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“龙计划”二期2011年学术研讨会

POLINSAR (ID. 5344)

First Studies of IECAS–X/P–SAR System

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Outline

- ➢ System Overview
- ➢ X-Band Twin-Antenna InSAR
- ➢ P-Band Quad-Pol SAR
  - ☐ Polarimetric Calibration
  - ☐ Single-Pass PolSAR Processing
  - ☐ Repeat-Pass InSAR/PolInSAR Processing
- ➢ Summary

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IECAS-X/P-SAR system

Fully polarimetric SAR ,P-band

Single-pass InSAR, X-band

MOST
Mapping, Western China

X-InSAR
- high precision DSM extraction
- X-PolInSAR (undergoing)

P-PolSAR (experimental mode)
- classification, DEM estimation
- repeat pass P-InSAR, P-PolInSAR

X/P dual-frequency (experimental mode)
- precision DEM / DTM extraction

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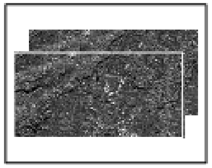
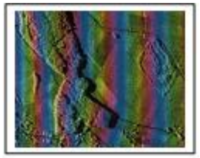
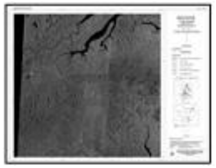
X-InSAR Data Processing

Entire Data Processing Chain

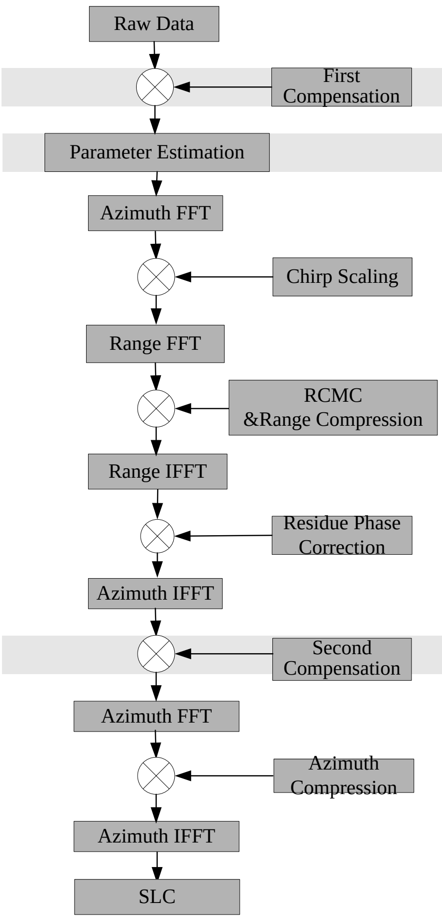
Flight Planning → Data Acquiring → SAR Processing → InSAR Processing → Cartographic Processing







ECS (Extended Chirp Scaling) algorithm with auto-registration



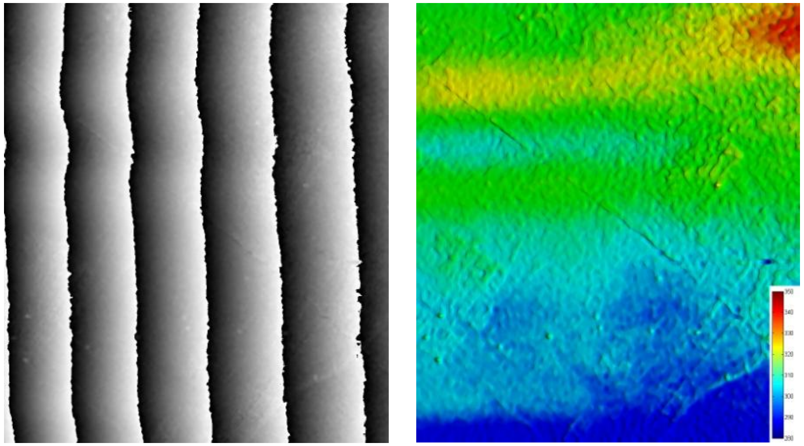
SAR imaging integrated with motion compensation

Motion Compensation

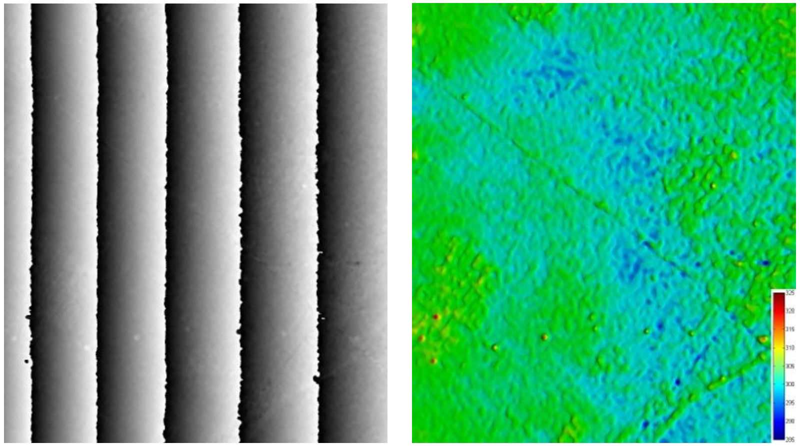
- Phase correction is introduced to motion compensation
- Suitable for platform with severe attitude angle, as yaw angle
- Data set:
  WEI RIVER of Shaanxi

