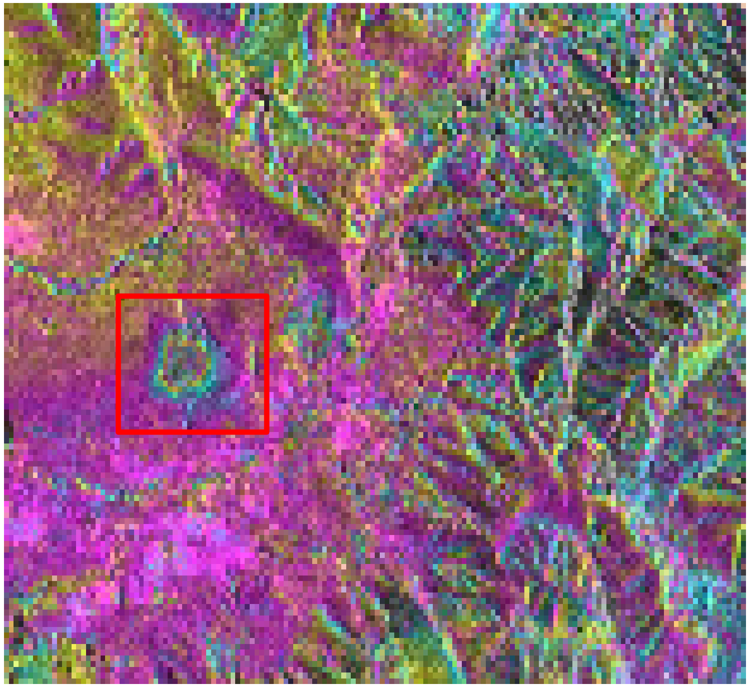
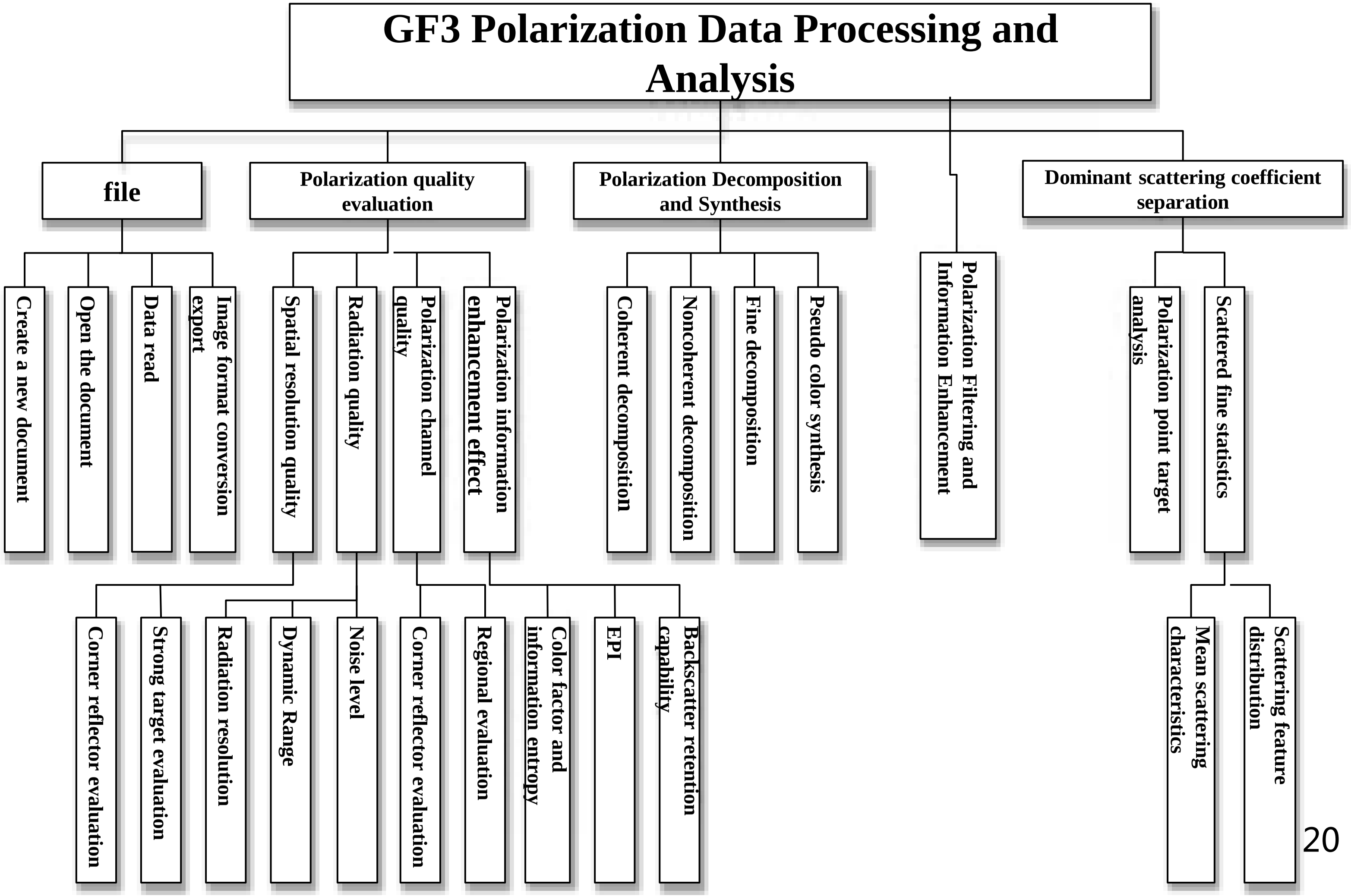


Figure2

In Songshan mining area , mining led to ground subsidence, the red frame within the circular area shown as the ground subsidence 3 cm

