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Terrain Correction Methods for Multi-Dimensional SAR Data Applied to Forest AGB Estimation

Erxue Chen[1], Zengyuan Li[1], Lei Zhao[1],

Wen Hong[2], Laurent Ferro Famil[3]

[1] Institute of Forest Resources Information Technique, CAF

[2]Institute of Electronic , CAS

[3]I.E.T.R - Univ Rennes 1

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Outlines

1. Background
2. Three-Stage Terrain Correction Method For PolSAR
3. Terrain Correction Method For InSAR coherence
4. The combined estimation approach of Forest AGB based on CASMSAR (X-InSAR, P-PolSAR)
5. Summary

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1. Background

- Single-Dimensional SAR
  - Single-Polarization; Single-Frequency; Single-Baseline.
- Multi-Dimensional SAR (Yirong Wu, 2013)
  - Multi-Polarization; Muti-Frequency; Multi-Baseline; and their Combinations.
- Based on Multi-Dimensional SAR, we can obtain more characteristics associated with forest AGB.
  - Multi-Dimensional SAR is one of the most promising technologies that can estimate forest AGB of large area.

1. Background

- **Terrain effects is a big problem for the application of Single/Multi-Dimensional SAR data**
  - **Owing to the characteristics of side-looking illumination by SAR sensors.**
- **Current terrain correction methods are not fully applicable to Multi-Dimensional SAR data**
  - **Most methods proposed for a single backscatter intensity value**

Radar illumination

PolSAR PauliRGB

Terrain Effects!

Radar illumination

InSAR Coherence

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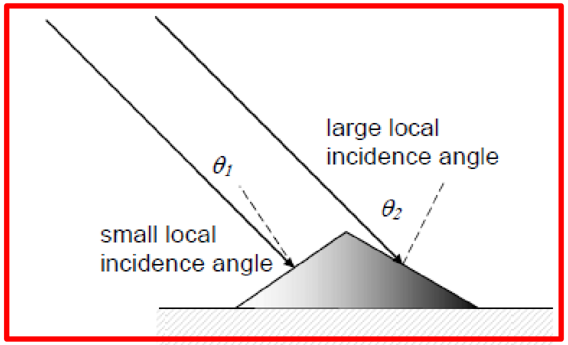
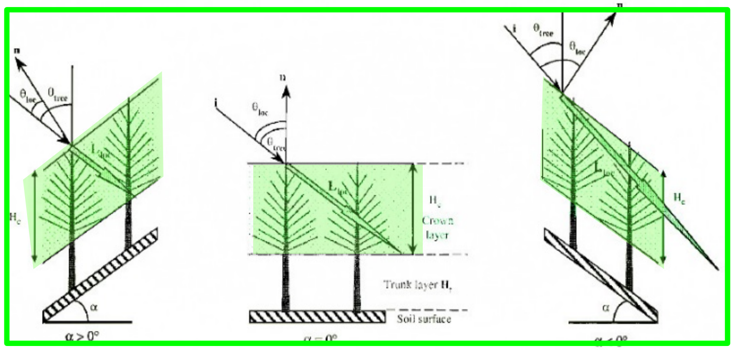
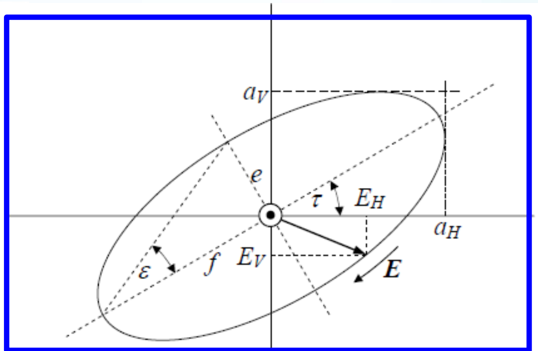
2. Three-Stage Terrain Correction Method for PolSAR Data

2.1 Background

- The influence of topography on PolSAR image
  - Variation of Effective Scattering Area (ESA)
    - It is due to radar observation geometry and local terrain. In other words, it is the variation of the number of the scatterer in one pixel.
  - Variation of local scattering mechanisms, etc.
    - This phenomenon is commonly known as Angular Variation Effect (AVE) that mainly appears in vegetation area
  - Variation of polarization states
    - It is caused by azimuth slopes that induce Polarization Orientation Angle (POA) changes.







（T. Castel 2001）

2. Three-Stage Terrain Correction Method for PolSAR Data

2.1 Background

- Effective Scattering Area correction (ESAc)
  - Based on local incidence angle

$$\sigma^0 = \beta^0 \cdot \sin\theta_{loc} \qquad \text{(Freeman, 1989)}$$

  - Based on surface tilt angles

$$\sigma^0 = \beta^0 \cdot \sin(\theta - \theta_r)\cos\theta_a \qquad \text{(Zyl, 1993)}$$

  - Based on projection angle

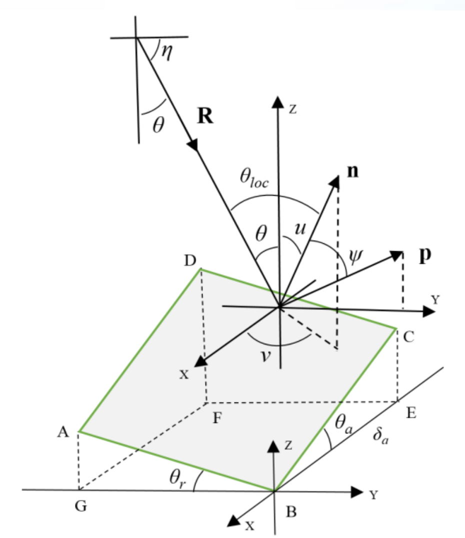
$$\sigma^0 = \beta^0 \cdot \cos\psi \qquad \text{(Ulander, 1996)}$$

  - Based on area integral

$$\sigma^0 = \beta^0 \cdot \frac{A_\beta}{\int_{DEM} A_\sigma} \qquad \text{(David Small, 2011)}$$

  - ***More and more accurate method proposed for calculating the effective scattering area***

More Accurate !



2. Three-Stage Terrain Correction Method for PolSAR Data

2.1 Background

- Angular Variation Effect correction (AVEc)

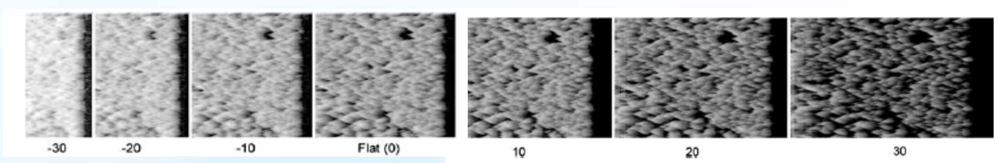
Basic Model: $\sigma_{\theta_{loc}} \approx \sigma / \cos^{n}(\theta_{loc})$ ***n is the core !!!***

- Based on semi-empirical model derived from radiative transfer model

$$n = 1 + a \log\left(\frac{1 - \exp(-b\tau)}{1 - \exp(-c\tau)}\right)$$

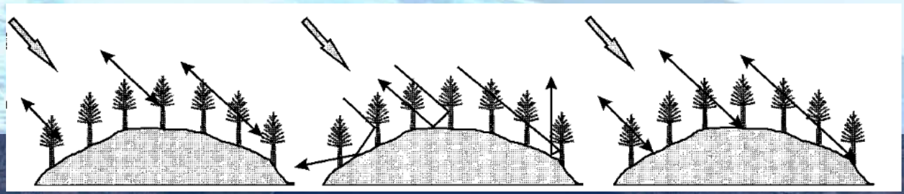
τ: crown optical depth （T. Castel, 2001）

- Based simulate SAR image derived from forward simulate model



（G. Sun, 2002）

- ***These method can not adaptively determining the value of n and not suitalbe to PolSAR matrix data.***