  Flight height:
  10,000m

  Average yaw angle:
  10.8degree



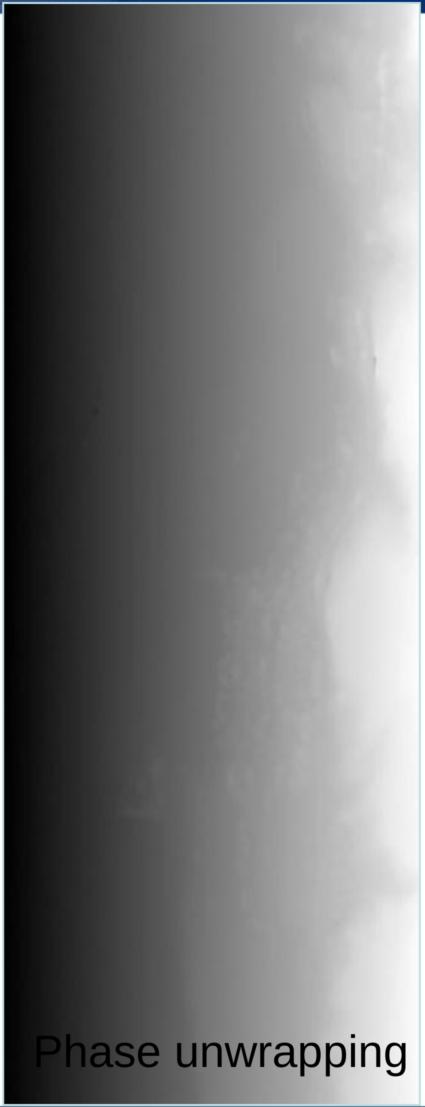
Before phase correction



After phase correction

X-InSAR Data Processing

InSAR Processing

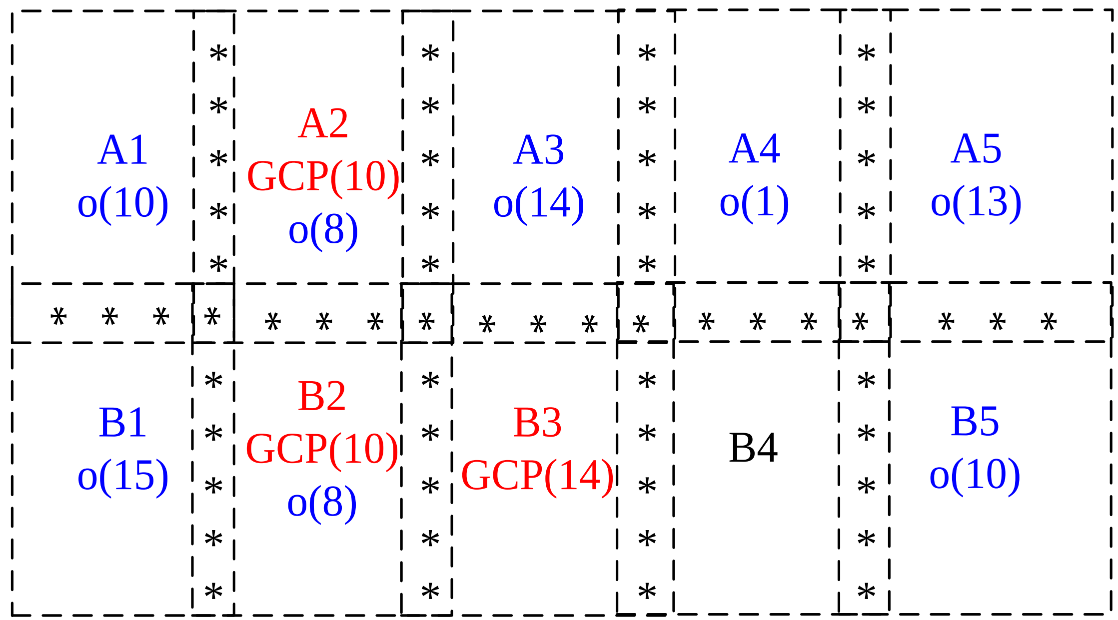


Bundle Adjustment Calibration

- GCPs
  -"GCP"
  - limited area, A2,B2,B3

- Corresponding points
  - "*"
  - overlaped area

- error statistics points
  - "o"
  - distribute across the whole area

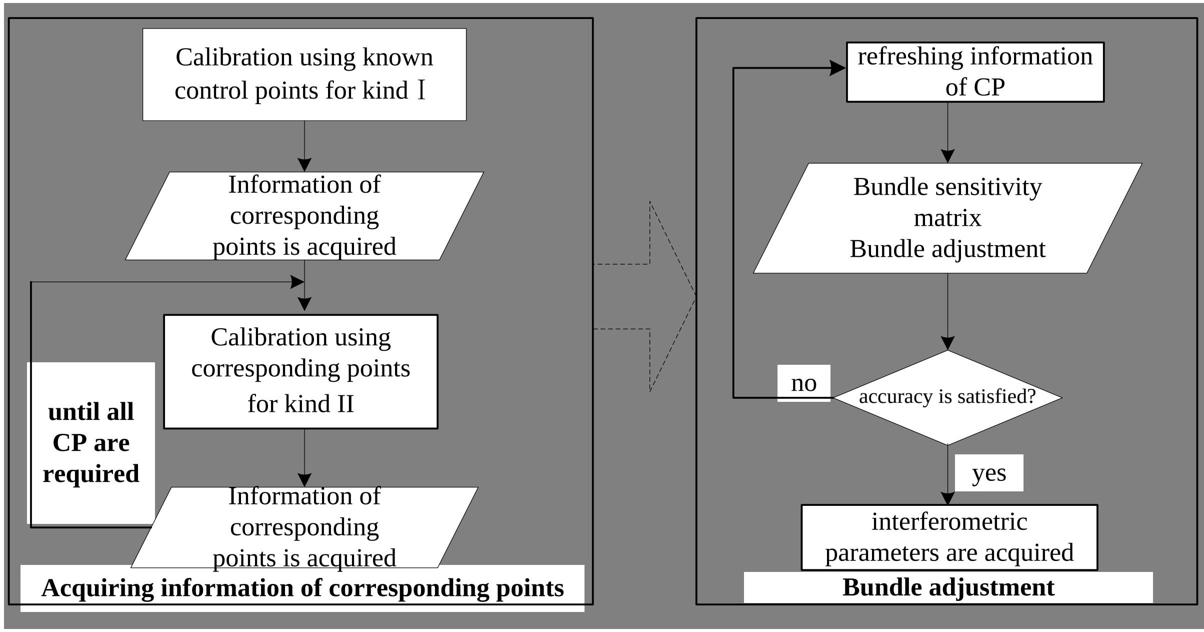


Bundle Adjustment Calibration

- simultaneous multiple adjustment of critical parameters for the SAR images using corresponding points.

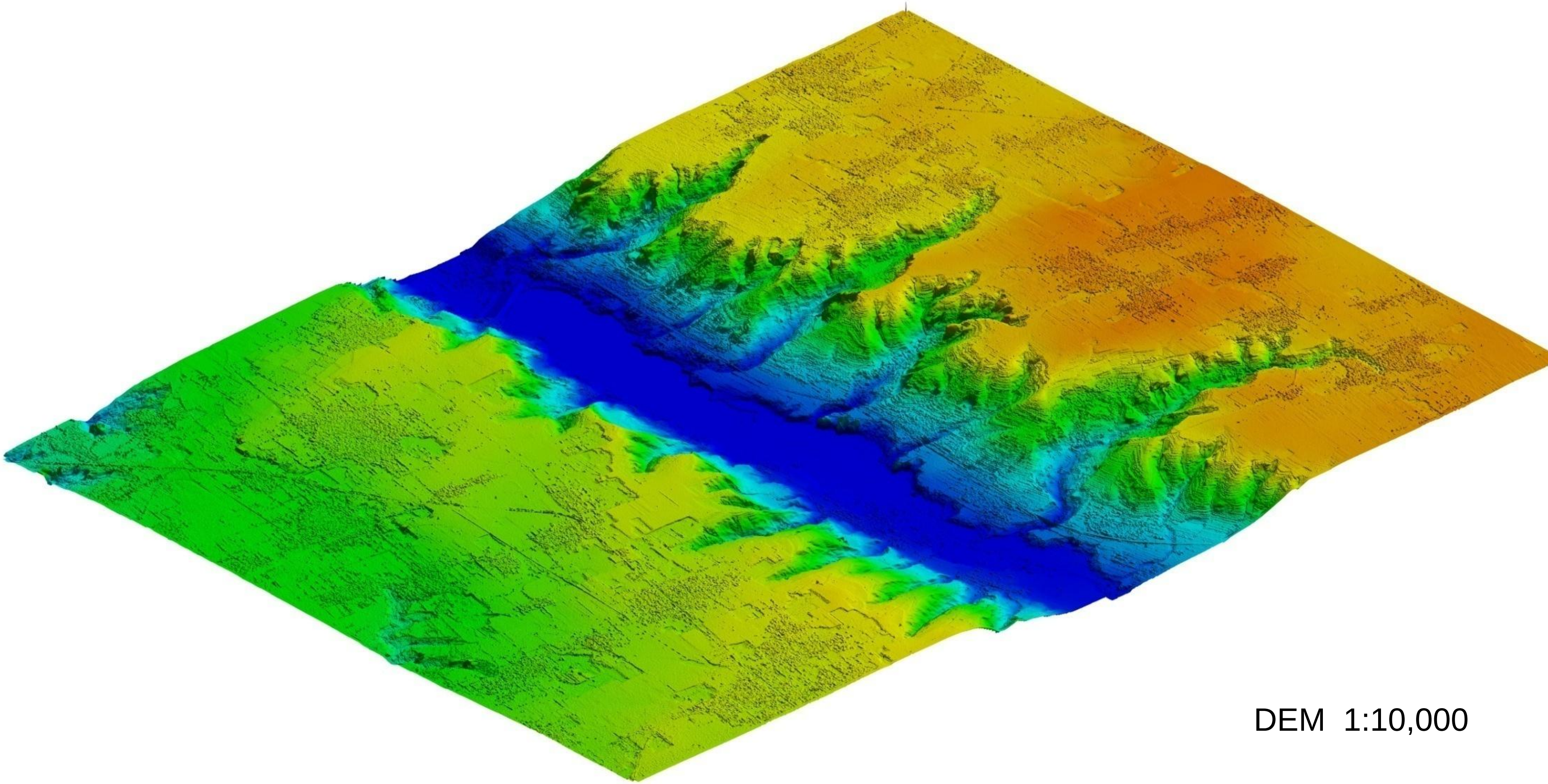
- Interferometric parameters of blocks without GCPs can be acquired by height transferred.

- Error of different overlapping pairs can be minimized.



Flow chart of calibration

X-InSAR Data Processing



DEM 1:10,000

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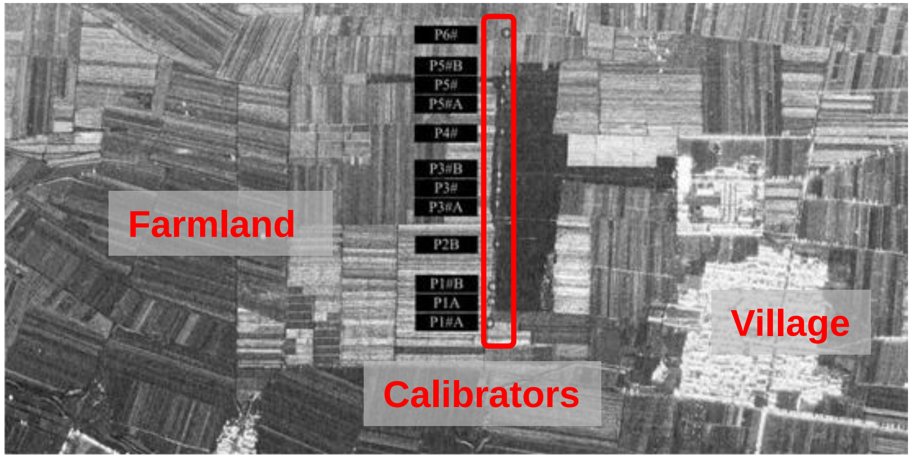
P-Band Quad-Pol SAR

Polarimetric Calibration

- Calibration Site
  - Farmland
  - Runway
  - Viliage
- Calibrator
  - Three 0° dihedral corner reflectors
  - Three 45° dihedral corner reflectors
  - Six trihedral corner reflectors
- Calribration Methodology
  - [Ref]A. Fore etc. 2009*

Test Site: Changzhi, Shanxi



Corner Reflector 1.5m

* Alex Fore , Bruce Chapman , Scott Hensley .etc, UAVSAR Polarimetric Calibration

Polarimetric Calibration

– Model

$$\boldsymbol{S}' = A\begin{bmatrix} 1 & v \\ z & 1 \end{bmatrix}^T \begin{bmatrix} S_{HH} & fg\exp(i\phi_t)S_{VH} \\ f/g\exp(i\phi_r)S_{HV} & f^2\exp(i\phi_L)S_{VV} \end{bmatrix} \begin{bmatrix} 1 & u \\ w & 1 \end{bmatrix} + A_n \begin{bmatrix} N_{vv} & N_{vh} \\ N_{hv} & N_{hh} \end{bmatrix}$$

$$= A\boldsymbol{R}^t\boldsymbol{S}\boldsymbol{T} + A_n\boldsymbol{N}$$

– Absolute Calibration

$$10\log_{10}[\sigma_{cr} / (S'_{hh}S'^{*}_{hh})] = -10\log_{10} A^2$$

– Channel Imbalances Removing

$$f = \left[S'_{vv}S'^{*}_{vv} / (S'_{hh}S'^{*}_{hh}) \right]^{1/4}$$

$$g = \left[<|S'_{hv}|^2> / |< S'_{vh}|^2> \right]^{1/4}$$

– Phase Bias Removing

$$\left.\begin{matrix} \arg\left(S'_{vv}\cdot S'^{*}_{hh}\right) \\ \arg\left(\left\langle S'_{hv}\cdot S'^{*}_{vh}\right\rangle\right) \end{matrix}\right\} \Rightarrow (\phi_r, \phi_t)$$

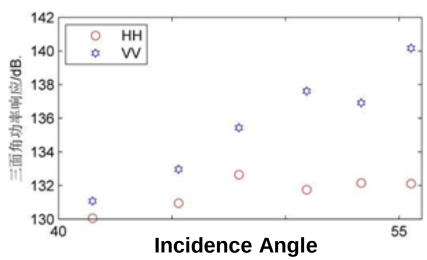
– Cross-Talk Calibration

$$C^0_{ij} = < O_i O_j^* > \qquad \Delta_0 = C^0_{11}C^0_{44} - |C^0_{14}|^2$$

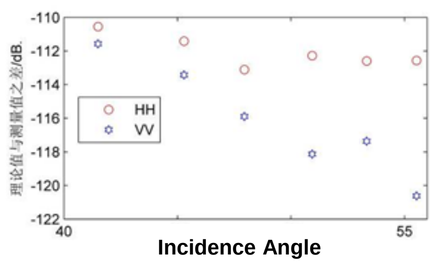
$$\begin{aligned} u_0 &= (C^0_{44}C^0_{21} - C^0_{41}C^0_{24}) / \Delta_0, \\ v_0 &= (C^0_{11}C^0_{24} - C^0_{21}C^0_{14}) / \Delta_0, \\ z_0 &= (C^0_{44}C^0_{31} - C^0_{41}C^0_{34}) / \Delta_0, \\ w_0 &= (C^0_{11}C^0_{34} - C^0_{31}C^0_{14}) / \Delta_0, \end{aligned}$$