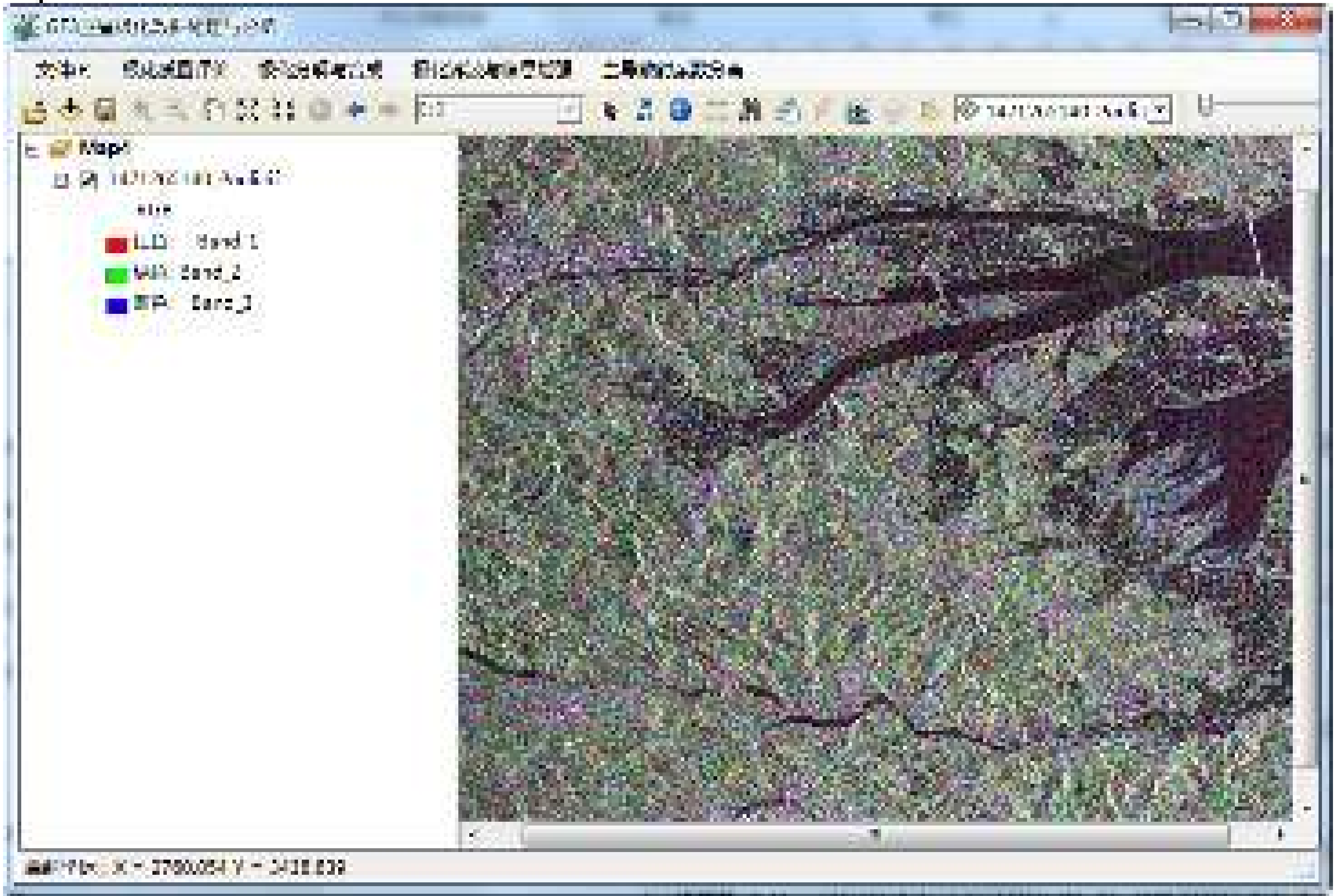
3.2 Polarization Analysis and Application

Research content of the project



- GF3 Polarization Data Processing and Analysis
  - file
    - Create a new document
    - Open the document
    - Data read
    - Image format conversion export
  - Polarization quality evaluation
    - Spatial resolution quality
      - Corner reflector evaluation
      - Strong target evaluation
    - Radiation quality
      - Radiation resolution
      - Dynamic Range
      - Noise level
    - Polarization channel quality
      - Corner reflector evaluation
      - Regional evaluation
    - Polarization information enhancement effect
      - Color factor and information entropy
      - EPI
      - Backscatter retention capability
  - Polarization Decomposition and Synthesis
    - Coherent decomposition
    - Noncoherent decomposition
    - Fine decomposition
    - Pseudo color synthesis
  - Polarization Filtering and Information Enhancement
  - Dominant scattering coefficient separation
    - Polarization point target analysis
    - Scattered fine statistics
      - Mean scattering characteristics
      - Scattering feature distribution

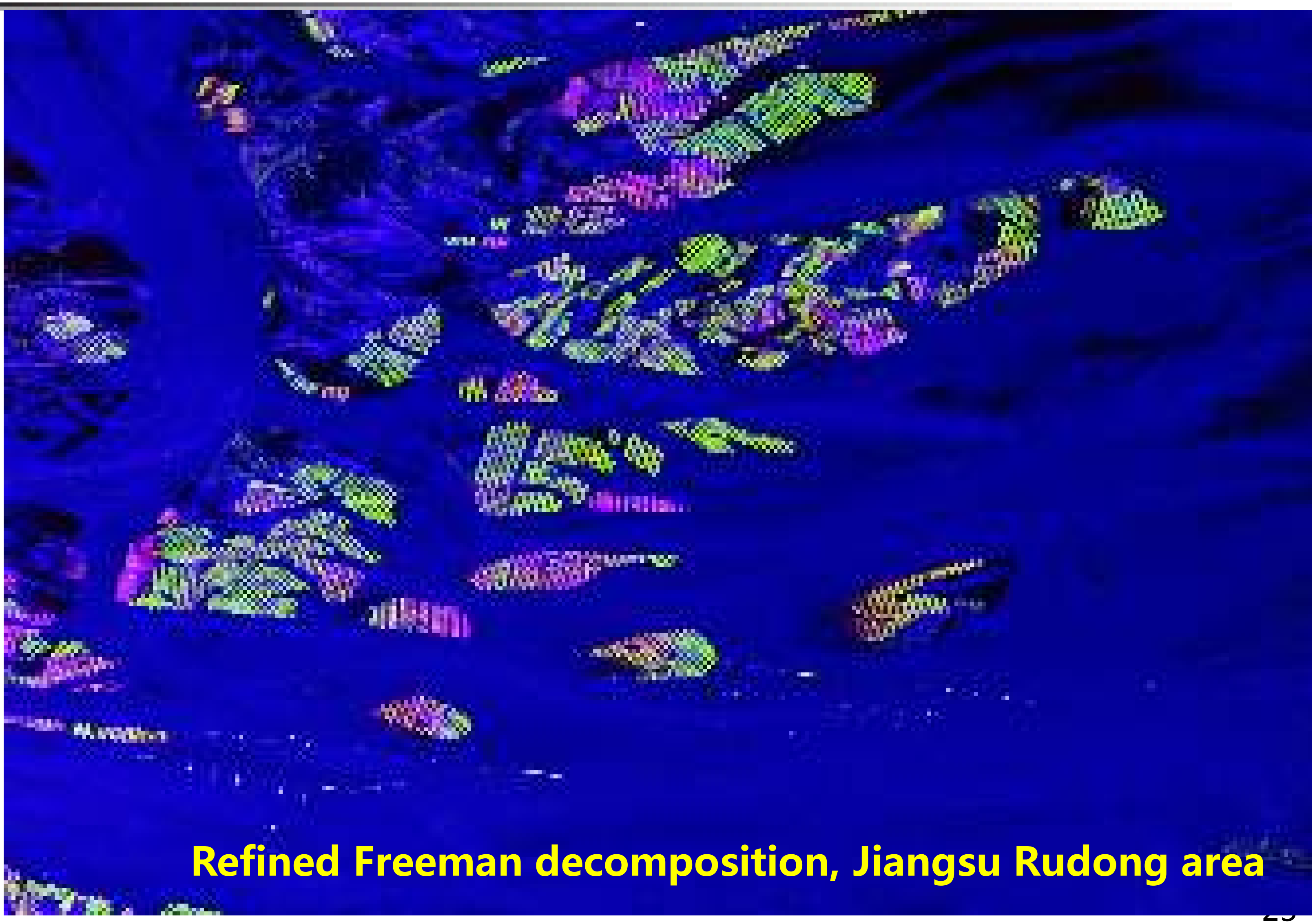
3.2 Polarization Analysis and Application