2. Three-Stage Terrain Correction Method for PolSAR Data

2.1 Background

- Polarization Orientation Angle correction (POAc)
  - Based on Local imaging geometry (DEM) （Lee; Schuler, 2000）

$$\tan\theta_p = \frac{\tan\theta_a}{-\tan\theta_r \tan\theta + \sin\theta}$$

θ_p POA shift angle

  - Based circular polarization method

$$\theta_p = Arg(\langle S_{RR} S_{LL}^* \rangle) / 4$$

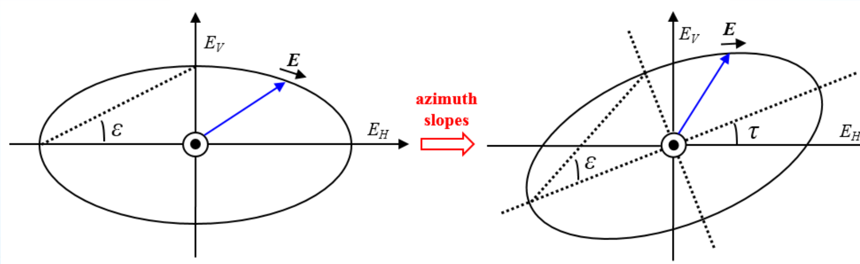
S_{RR} : rignt-right circular polarization
S_{LL} : left-left circular polarization

The most commonly used algorithms !

$$C = \begin{bmatrix} \langle |S_{HH}|^2 \rangle & \langle \sqrt{2} S_{HH} S_{HV}^* \rangle & \langle S_{HH} S_{VV}^* \rangle \\ \langle \sqrt{2} S_{HV} S_{HH}^* \rangle & \langle 2 |S_{HV}|^2 \rangle & \langle \sqrt{2} S_{HV} S_{VV}^* \rangle \\ \langle S_{VV} S_{HH}^* \rangle & \langle \sqrt{2} S_{VV} S_{HV}^* \rangle & \langle |S_{VV}|^2 \rangle \end{bmatrix}$$

$$C_{POAC} = VCV^T$$

$$V = \frac{1}{2} \begin{bmatrix} 1+\cos 2\theta & \sqrt{2}\sin 2\theta & 1-\cos 2\theta \\ -\sqrt{2}\sin 2\theta & 2\cos 2\theta & \sqrt{2}\sin 2\theta \\ 1-\cos 2\theta & -\sqrt{2}\sin 2\theta & 1+\cos 2\theta \end{bmatrix}$$



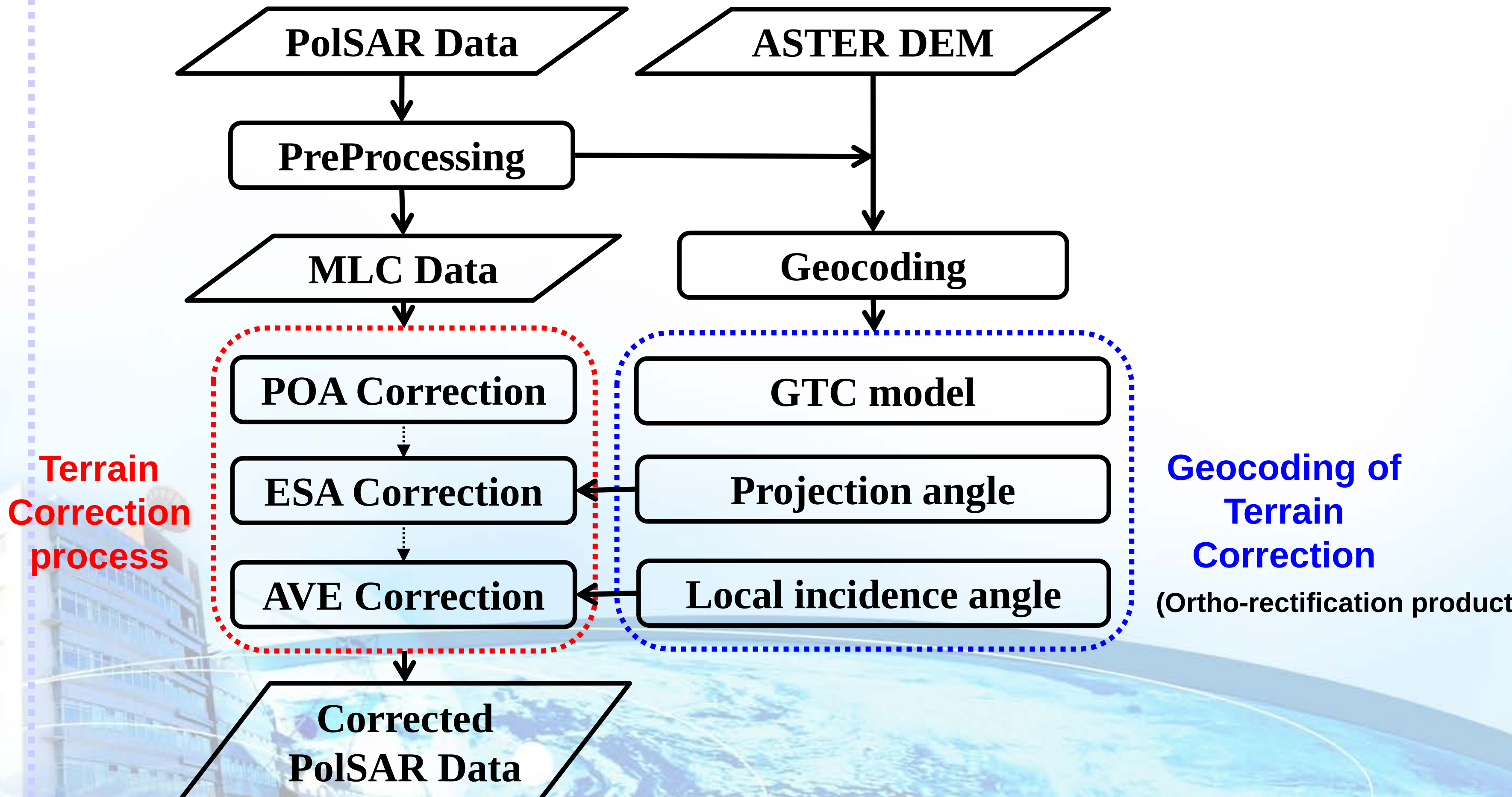
τ: polarization orientation angle

ε: ellipticity angle

2. Three-Stage Terrain Correction Method for PolSAR Data

2.2 Methods

- Flow chart



2. Three-Stage Terrain Correction Method for PolSAR Data

2.2 Methods

- Three-Stage Terrain Correction

$$\sigma^0_{rtc} = \boxed{\sigma^0_{POC}} \cdot \boxed{\cos\psi} \cdot \boxed{\left(\frac{\cos\theta_{ref}}{\cos\theta_{loc}}\right)^n}$$

$$C_{POC} = VCV^T$$

$$V = \frac{1}{2}\begin{bmatrix} 1+\cos 2\theta & \sqrt{2}\sin 2\theta & 1-\cos 2\theta \\ -\sqrt{2}\sin 2\theta & 2\cos 2\theta & \sqrt{2}\sin 2\theta \\ 1-\cos 2\theta & -\sqrt{2}\sin 2\theta & 1+\cos 2\theta \end{bmatrix}$$

Stage①:POA Correction

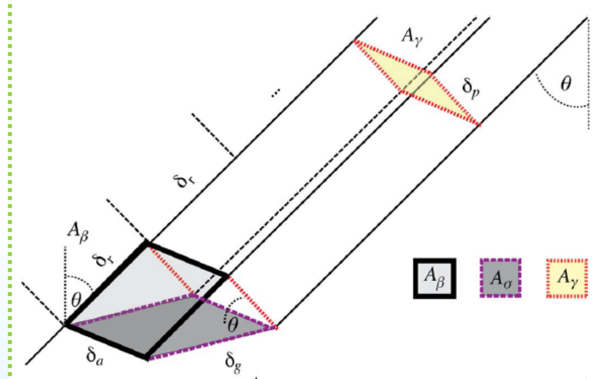
- Circular polarization method

Stage②:ESA Correction

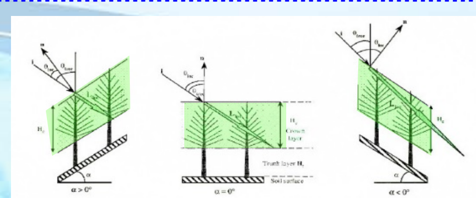
- Projection angle method

Stage③:AVE Correction

- Minimum correlation coefficient method



(D. Small 2011)