P-Band Quad-Pol SAR

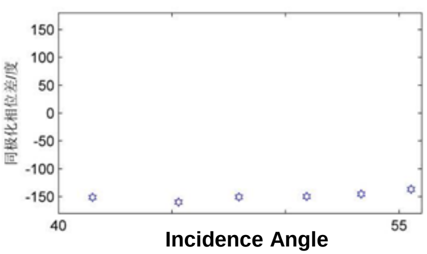
□Polarimetric Calibration



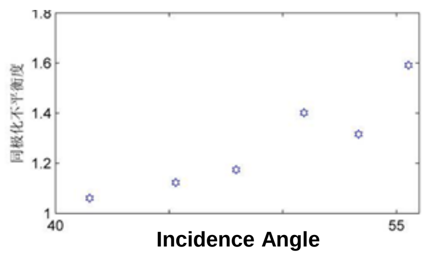
Intensity of Tri_Reflc



Intensity: Estim-Meas

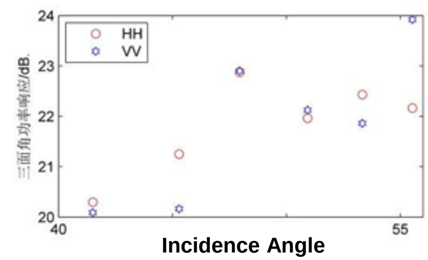


Co-Pol Phase Difference

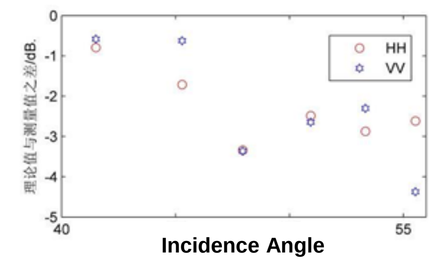


Co-Pol Imbalance

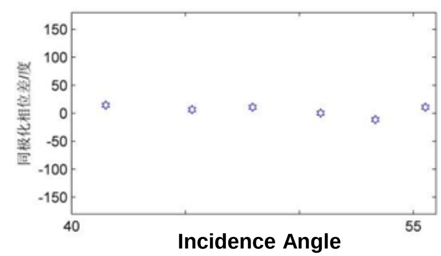
Before Claibration : intensity , phase



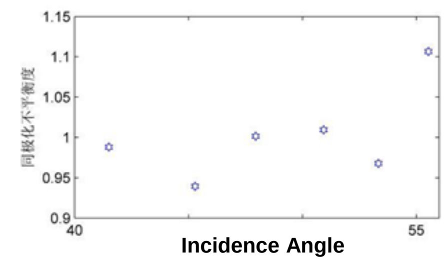
Intensity of Tri_Reflc



Intensity: Estim-Meas



Co-Pol Phase Difference



Co-Pol Imbalance

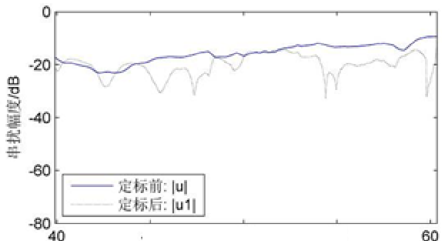
After Claibration : intensity , phase

- □Intensity difference between far range and near range < 4dB
- □Intensity difference between HH and VV < 2dB
- □Phase difference between HH and VV →0°
- □Co-Pol Imbalance ratio →1