3.2 Polarization Analysis and Application

Pauli decomposition pseudo - color image, Chongming Island area, Shanghai

3.2 Polarization Analysis and Application



Refined Freeman decomposition, Jiangsu Rudong area

3.2 Polarization Analysis and Application ——Image segmentation

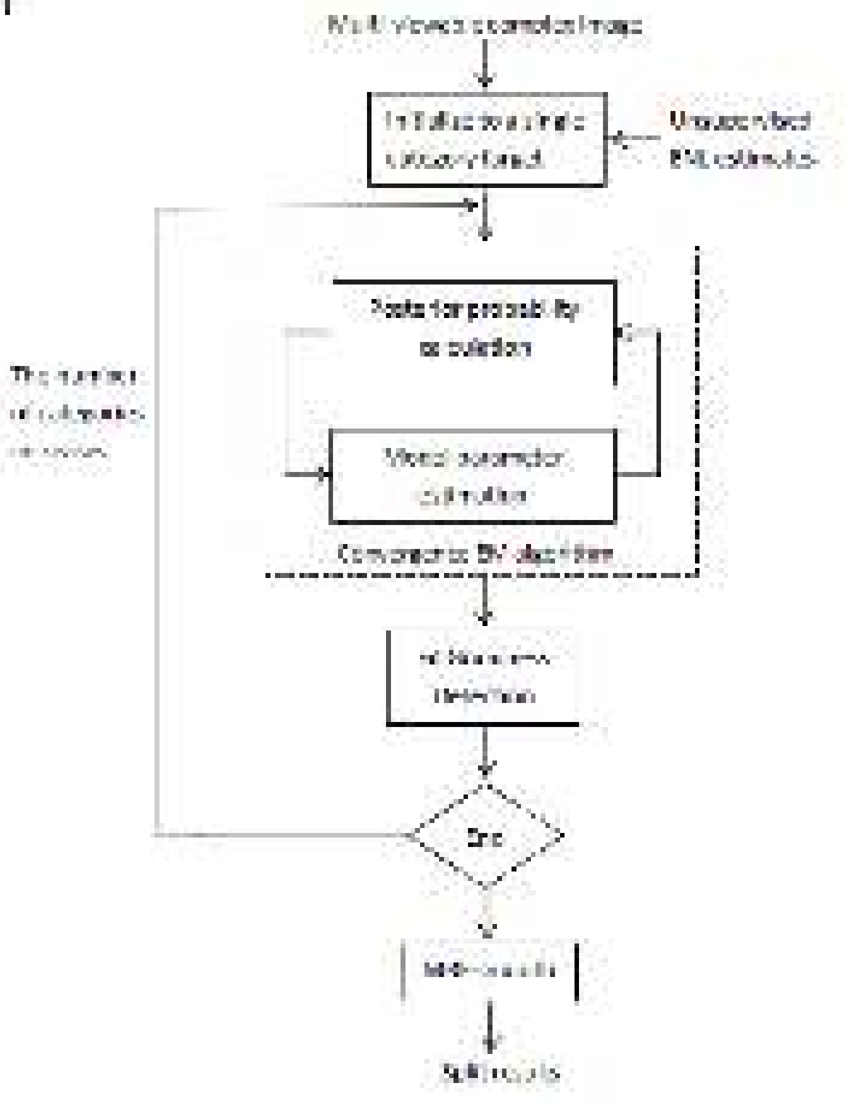
◆ **Polarimetric SAR Image Segmentation Algorithm Based on Non - Gaussian Mixture Model**

Non-Gaussian distribution

$$k_n(\mathbf{C};L,\mathbf{S},\mathbf{q})=\begin{cases} y_d^{(0)}(L)+\ln|\mathbf{S}|-d\ln L+d\,q k_1 \\ y_d^{(n-1)}(L)+d^n k_n(T;\mathbf{q}) & n>1 \end{cases}$$

Goodness-of-fit Testing

- **The degree of fitting the model to the data sample is examined**
- **Avoid the initial split settings - initialize to a single class**
- **Automaticly judge the number of categories – separate the worst fitting category**



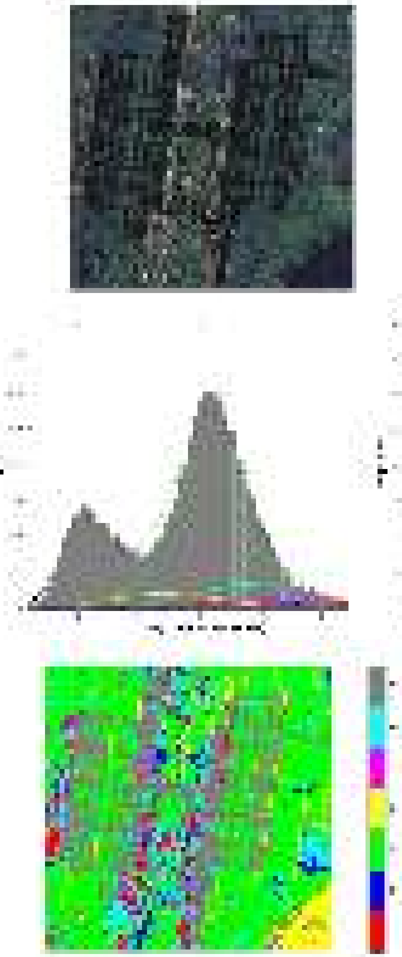
3.2 Polarization Analysis and Application ——Image segmentation