(T. Castel 2001)

2.2 Methods

- Minimum correlation coefficient method
  - We can evaluate the correction result by the correlation between corrected backscatter value and the local incident angle.

$$\sigma_{\theta_{loc}} = \sigma \cdot \left(\frac{\cos \theta_{ref}}{\cos \theta_{loc}} \right)^{n} \Rightarrow \begin{aligned} f(n) &= \rho(\theta_{loc}, \sigma_{\theta_{loc}}) \\ n &= \arg\min\{abs[f(n)]\} \end{aligned}$$

  - The value of ***n*** for each polarization channel： $n(hh)=N_1, n(hv)=N_2, n(vv)=N_3$
  - So, we get the correction coefficient for each polarization channel：

$$k_{hh} = \left(\frac{\cos \theta_{ref}}{\cos \theta_{loc}} \right)^{N_1} \qquad k_{hv} = \left(\frac{\cos \theta_{ref}}{\cos \theta_{loc}} \right)^{N_2} \qquad k_{vv} = \left(\frac{\cos \theta_{ref}}{\cos \theta_{loc}} \right)^{N_3}$$

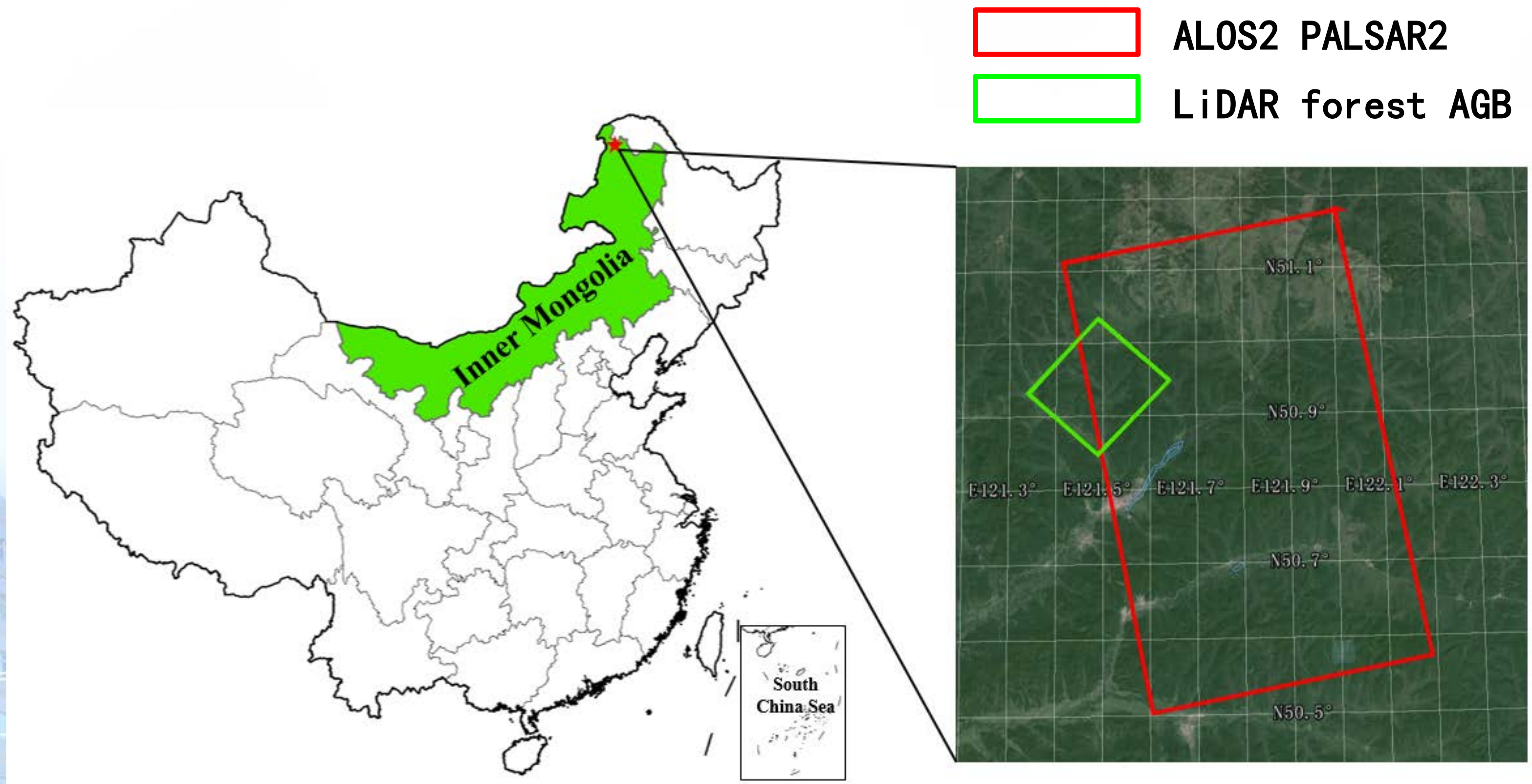
  - Finaly, the correction coefficient matrix ***K*** for polarization covariance matrix ***C*** is:

$$K = \begin{bmatrix} k_{hh} & \sqrt{k_{hh}k_{hv}} & \sqrt{k_{hh}k_{vv}} \\ \sqrt{k_{hh}k_{hv}} & k_{hv} & \sqrt{k_{hv}k_{vv}} \\ \sqrt{k_{hh}k_{vv}} & \sqrt{k_{hv}k_{vv}} & k_{vv} \end{bmatrix} \qquad C_{out} = C \odot K$$

Note：$\odot$ is the Hadamard product.

2.3 Test Data

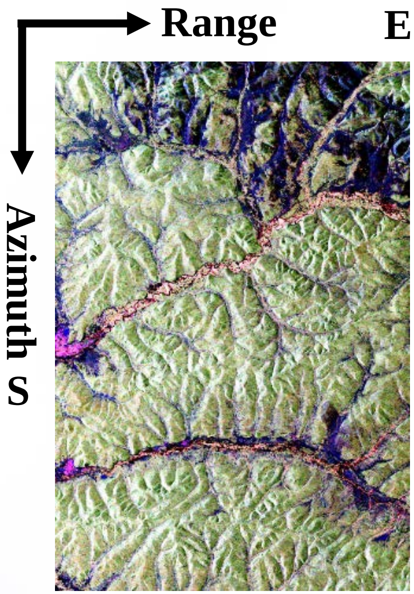
- DaXingAnLing test site in Inner Mongolia
  - The location of study site:



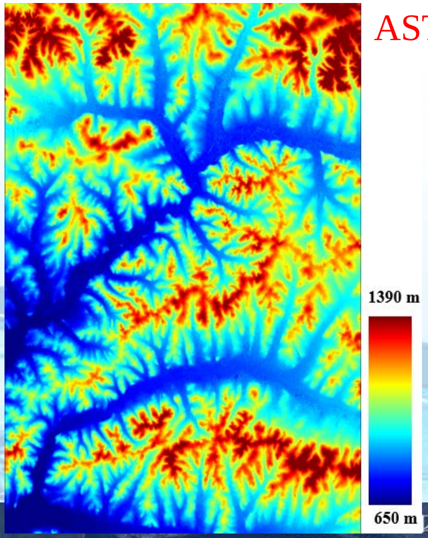
2. Three-Stage Terrain Correction Method for PolSAR Data

2.3 Test Data

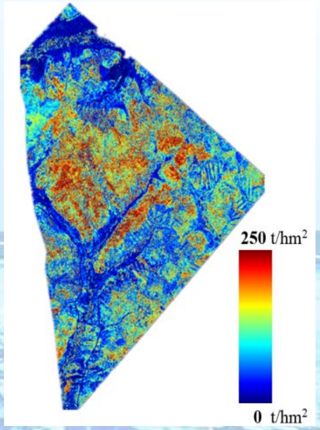
- Data
  - PolSAR Data
    - **ALOS-2 PALSAR-2 HBQ**
    - **2014-8-29**
    - **L-band**
    - **2.64 m×2.86m**
  - Reference Data



Pauli RGB



ASTER DEM(30m)