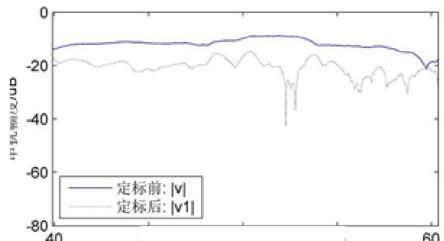
u,w 串扰定标

P-Band Quad-Pol SAR

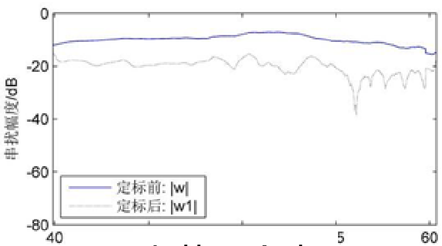
Polarimetric Calibration



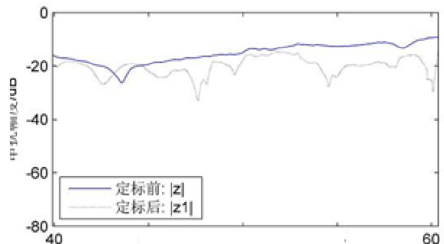
Cross Talk of |u|



Cross Talk of |v|



Cross Talk of |w|

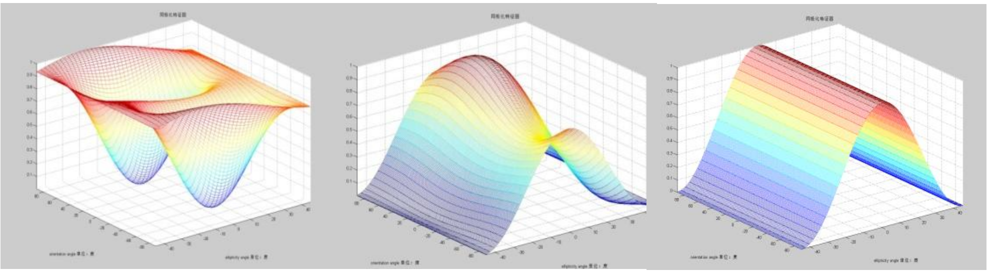


Cross Talk of |z|

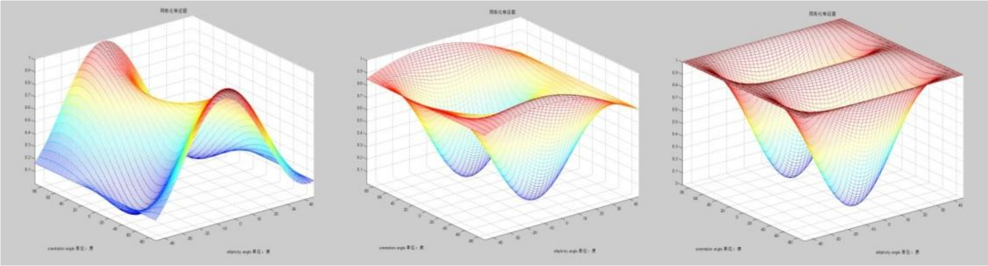
- Cross Talk < -30dB

Polarization Response

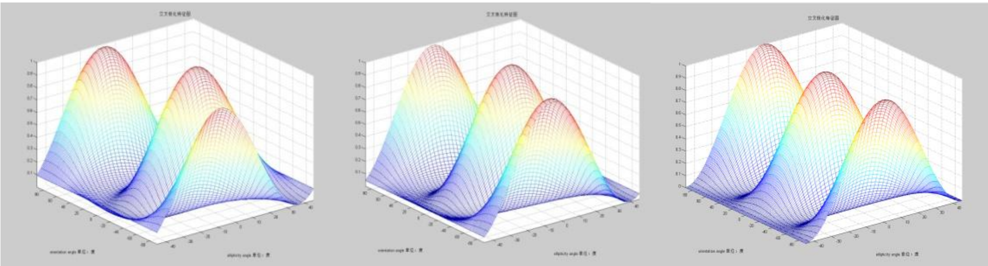
Measure After Cal Model



Trihedral corner reflector



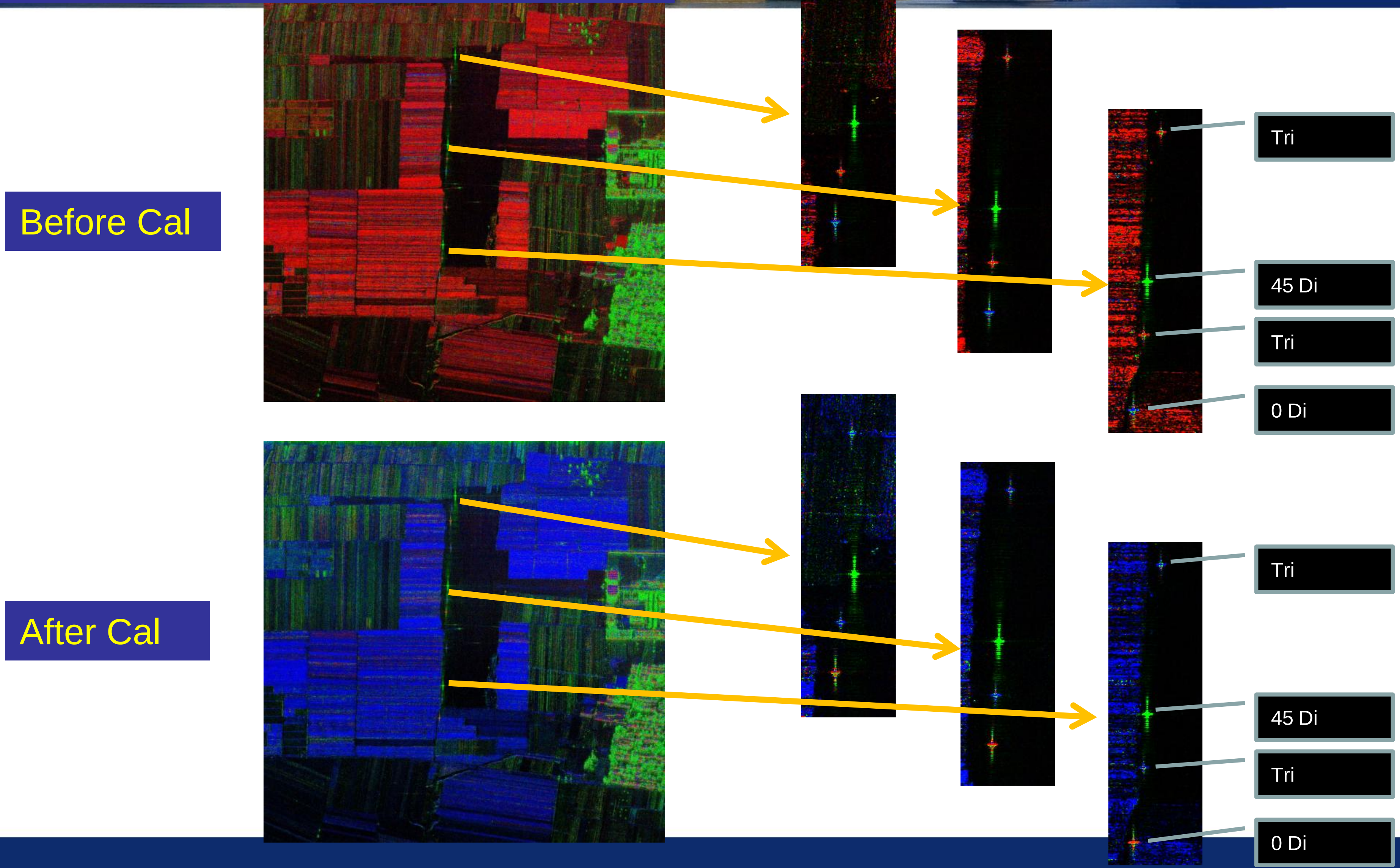
Dihedral corner reflector 0°



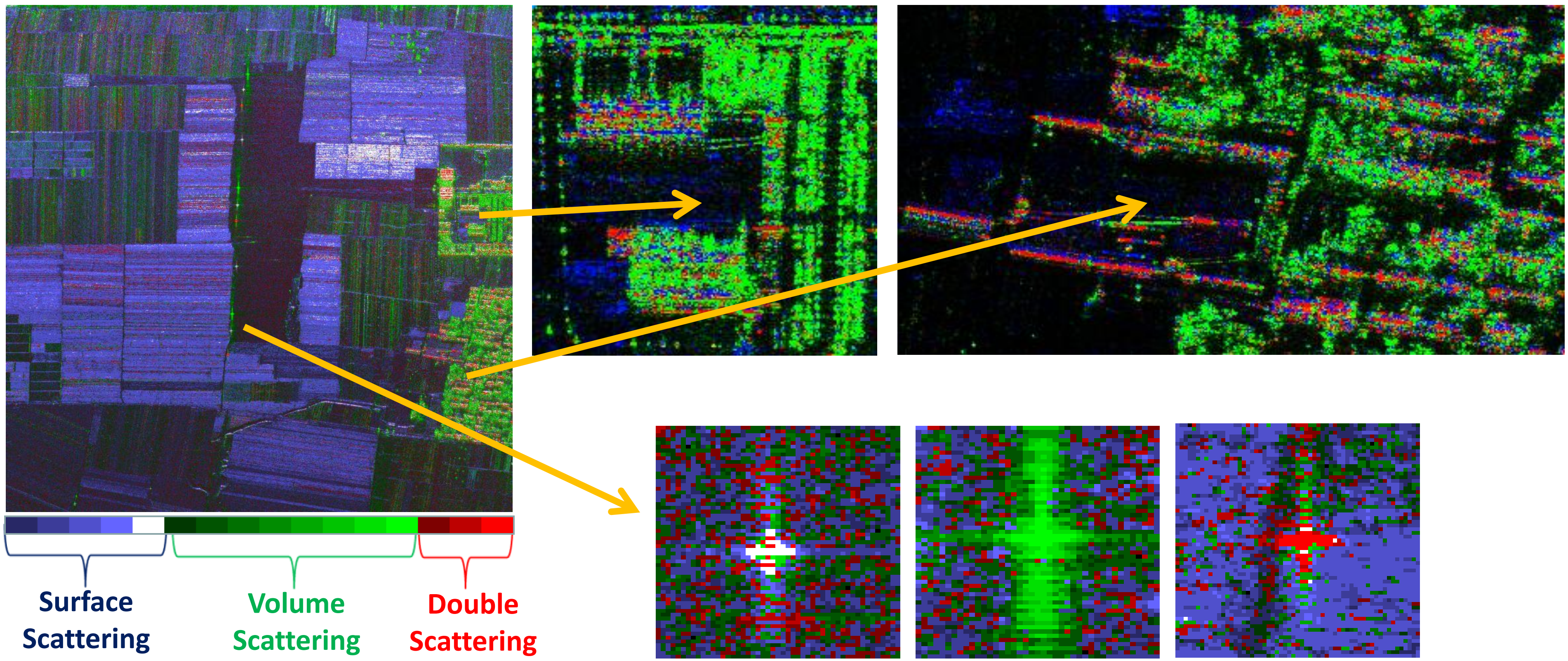
Dihedral corner reflector 45°

P-Band Quad-Pol SAR

Freeman-Durden Decomposition



Freeman-Durden Wishart Classification



Trihedral corner reflector

Dihedral corner reflector 45°

Dihedral corner reflector 0°

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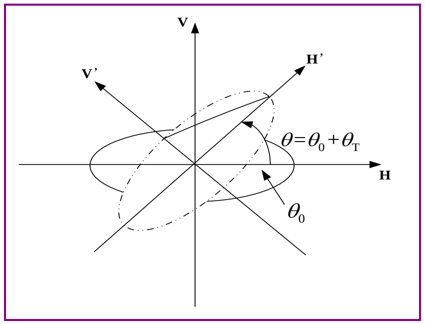
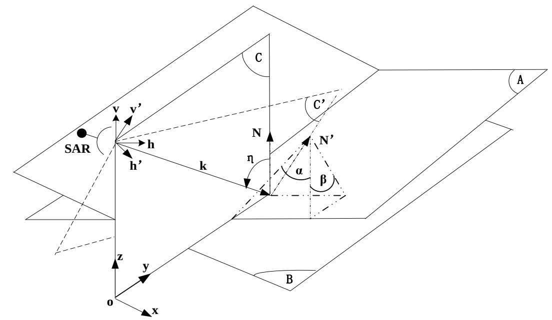
Polarimetric Topography Estimation Model



Polarization ellipse rotation



A geometrical scheme illustration of incidence plane, flat and tilted surfaces and polarization ellipse rotation

Topography-POA shift model （Lee, 1998）

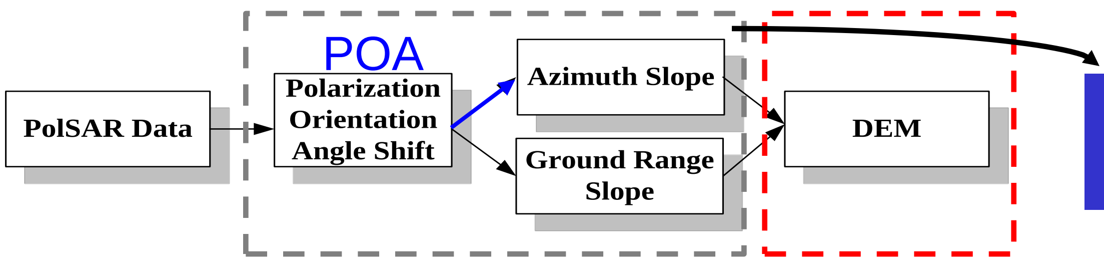
$$\tan\theta_T = \frac{\tan\omega}{\sin\eta - \cos\eta\tan\beta}$$

ω: azimuth slope

β: ground range slope

η: incidence angle

Flow chart:



Compensation-Lambertian method

P-Band Quad-Pol SAR

Basic principle of the Compensation-Lambertian method*

POA Shift —Slope Model**

$$\tan(\theta) = \frac{\tan(\omega)}{\sin(\varphi) - \cos(\varphi)\tan(\beta)}$$

** J. S. Lee et al, "Polarimetric SAR Data Compensation for Terrain Azimuth Slope Variation", 2000

Lambertian Model***

$$I(\omega,\beta) = K\sigma_0 R_g R_a \frac{\cos(\varphi)\sin^2(\varphi+\beta)}{\cos(\varphi+\beta)}\cos(\omega)$$

$$I = \frac{m_{22}+m_{33}}{2} + \frac{\sqrt{(m_{22}-m_{33})^2 + 4m_{23}{}^2}}{2}\sin(4\varphi - \tan^{-1}(\frac{m_{33}-m_{22}}{2m_{23}}))$$

*Yang LI et al, "Estimation of Terrain Slope Using A Compensation-Lambertian Method from Single-Pass POLSAR Data", IGARSS 2008.

Polarization Orientation Angle (POA) Shift*

Polarization Compensation**

$$T^{new} = UTU^T, U = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos 2\theta & \sin 2\theta \\ 0 & -\sin 2\theta & \cos 2\theta \end{bmatrix}$$

$$\tan(0) = \frac{\tan(0)}{\sin(\varphi) - \cos(\varphi)\tan(\beta)}$$

$$I(0,\beta) = K\sigma_0 R_g R_a \frac{\cos(\varphi)\sin^2(\varphi+\beta)}{\cos(\varphi+\beta)}\cos(0)$$

Initial Slope

$$\omega = arc\cos(\frac{I(\omega,\beta)}{I(0,\beta)})$$

$$\beta = arc\tan(\frac{\sin\varphi - \tan\omega / \tan\theta}{\cos\varphi})$$

Full Multigrid Method (2nd order)