GF3's data set

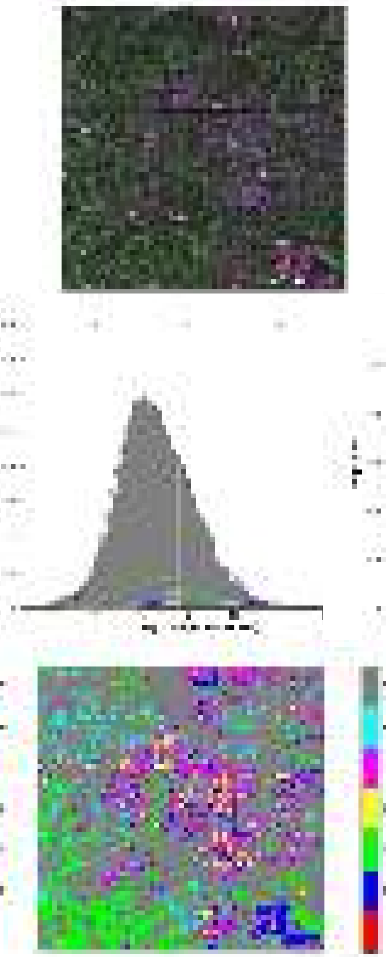
C-band，Full polarization mode，Resolution 8m

Image number	Size (pixels)	Center Point Incident (°)	Latitude and longitude	Scenes
1	1200*1200	29.3076	(31.1260° N, 121.8114° E)	Pudong Airport
2	1200*1200	29.8435	(30.9974° N, 121.5748° E)	Shanghai City
3	1200*1200	28.1484	(31.2684° N, 121.5187° E)	suburbs
4	1200*1200	36.4334	(33.8211° N, 120.3504° E)	Farmland area
5	1200*1200	35.4514	(34.0812° N, 120.5168° E)	Offshore and vessel

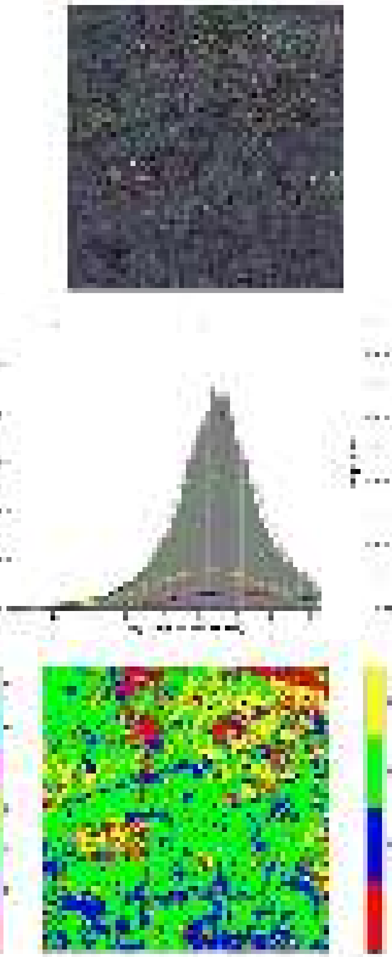
3.2 Polarization Analysis and Application ——Image segmentation



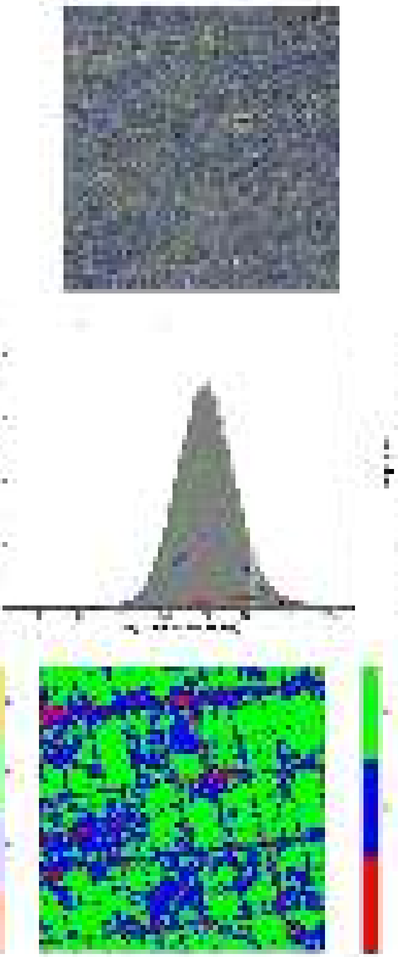
To extract the complete structure of the airport, and to distinguish the SAR image on the more close to the airport runway and water



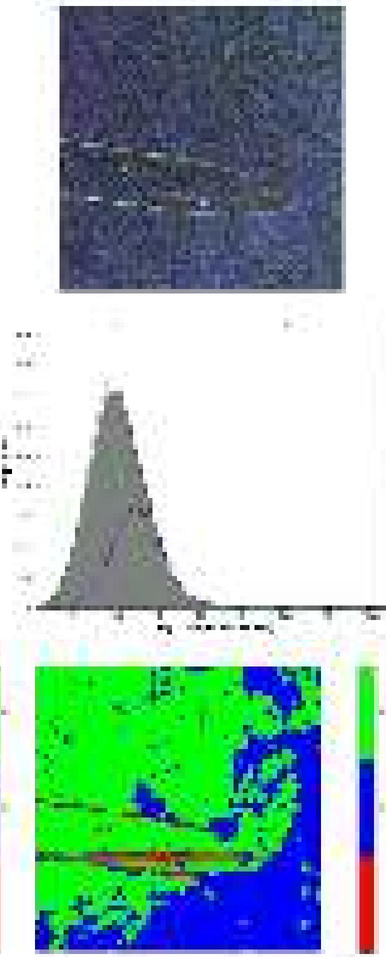
Separate the building with different orientations and densities in the scene



Extracted from the scene of the discrete distribution of water and construction area