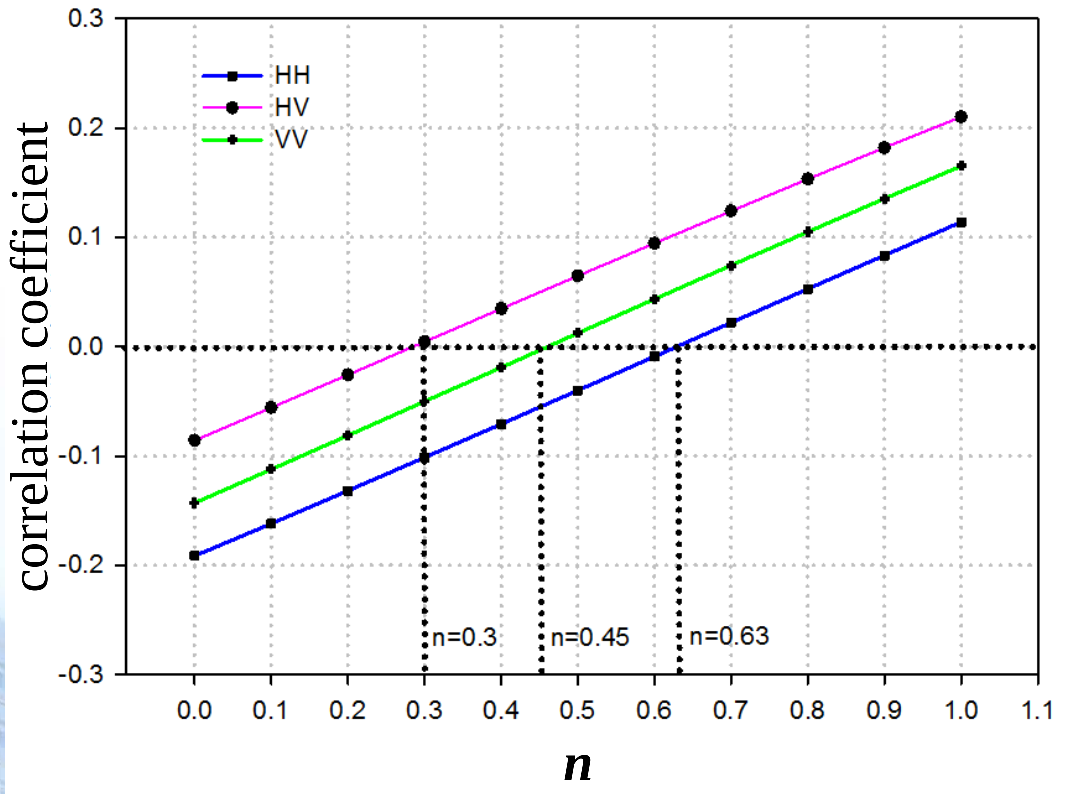


LiDAR forest AGB

2. Three-Stage Terrain Correction Method for PolSAR Data

2.4 Result and Analysis • Angular Variation Effect correction (AVEc)

- Minimum correlation coefficient method



$$f(n) = \rho(\theta_{loc}, \sigma_{\theta_{loc}})$$

$$n = \arg\min\{abs[f(n)]\}$$

$n(hh)=0.63$
$n(hv)=0.30$
$n(vv)=0.45$

$$K = \begin{bmatrix} m^{0.630} & m^{0.465} & m^{0.540} \\ m^{0.465} & m^{0.300} & m^{0.375} \\ m^{0.540} & m^{0.375} & m^{0.450} \end{bmatrix}$$

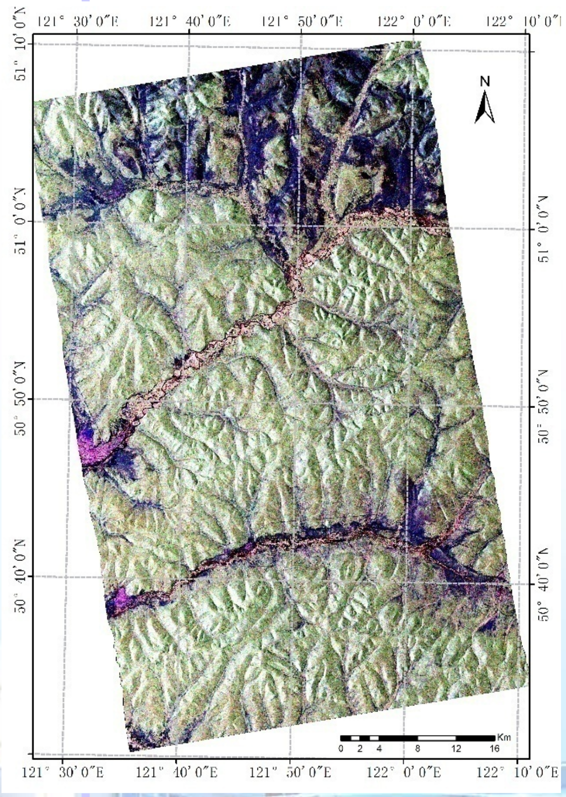
$$m = \frac{\cos\theta_{ref}}{\cos\theta_{loc}}$$

$$C_{out} = C \odot K$$

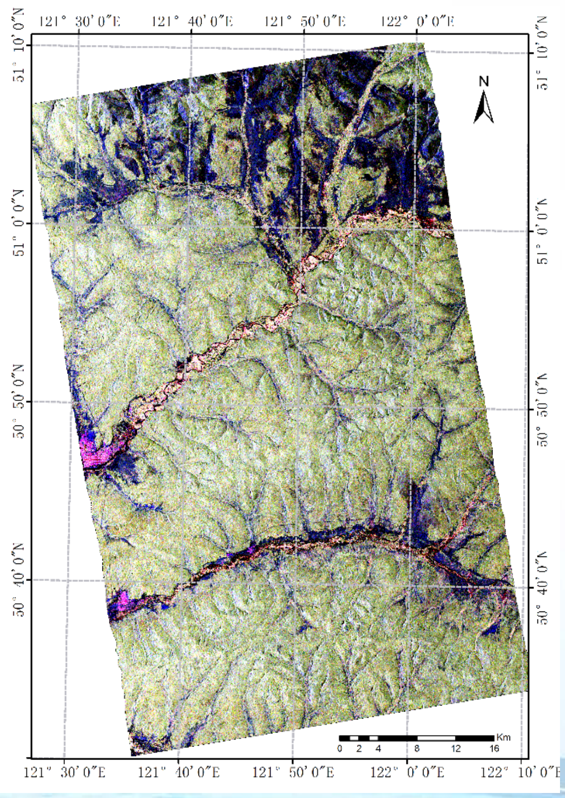
- ***The same values of n corresponding to different correlations coefficient. This illustrates that different polarization should adopt different values of n.***

2.4 Result and Analysis

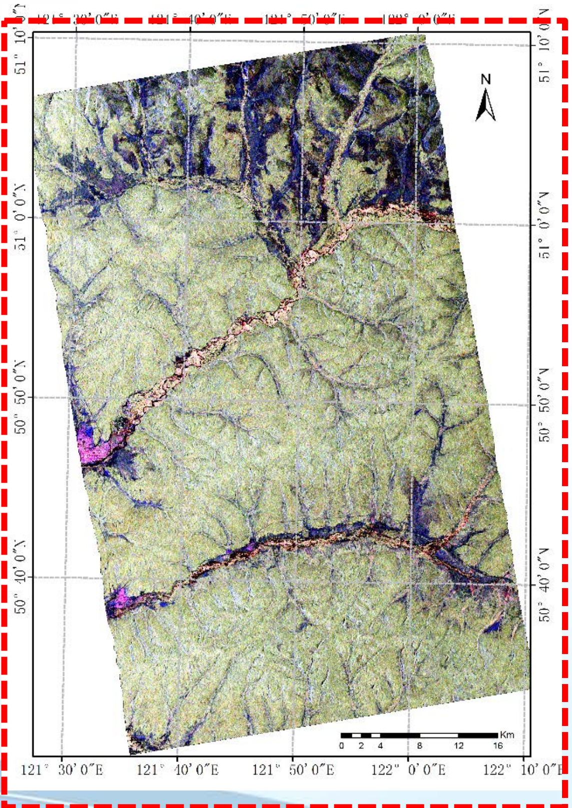
- Angular Variation Effect correction result (AVEc)