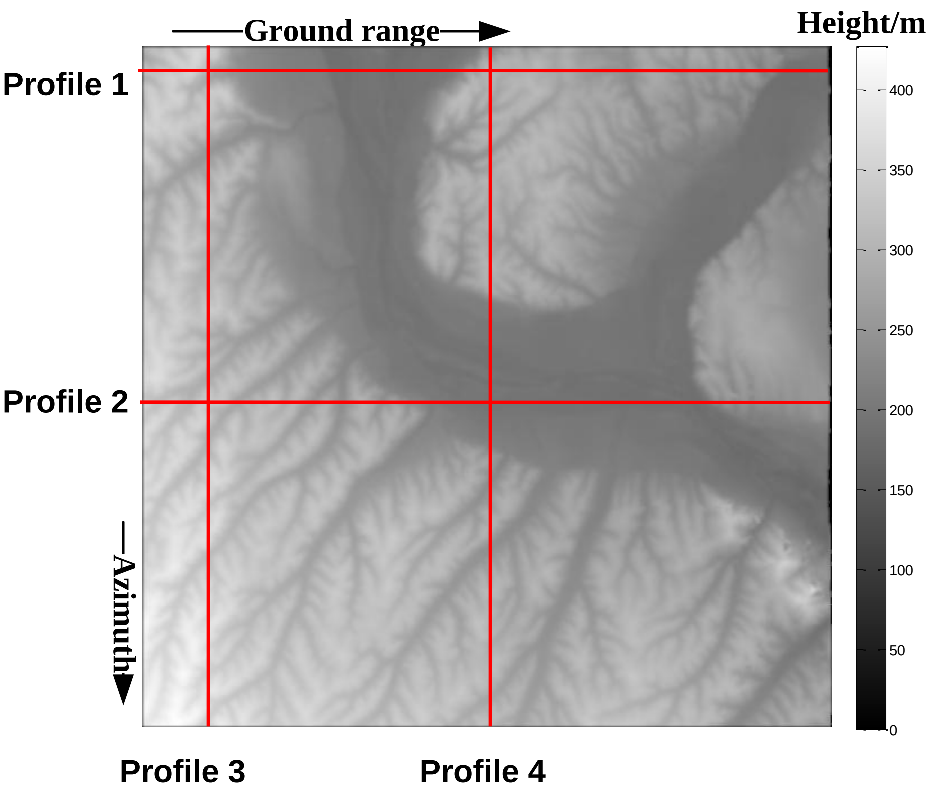
Estimated Height Value *H*

Slope Estimation

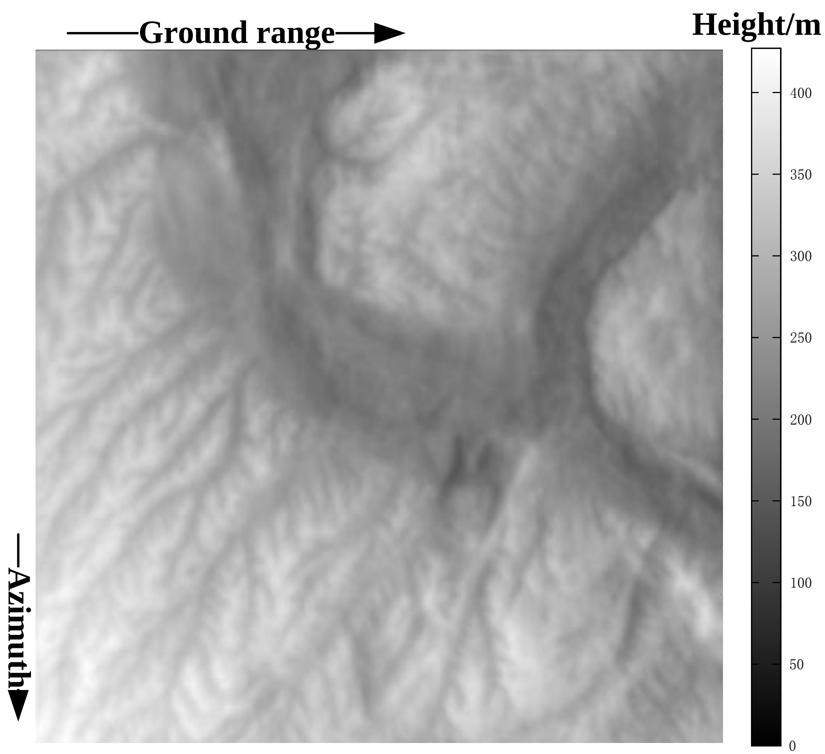
$$\omega(x,y) \approx \arctan(\frac{H(x,y) - H(x-1,y)}{R_a})$$

$$\beta(x,y) \approx \arctan(\frac{H(x,y) - H(x,y-1)}{R_g})$$

DEM estimation results



InSAR DEM



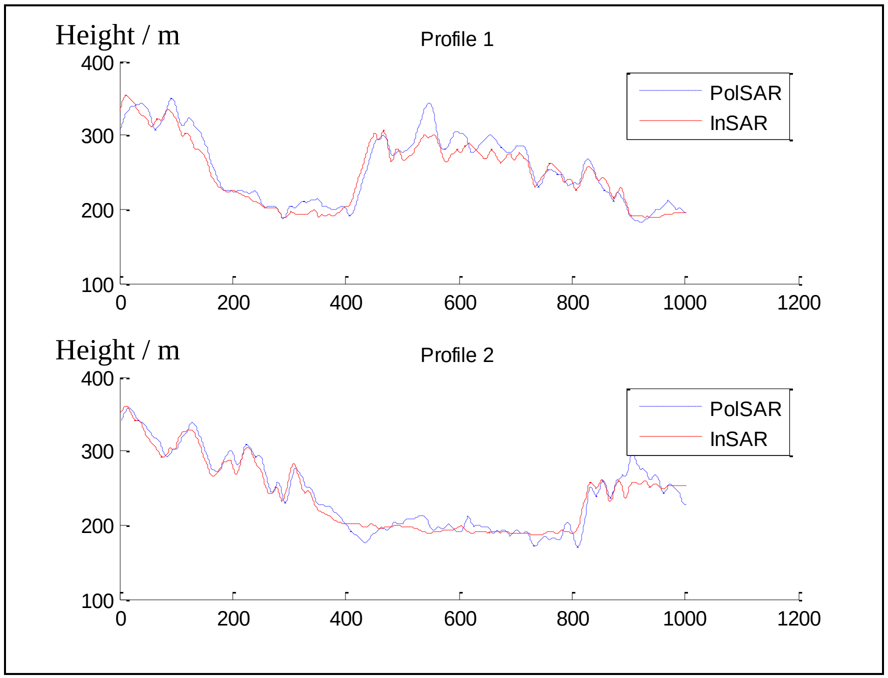
POLSAR DEM

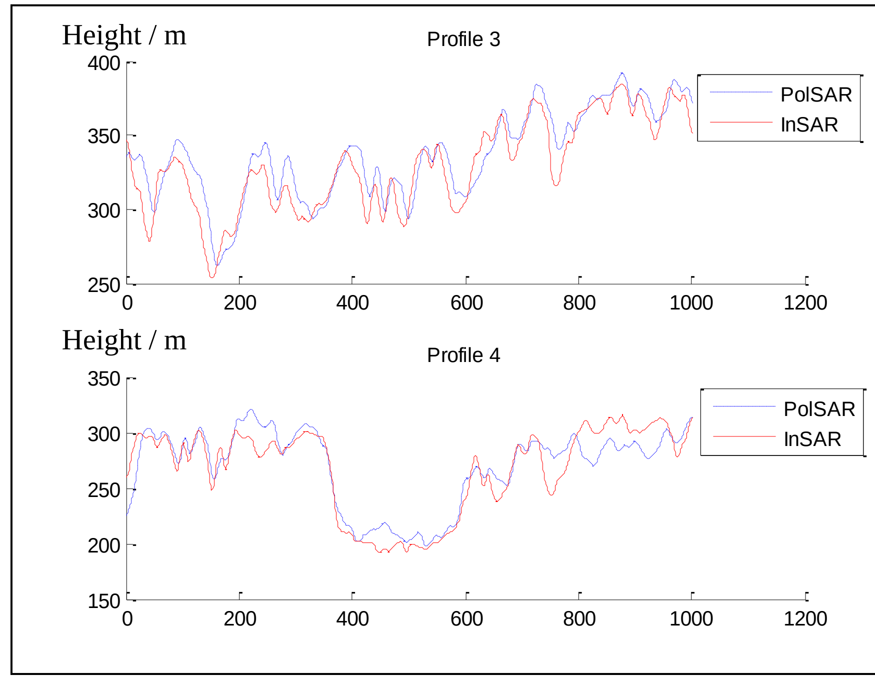
AIRSAR, L-band, Camp Roberts, California, Resolution 10m×10m

P-Band Quad-Pol SAR

DEM estimation results

- **Profile line comparison**



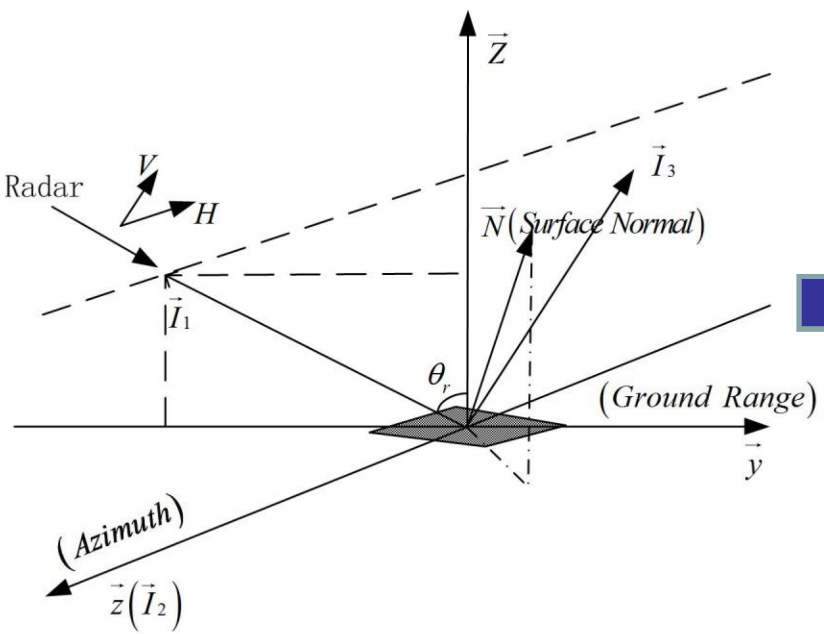


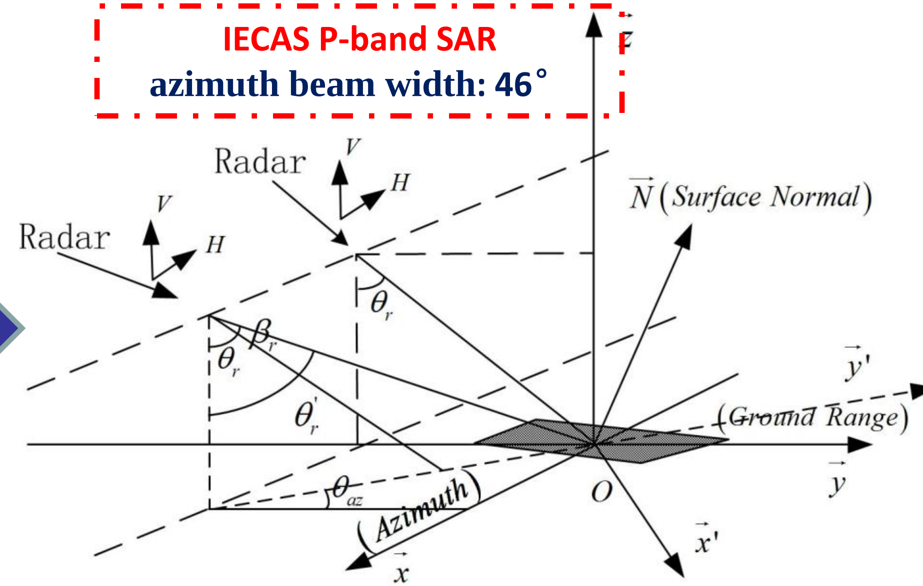
Size：1024×1024

RMSE: 19m

P-Band Quad-Pol SAR

New Polarimetric Topography Estimation Model





$$\tan\theta = \frac{\tan\omega}{-\tan\gamma\cos\theta_r + \sin\theta_r}$$

$$\tan\theta = \frac{\cos\theta_{az}\cdot\tan\omega + \sin\theta_{az}\cdot\tan\gamma}{(\sin\theta_{az}\cdot\tan\omega - \cos\theta_{az}\cdot\tan\gamma)\cdot\cos\theta_r' + \sin\theta_r'}$$