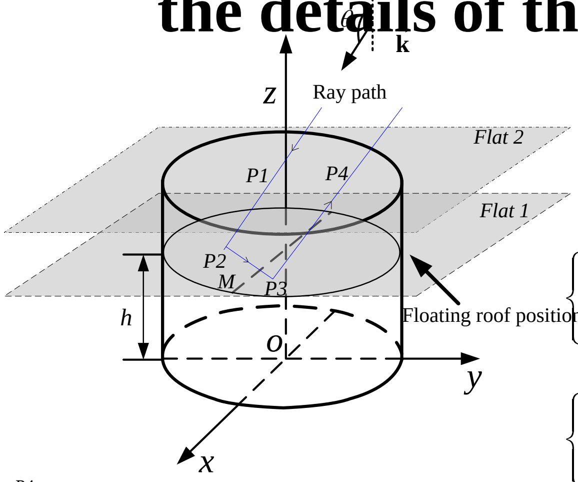
Separate the vegetation coverage area and bare soil in the scene



Detection of the scene to extract the ship and other artificial targets, but the strong side of the target sideline affect the extraction results

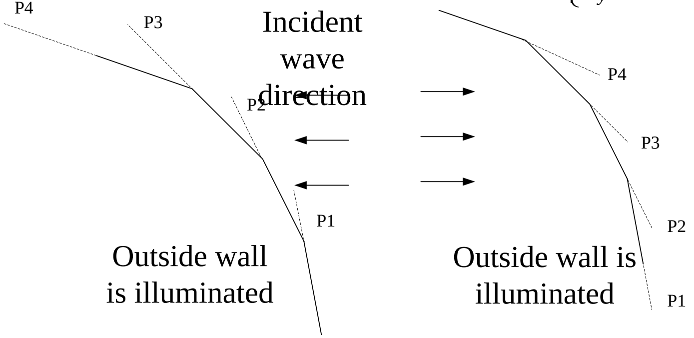
3.3 Simulation and Interpretation of High Resolution SAR Target

- **Simple shape modeling and simulating- interpreting the details of the image**



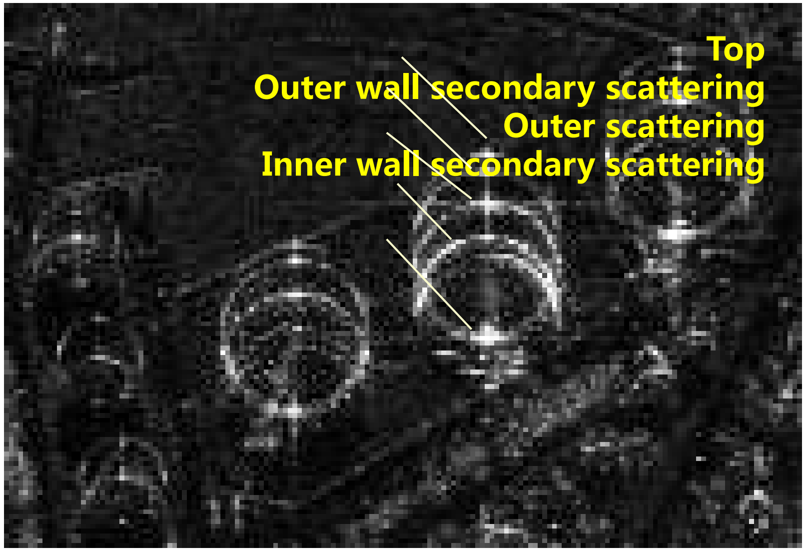
$$\begin{cases} P_x = r\cos\varphi_n - rh^{'}\tan\theta\tan\varphi_n\sin\varphi_n \\ P_y = r\sin\varphi_n + rh^{'}\tan\theta\tan\varphi_n\cos\varphi_n \end{cases}$$

$$\begin{cases} P_x = r\cos\varphi_n + rh^{'}\tan\theta\tan\varphi_n\sin\varphi_n \\ P_y = r\sin\varphi_n - rh^{'}\tan\theta\tan\varphi_n\cos\varphi_n \end{cases}$$



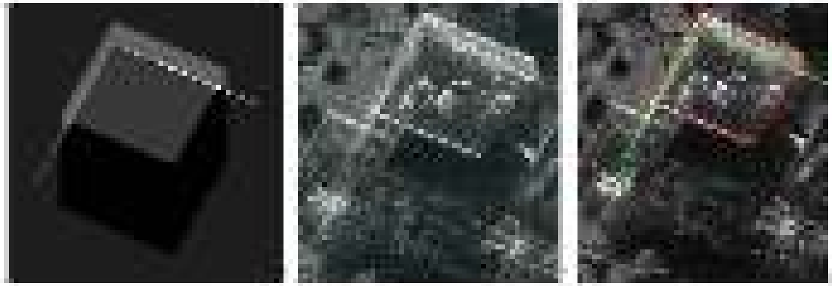
The radius of the secondary scattering arc is larger than the radius of the tank;
The inner radius of the secondary scattering arc is larger.

Yueting Zhang, Chibiao Ding, **Xiaolan Qiu**, Fangfang Li. "The Characteristics of the Multipath Scattering and the Application for Geometry Extraction in High-Resolution SAR Images[J]". IEEE Transactions on Geoscience & Remote Sensing, 2015, 53(8): 1-13.

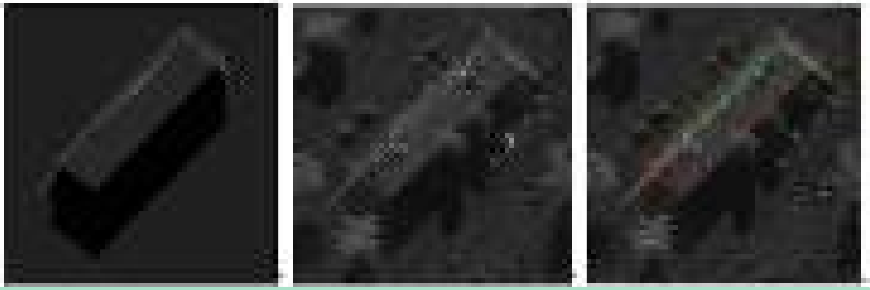


3.3 Simulation and Interpretation of High Resolution SAR Target

- **Simple shape modeling and simulating - interpreting the details of the image**



Flat roof building 1: Simulation, Measurement and Markings



Flat roof building 2: Simulation, Measurement and Markings

[illegible]