GTC Pauli RGB



POAc+ESAc Pauli RGB

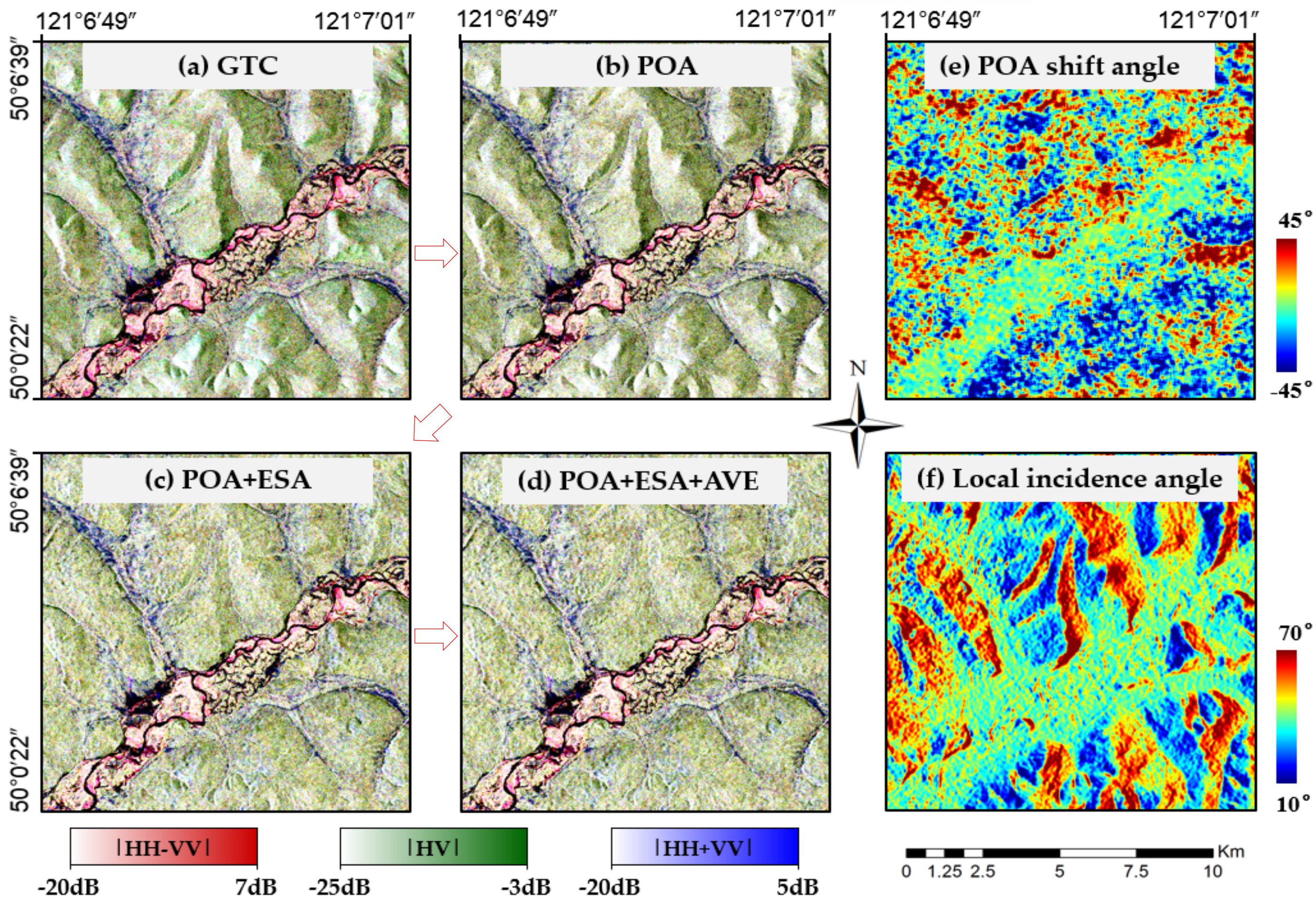


POAc+ESAc+AVEc Pauli RGB

- ***The remaining terrain effects in PolSAR image has been effectively removed, there is no significant difference between front slope and back slope.***

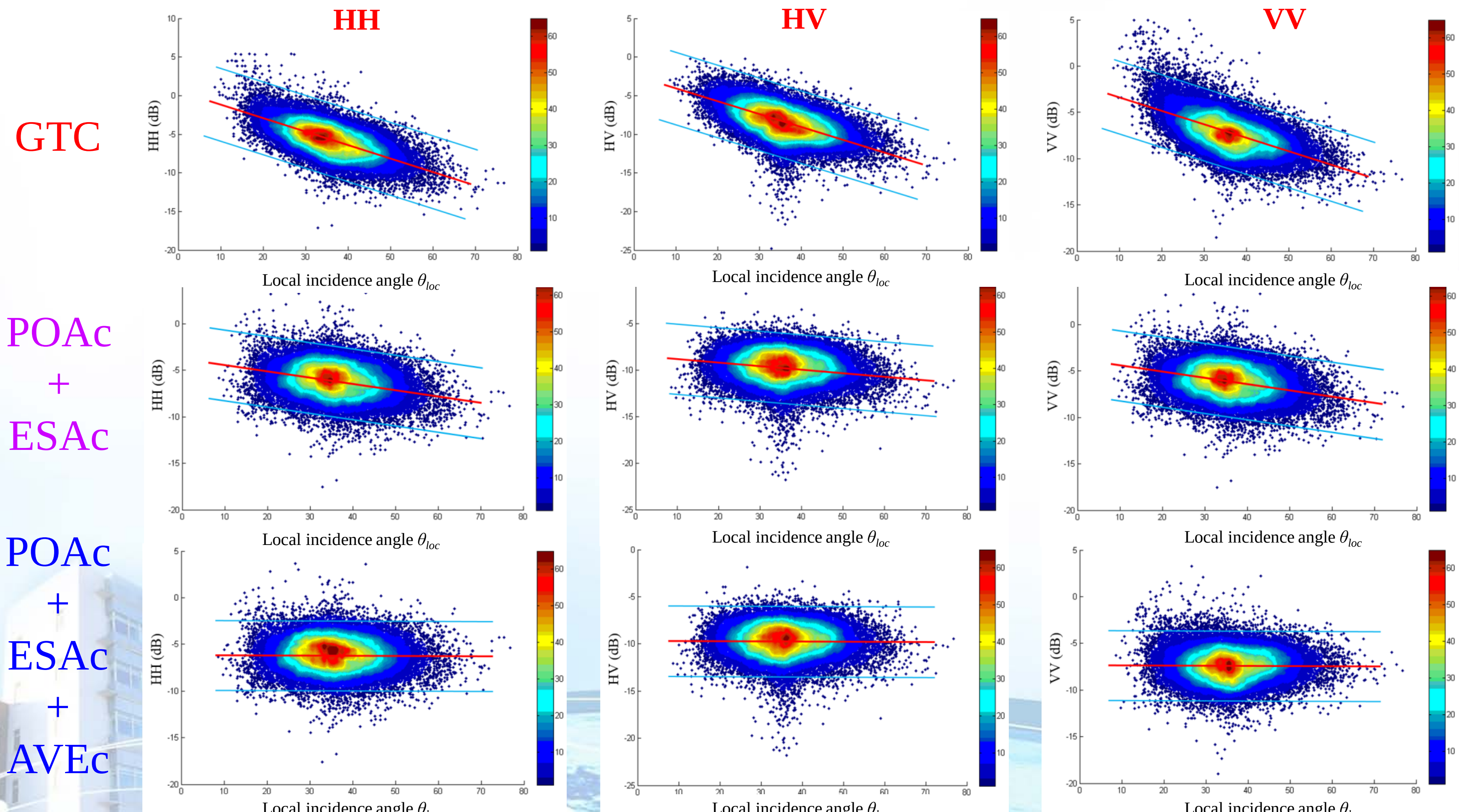
2.4 Result and Analysis

- Different stage Terrain Correction result (Enlarged)