New feature is used to estimate the two orthogonal slopes from single-pass POLSAR data

P-Band Quad-Pol SAR

New Polarimetric Topography Estimation Model

IECAS P-band SAR

azimuth beam width: 46°

POA Estimation:

-Subaperture Proc
-POA est. from different observation angles

Slope Estimation:

-two-element linear regression

Polarization Orientation Angle (POA) Shift*

Polarization Compensation**

$$T^{new} = UTU^{T}, U = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos 2\theta & \sin 2\theta \\ 0 & -\sin 2\theta & \cos 2\theta \end{bmatrix}$$

$$\tan(0) = \frac{\tan(0)}{\sin(\varphi) - \cos(\varphi)\tan(\beta)}$$

$$I(0,\beta) = K\sigma_0 R_g R_a \frac{\cos(\varphi)\sin^2(\varphi+\beta)}{\cos(\varphi+\beta)}\cos(0)$$

Initial Slope

$$\omega = arc\cos\left(\frac{I(\omega,\beta)}{I(0,\beta)}\right)$$

$$\beta = arc\tan\left(\frac{\sin\varphi - \tan\omega / \tan\theta}{\cos\varphi}\right)$$

Full Multigrid Method (2nd order)

Estimated Height Value *H*

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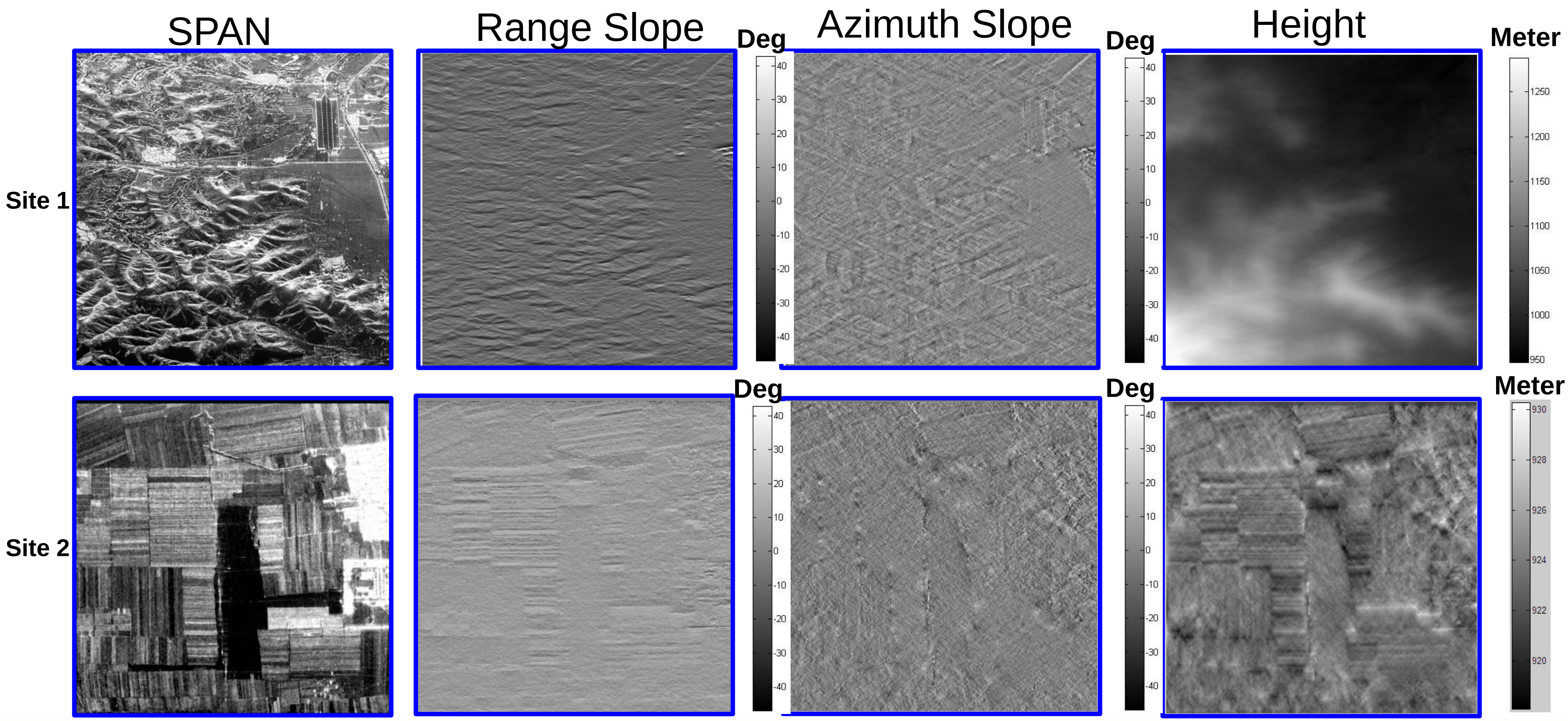
$$\omega(x,y) \approx \arctan\left(\frac{H(x,y) - H(x-1,y)}{R_a}\right)$$