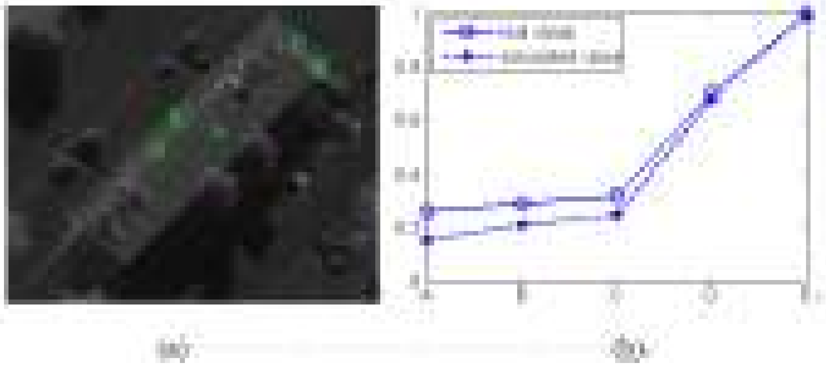
[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

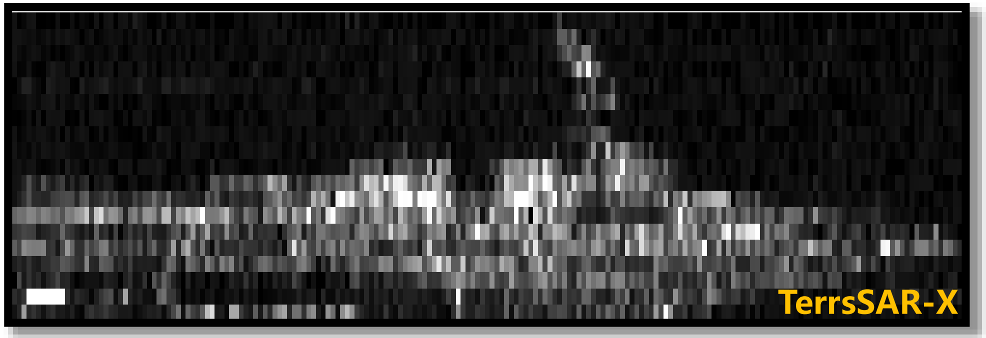


Flat roof building 2: (a) Markings of feature A, B, C, D (b) Amplitude Comparison of simulation and measurement for each feature

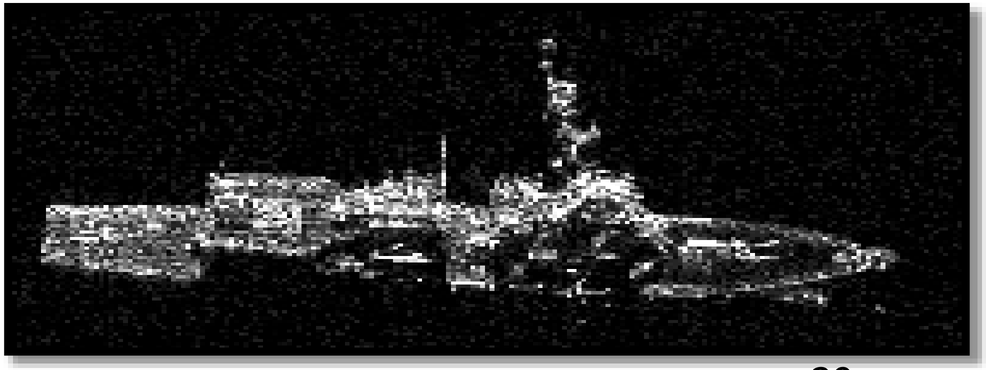
3.3 Simulation and Interpretation of High Resolution SAR Target

- **Complex target modeling and simulating**
  - ☐ **Method: 3D modeling + POVRay + PO method + point target impulse response convolution According to the actual image, optimize the model parameter settings**

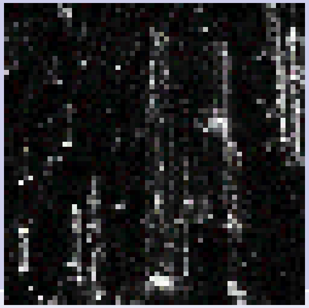
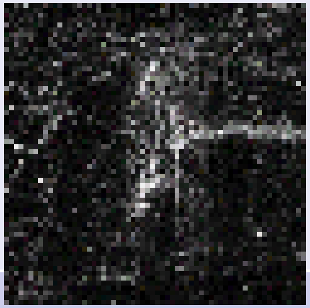
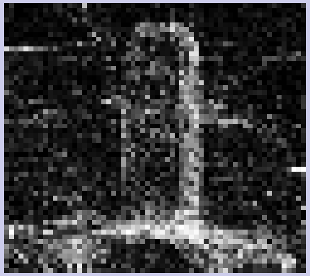
Actual image



Simulation image

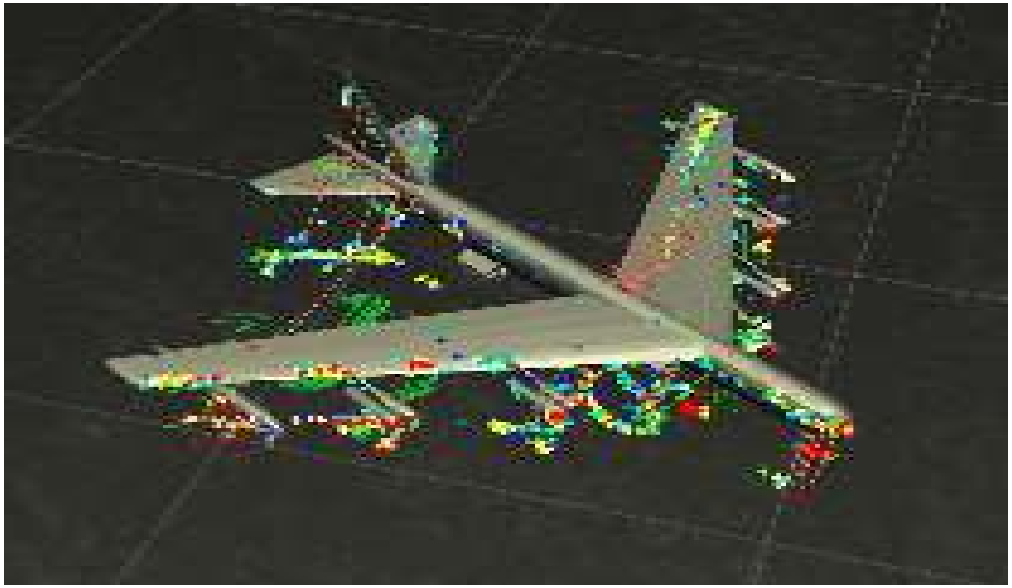


3.3 Simulation and Interpretation of High Resolution SAR Target

Building name	Optical image	SAR image	Actual height (m)	Measuring height (m)	Accuracy	Average accuracy
Shanghai Center Building			632.00	624.28	98.78%	98.54%
Hong Kong Global Trade Plaza			484.00	476.33	98.41%	
Hong Kong International Financial Center Phase II			412.00	405.98	98.53%	