2.4 Result and Analysis

- Terrain Correction results of different stage

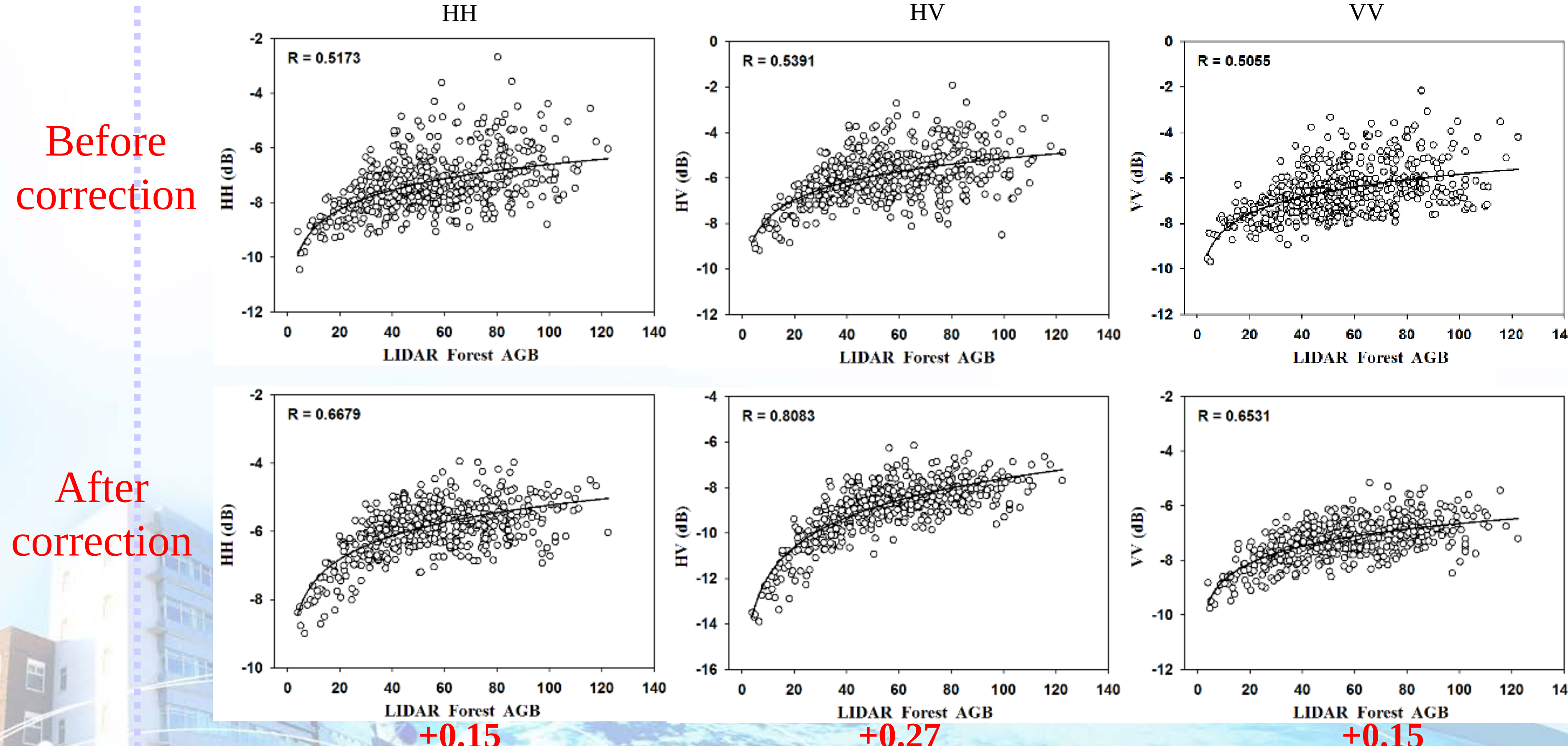


Compare scatter plots of different correction stage, along with the correction stages performed, the correction result is getting better and better.

2. Three-Stage Terrain Correction Method for PolSAR Data

2.4 Result and Analysis

- The correlation between backscatter coefficient and forest AGB



- *Obviously, the corrected backscatter coefficients have the better correlation with forest AGB than uncorrected case.*

Outlines

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3. Terrain Correction Method For InSAR coherence

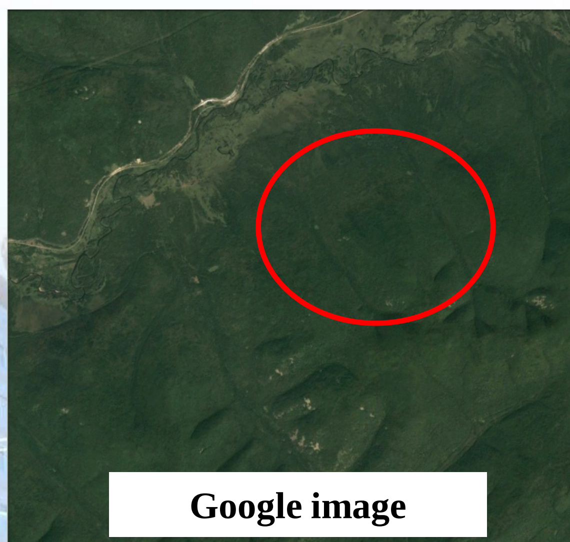
4. The combined estimation approach of Forest AGB based on CASMSAR (X-InSAR, P-PolSAR)

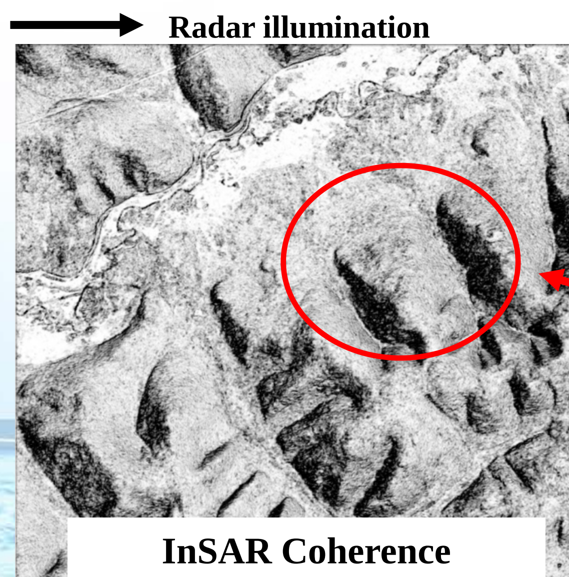
5. Summary

3. Terrain Correction Method for InSAR Coherence

3.1 Background

- InSAR coherence is an important feature for land cover type mapping and forest AGB estimation.
- InSAR coherence is also affected by terrain relief.
- There are few correction method developed for forest applications.
- We developed SINC differential correction method for InSAR coherence.





3.2 Methods

- Sources of InSAR decorrelation (Coherence)

$$\gamma = \gamma_{SNR} \cdot \gamma_t \cdot \gamma_{proc} \cdot \gamma_s \cdot \gamma_v$$

（Cloude, 2009）

- γ_{SNR} Signal-to-noise decorrelation;
- γ_t Temporal decorrelation;
- γ_{proc} Data processing decorrelation;
- γ_s Baseline decorrelation;
- γ_v Volume decorrelation。

Related to local imagery geometry!