$$\beta(x,y) \approx \arctan\left(\frac{H(x,y) - H(x,y-1)}{R_g}\right)$$

P-Band Quad-Pol SAR

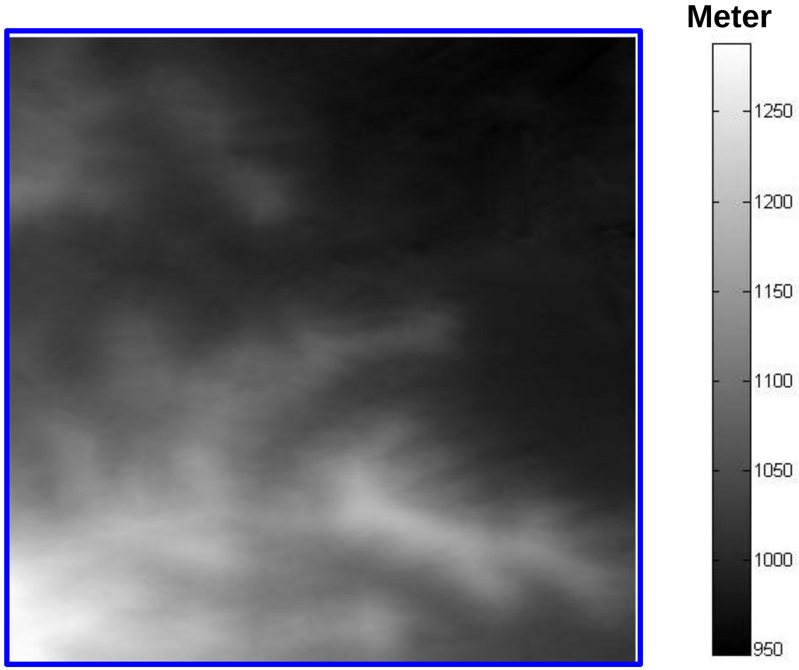
Polarimetric Topography Estimation



Polarimetric Topography Estimation

Site 1: Mountain Area

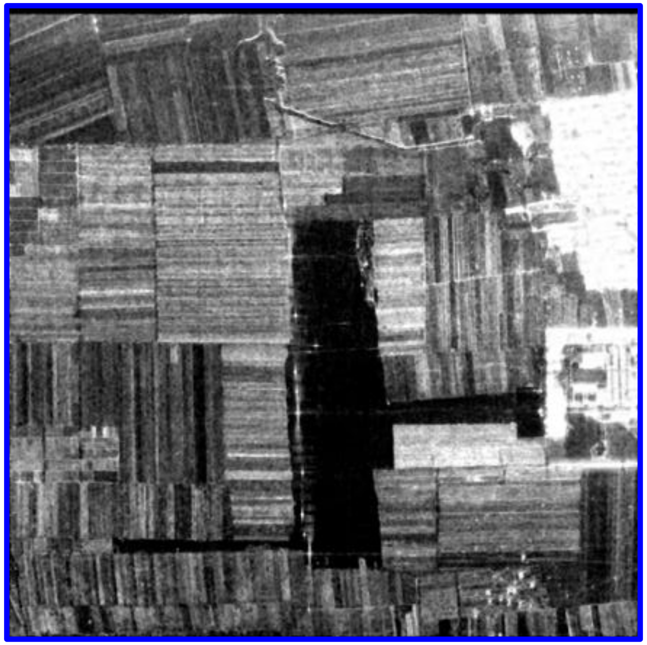
Intensity Map



Height Map

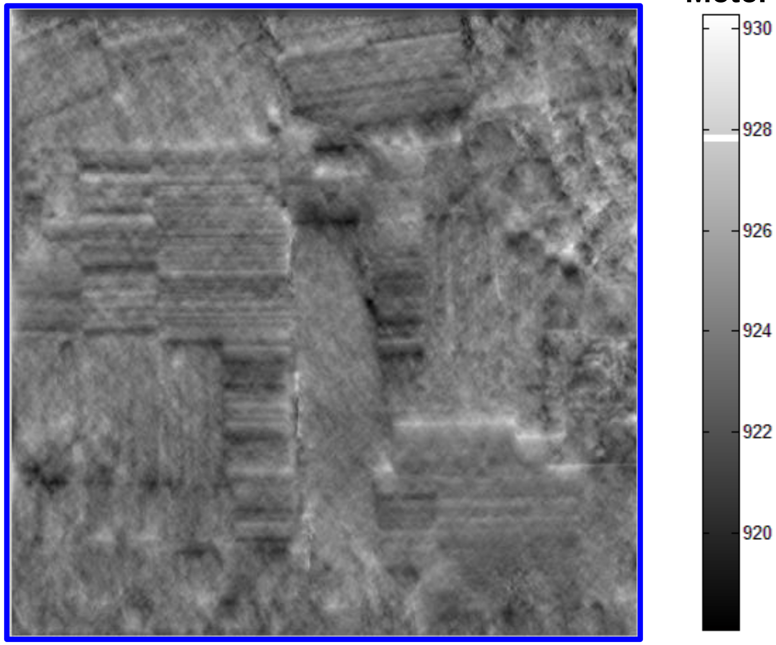
Polarimetric Topography Estimation

Site 1: Mountain Area



Intensity Map

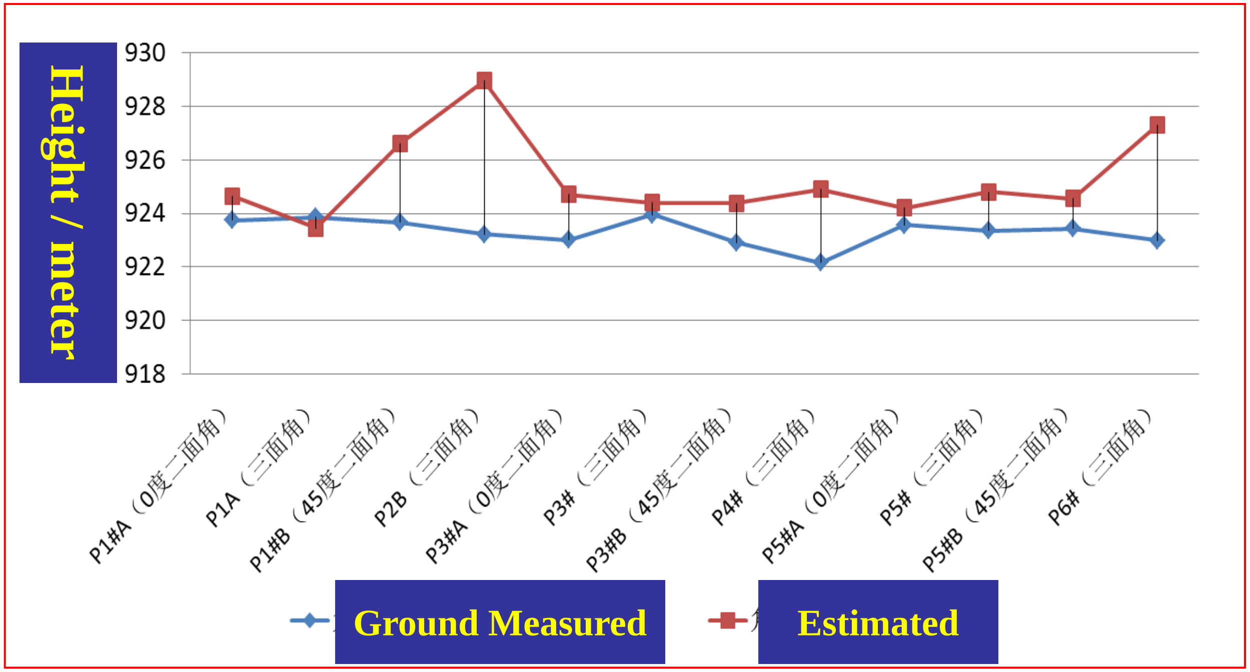
Meter



Height Map

Corner reflector Validation of Test 2

12 corner reflectors were used to validate the accuracy of Test 2 DEM



- Error: P1#B（2.9436m）P2B（5.7310m）P6#（4.3056m）

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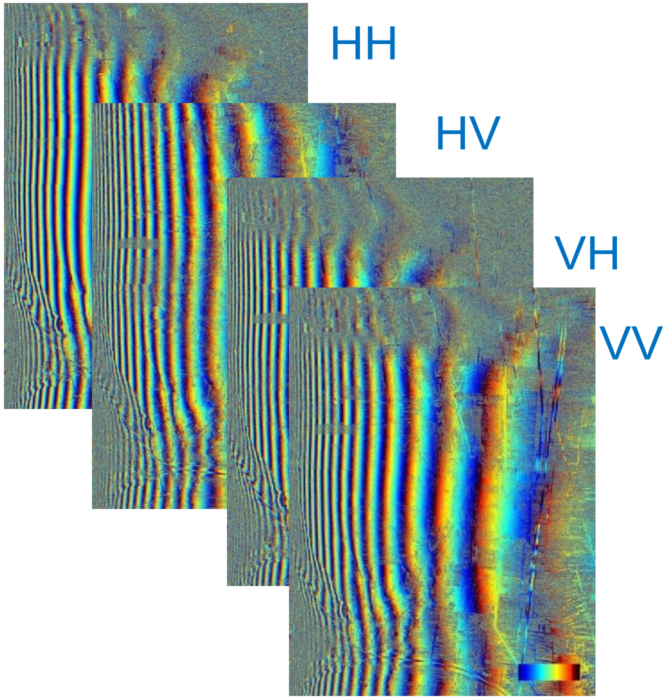
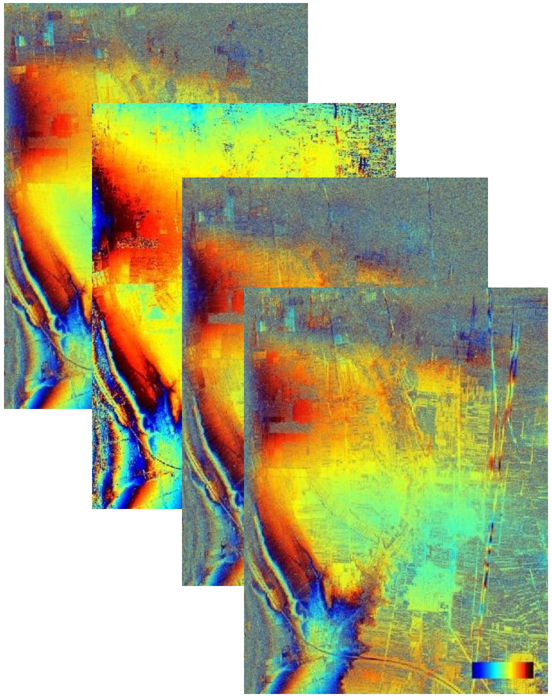
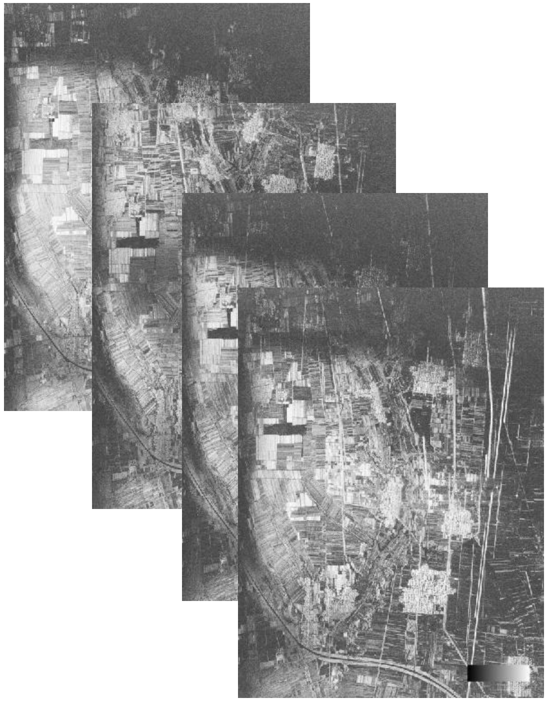
- Summary

□ Repeat-Pass PolInSAR Maps (5m Baseline)