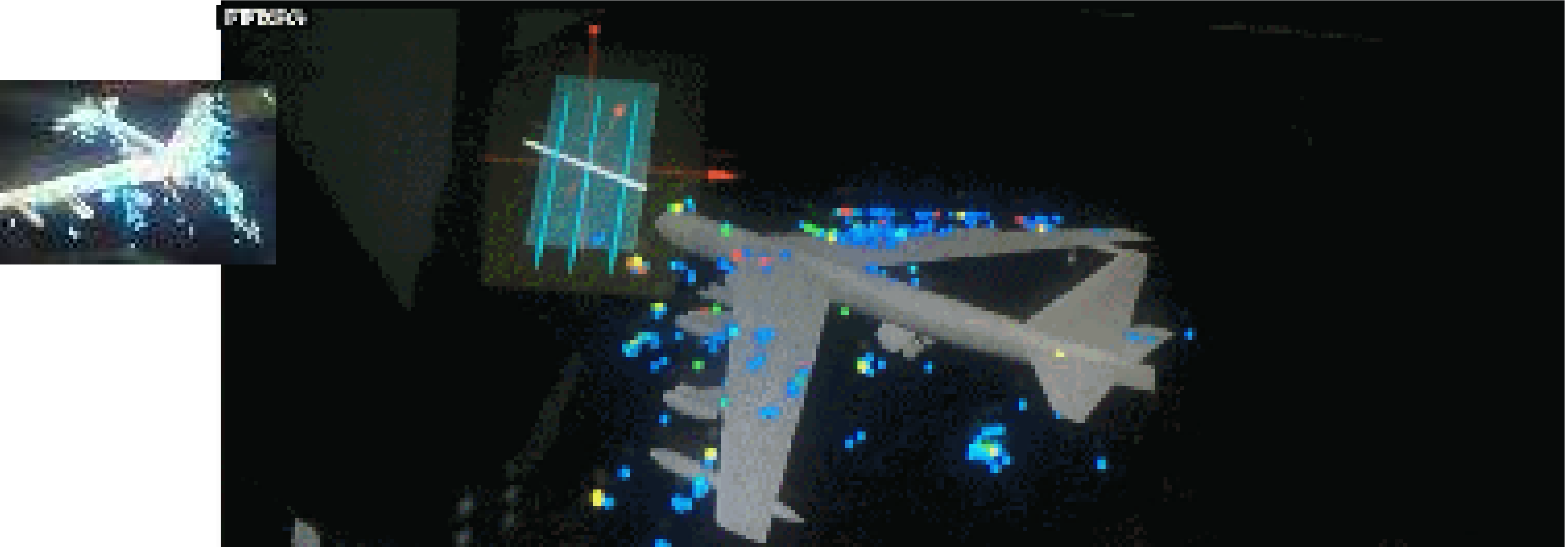
3.3 Simulation and Interpretation of High Resolution SAR Target

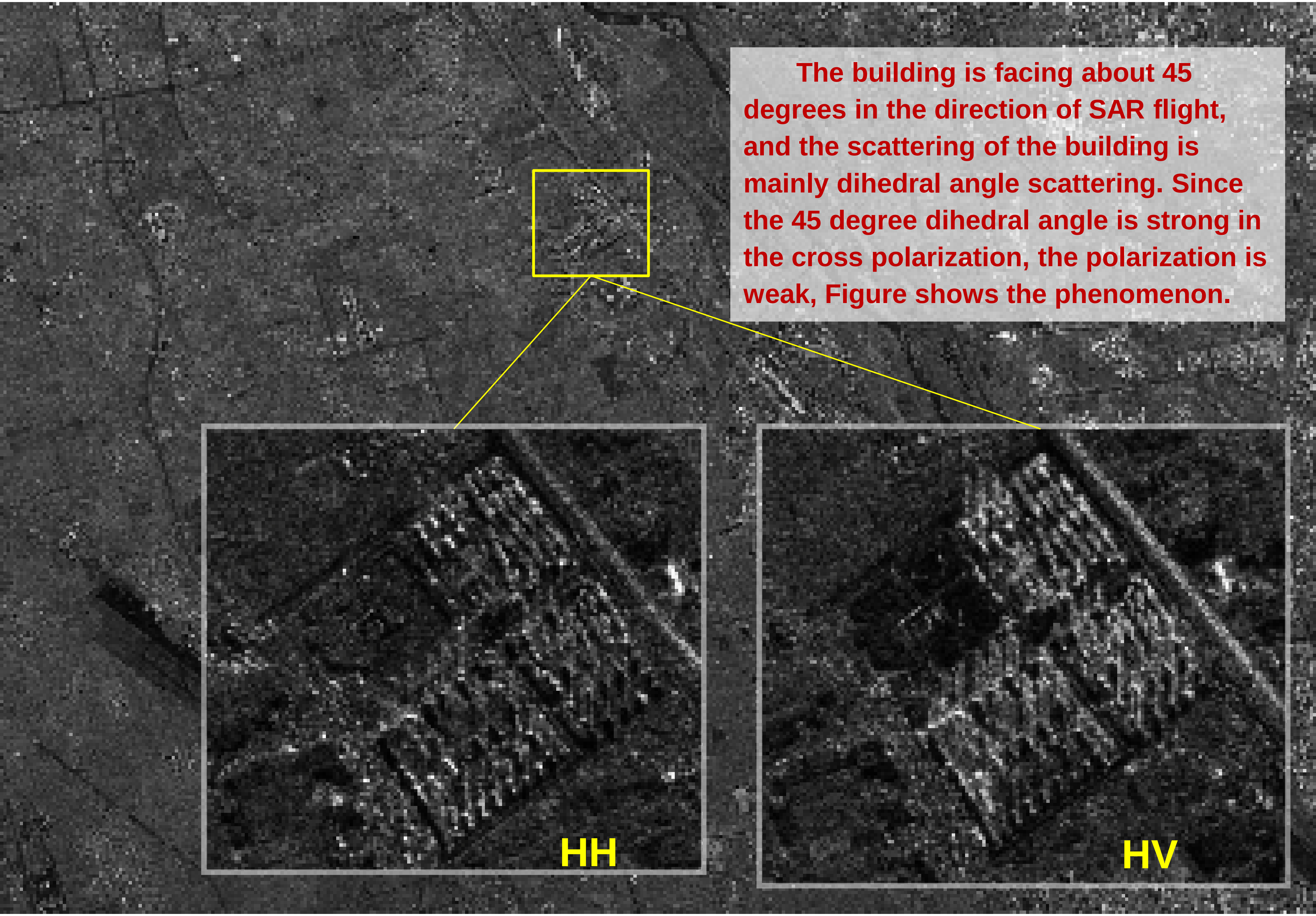
- Three - dimensional Visualization Based on Simulation of Inverse Projection
  - OBJECTIVE: To establish a more intuitive connection between the SAR scattering properties and the target physical structure
  - Use: Interpreter training, target recognition
  - Methods: The relationship between the scattering point and the three - dimensional position is obtained, and the inverse projection is matched
  - Display: VR and other means