3.2 Methods

- Baseline decorrelation

$$\gamma_s = 1 - \frac{cB_\perp}{W\lambda R\, tan(\theta - \eta)}$$

（Cloude, 2009; Yongsheng Zhou, 2010）

- c : Speed of light；
- $B_\perp$: Vertical baseline；
- λ : Wave length；
- η : Slope angle；
- θ : Radar look angle。
- W : Bandwidth；
- R : Slant-range。

- ***Baseline decorrelation can be compensated by above model.***

3.2 Methods

- Volume decorrelation

$$\gamma_v = \frac{\int_0^h f(h) e^{jk_z h} dh}{\int_0^h f(h) dh} \qquad k_z = \frac{2\pi B_\perp}{\lambda R \sin\theta}$$

（Cloude, 2009; Yongsheng Zhou, 2010）

- SINC model (while f(h) is a constant)：

$$\gamma_v = \frac{\sin(k_z h/2)}{k_z h/2} = \mathrm{sinc}(k_z h/2)$$

- Based on the relationship between Kz and slope angle(η), the relationship between γ_v and η is established:

$$k_z^{slope} = \frac{2\pi B_\perp}{\lambda R \sin(\theta - \eta)} \Rightarrow \gamma_v = \mathrm{sinc}\left[\frac{h\pi B_\perp}{\lambda R \sin(\theta - \eta)}\right]$$

3.2 Methods

- Volume decorrelation

$$\gamma_v = \boxed{sinc\left[\frac{h\pi B_\perp}{\lambda R\sin(\theta-\eta)}\right]}$$

Forest-dependent parameter (FDP)

Forest height（ h）

Forest-independent parameter(FIP)

Vertical baseline（ $B_\perp$ ）； Wave length（ λ ）；

Look angle（ θ ）； Slope angle（ η ）；

Slant-range（R）

- The **purpose** of coherence terrain correction：
  - **Removal the effect of FIP on coherence;**
  - **Only preserves the effect of FDP on coherence.**

3.2 Methods

- The derivation of differential coherence model
  - The volume decorrelation model considering the terrain effect:

Model 1: $\gamma_v^{slope} = sinc(k_z^{slope} h / 2)$

  - The volume decorrelation model without considering the terrain effect:

Model 2: $\gamma_v^{ref} = sinc(k_z^{ref} h / 2)$

  - From the model 1 to solve the FDP parameter, then substituted into the model 2. The **difference equation of coherence** was derived as follows:

$(\gamma_v^{slope}, \quad k_z^{slope})$

Terrain influence

$$\begin{aligned}\gamma_v^{ref} &= sinc\left\{k_z^{ref} h / 2\right\} \\ &= sinc\left\{k_z^{ref}\left[2\,sinc^{-1}(\gamma_v^{slope}) \big/ k_z^{slope}\right] / 2\right\}\end{aligned}$$

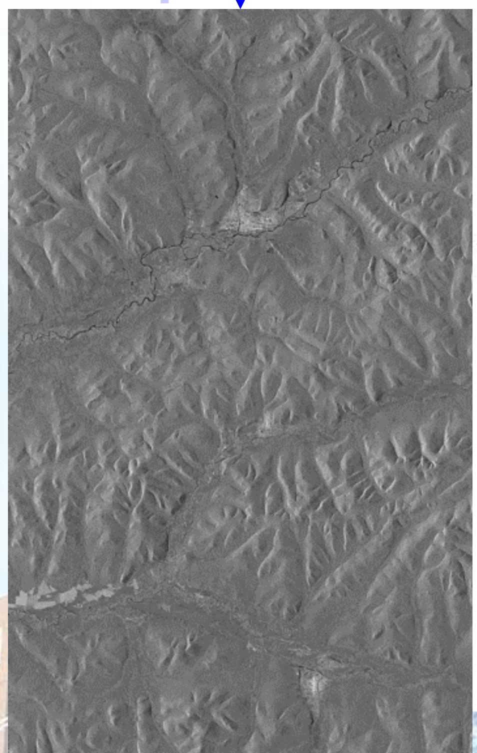
$(\gamma_v^{ref}, \quad k_z^{ref})$

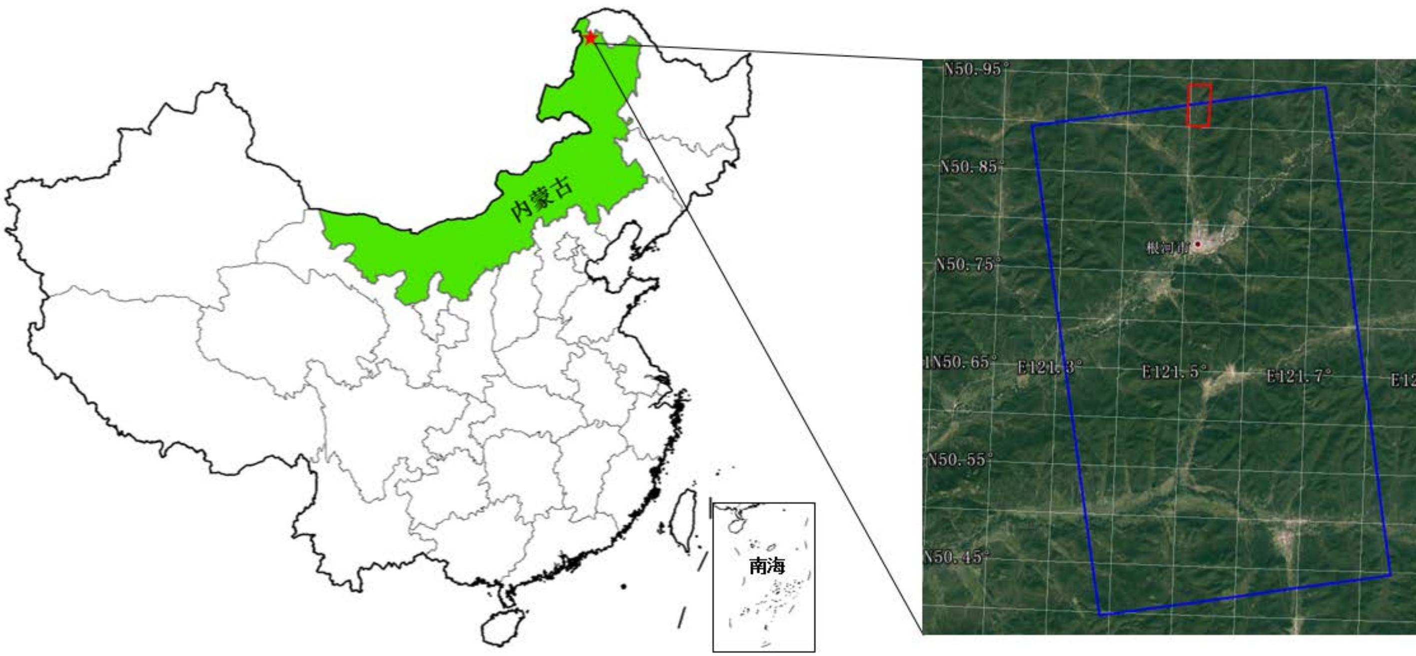
Without Terrain influence

  - Using the above model, the coherence under different imaging geometric conditions can be corrected to the same imaging geometry.

3.3 Test Data

- DaXingAnLing test site in Inner Mongolia
  - Space borne TanDEM-X InSAR data
  - Airborne double antenna X-band InSAR data





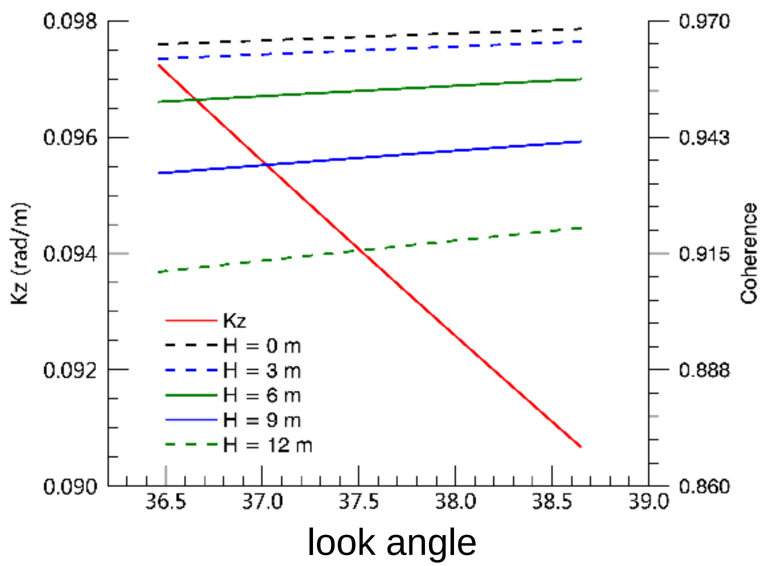
3.3 Test Data

- DaXingAnLing test site in Inner Mongolia
  - Space borne TanDEM-X InSAR data
  - Airborne double antenna X-band InSAR data

InSAR data parameter		
Data parameter	SAR sensors	
	TanDEM/TerraSAR-X	CASMSAR-X
Date of imaging	2012.8.14	2013.09.13
polarization mode	HH	HH
Range resolution (m)	1.36	0.25
Azimuth Resolution(m)	2.02	0.34
Platform height(km)	515.6	5.8
flight direction	From south to north	From west to east
Lookangle range	36.5° - 38.6°	22° - 54°
Bandwidth(MHz)	100	600
Baseline(m)	216	2.2