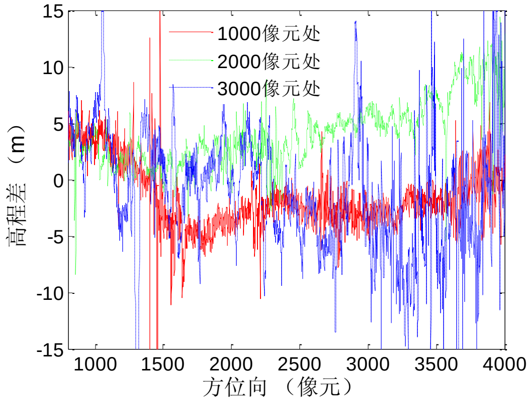
Interferograms

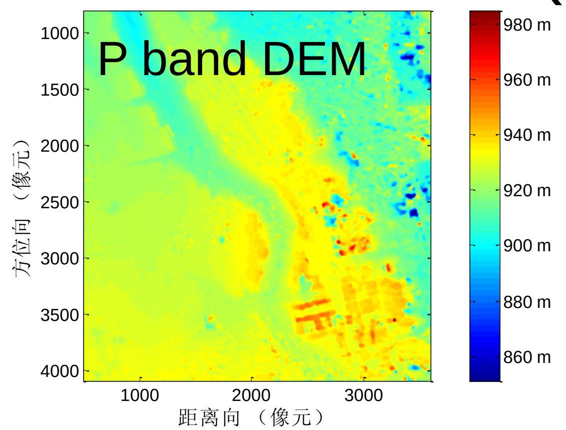
After Flat Earth Removing

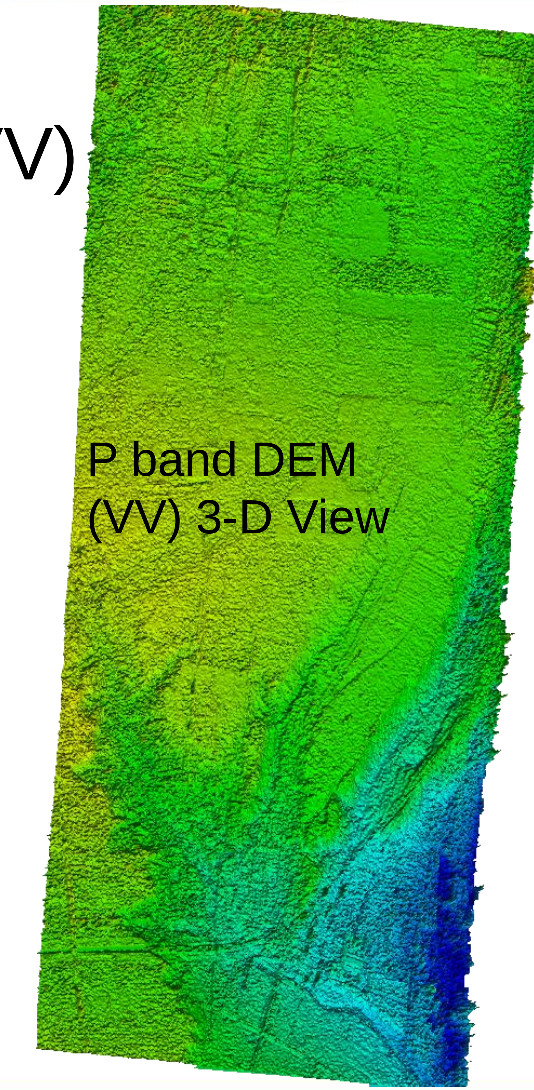
Coherence Maps

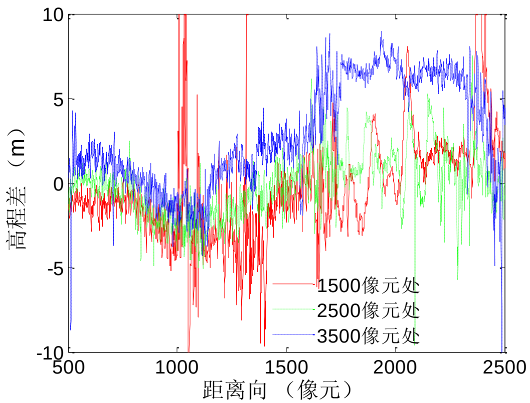
P-Band Quad-Pol SAR

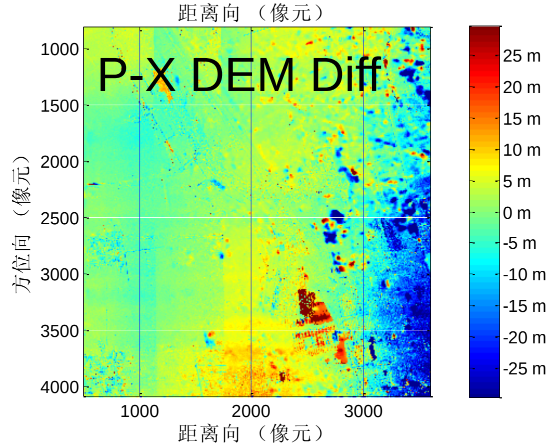
□ Repeat-Pass PolInSAR DEM (5m, VV)







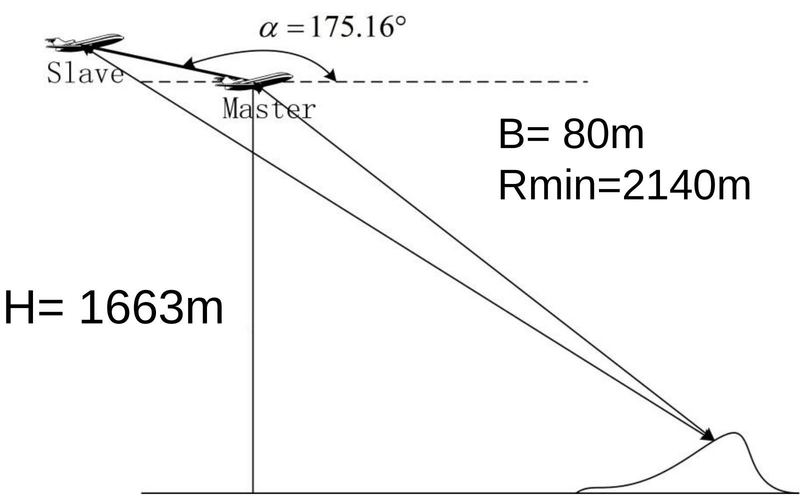


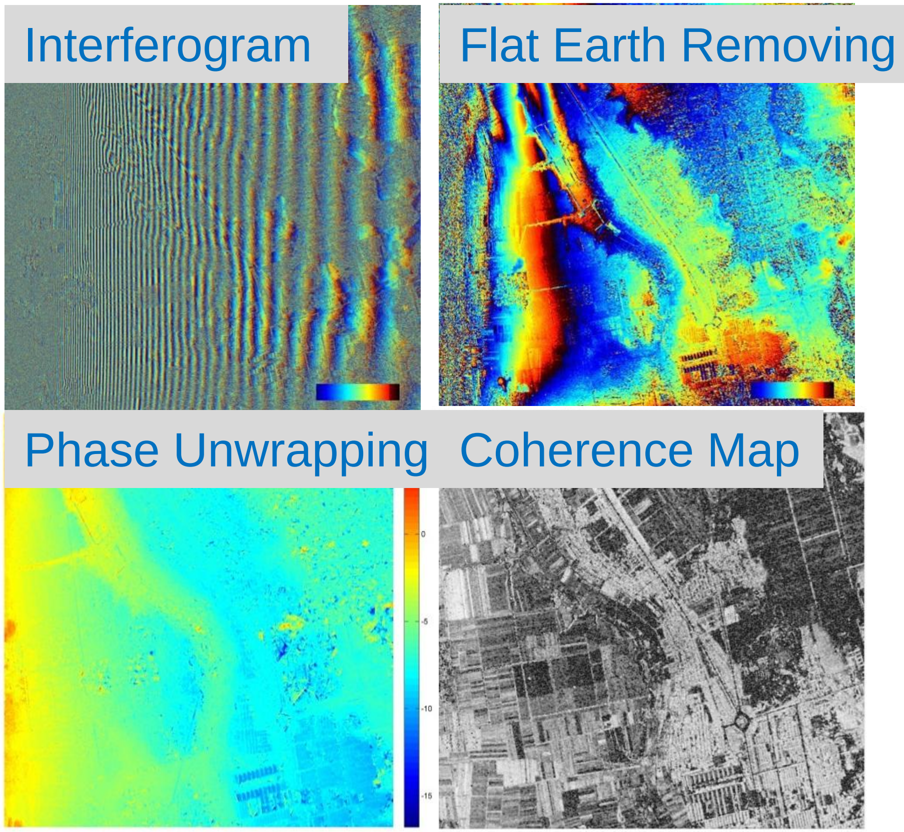


Accruacy: 6m, Ref: X-Band DEM

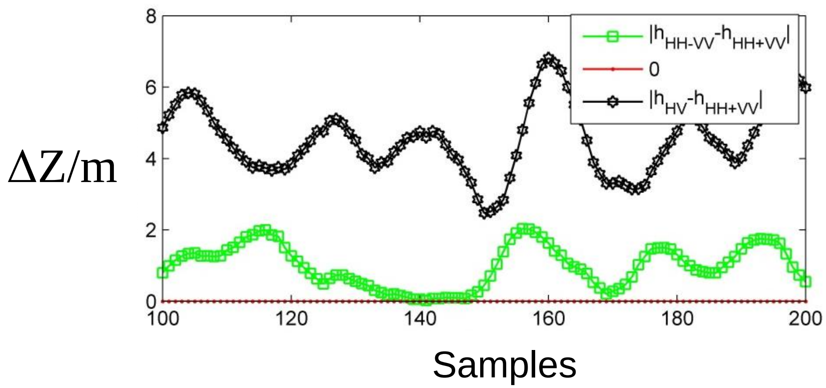
P-Band Quad-Pol SAR

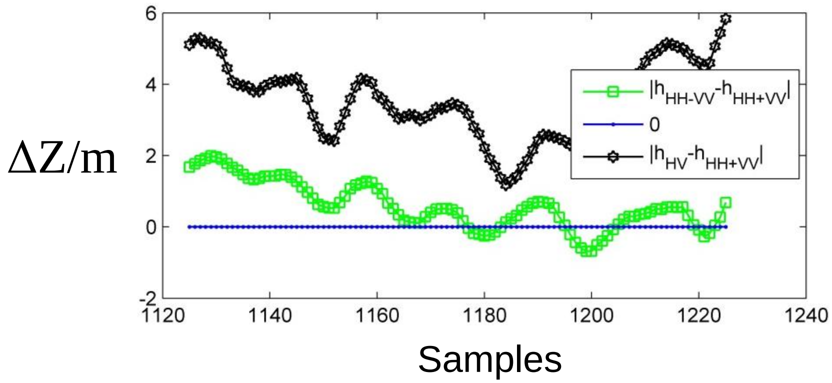
Repeat-Pass PolInSAR Maps (80m Baseline)

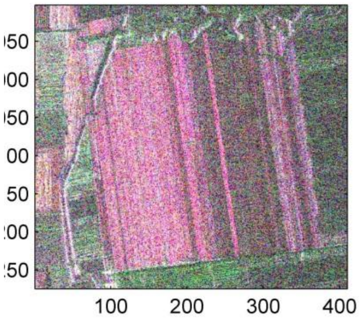


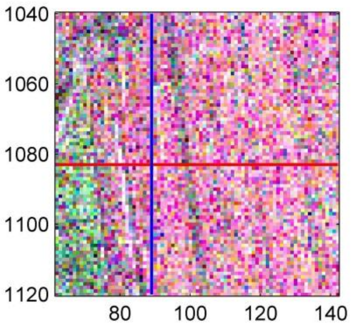


Farmland Scattering Center Variation with Polarization









Outline

- System Overview
- X-Band Twin-Antenna InSAR
- P-Band Quad-Pol SAR
  - Polarimetric Calibration
  - Single-Pass PolSAR Processing
  - Repeat-Pass InSAR/ PolInSAR Processing
- Summary

Summary

- Involved in all 4 packages
  - WP1. Land Cover Analysis
  - WP2. Earth Surface Deformation Monitoring and DEM
  - WP3. Forest Vertical Structure Parameters Extraction
  - WP4. PolSARpro Software Continued Development
- Future work
  - Continually contribute to the 4 packages
  - Classification methods for land use
  - Scattering models for terrain targets
  - IECAS-X/P-SAR system data processing
  - Young scientists and students

Thank you !

Welcome to IECAS!