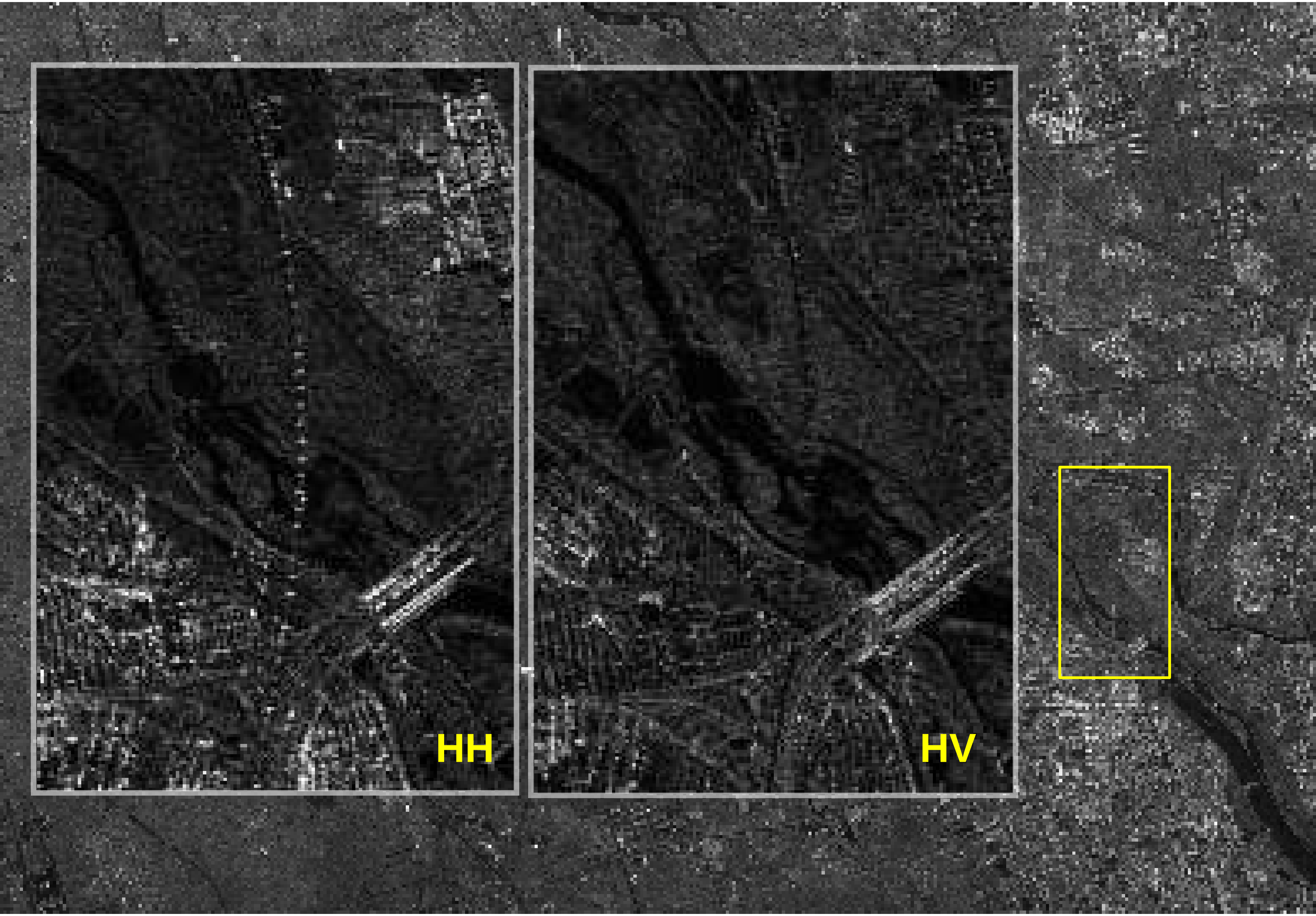
3.3 Simulation and Interpretation of High Resolution SAR Target

- **Three - dimensional Visualization Based on Simulation of Inverse Projection**
  - ☐ **OBJECTIVE: To establish a more intuitive connection between the SAR scattering properties and the target physical structure**
  - ☐ **Use: Interpreter training, target recognition**
  - ☐ **Methods: The relationship between the scattering point and the three - dimensional position is obtained, and the inverse projection is matched**
  - ☐ **Display: VR and other means**





The building is facing about 45 degrees in the direction of SAR flight, and the scattering of the building is mainly dihedral angle scattering. Since the 45 degree dihedral angle is strong in the cross polarization, the polarization is weak, Figure shows the phenomenon.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HV

Outline

1、Introduction of GF-3 and Our Tasks

2、GF-3 data processing and analysis

3、Applications of GF-3 products

4、Summary

Outline

1、Intriduction of GF-3 and Our Lab’s Task

2、GF-3 data processing and analysis

3、Application of GF-3 satellite

4、Summary

4. Summary

My colleagues and I will continue to focus on the critical requirements from Gaofeng-3 application, to improve the quality of our satellite products, and to refine our information extracting toolset. Our ongoing research on calibration of system based on big data mining have also made some progress. We hope to bring more values to all customs of our SAR satellite and the up-coming constellation.

THANK YOU!

IECAS 中国科学院电子学研究所

Institute of Electronics, Chinese Academy of Sciences