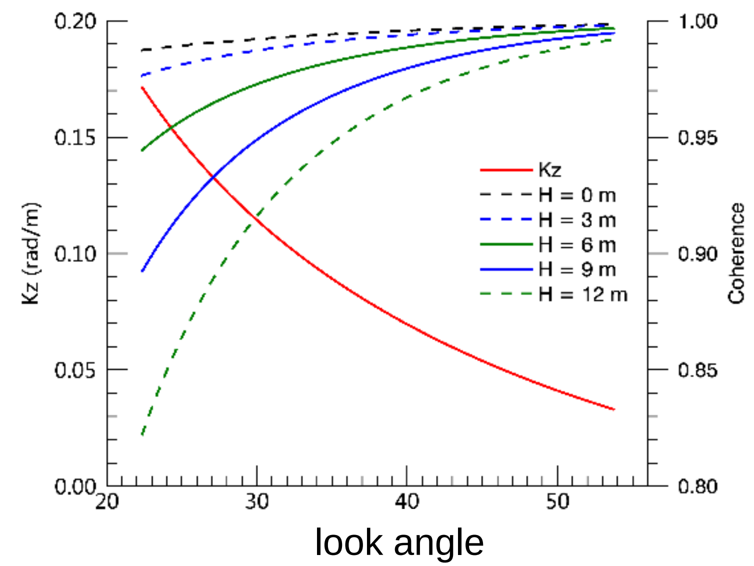
3.4 Result and Analysis

- The coherence simulation analysis based on space borne and airborne InSAR parameters
  - Influence of Radar look angle on coherence under flat terrain.



TanDEM/TerraSAR

Small look angle range

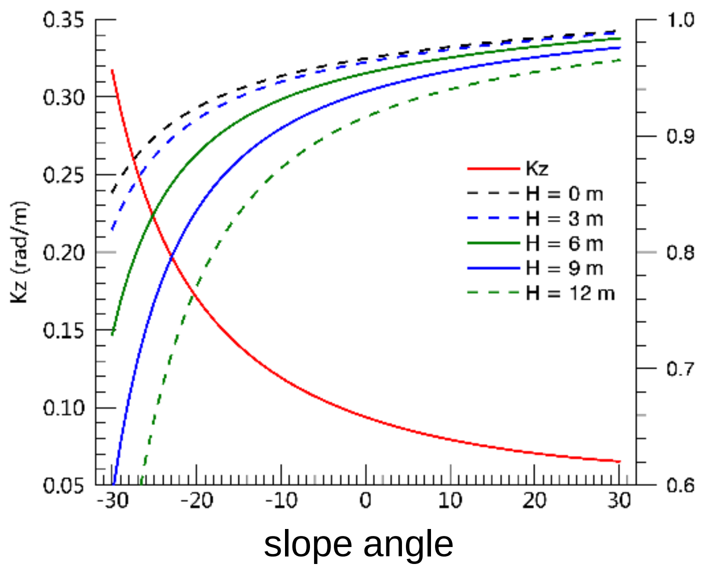


CASMSAR-X

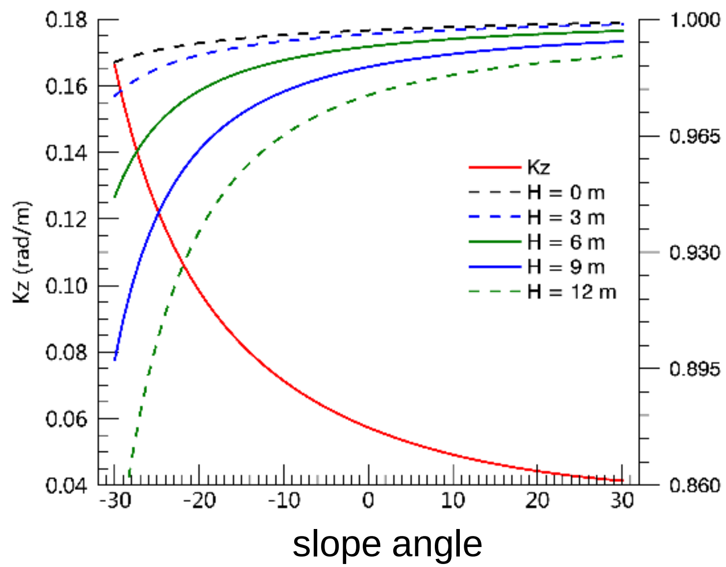
Big look angle range

3.4 Result and Analysis

- The coherence simulation analysis based on space borne and airborne InSAR parameters
  - Influence of slope angle on coherence under Fixed look angle (Center look angle)



TanDEM-X InSAR



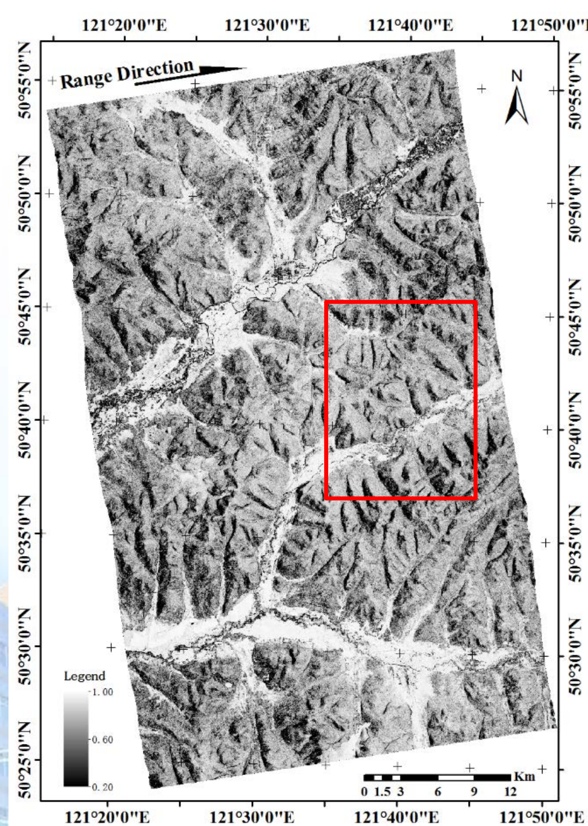
CASMSAR-X

- ***The coherence of TanDEM-X is more affected by the slope angle.***

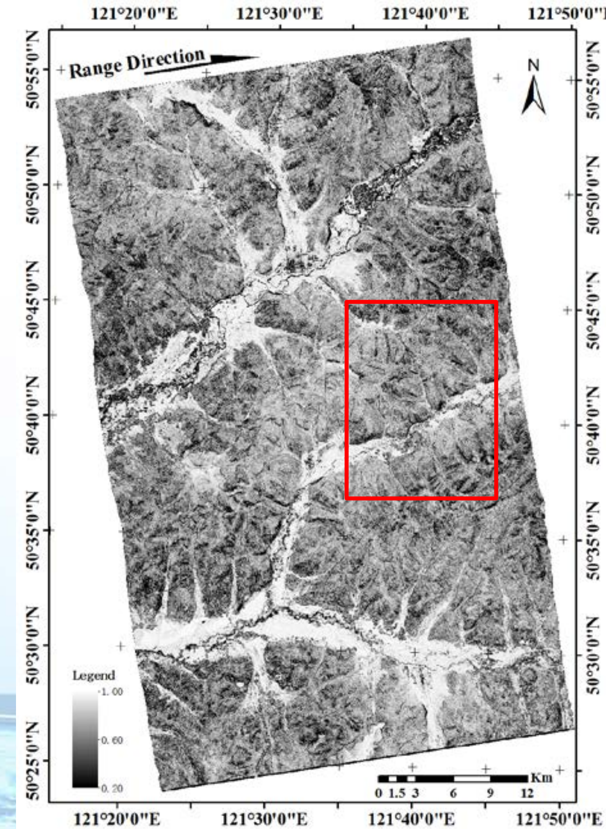
3.4 Result and Analysis

- The coherence correction results of space borne InSAR

Range direction



Before correction

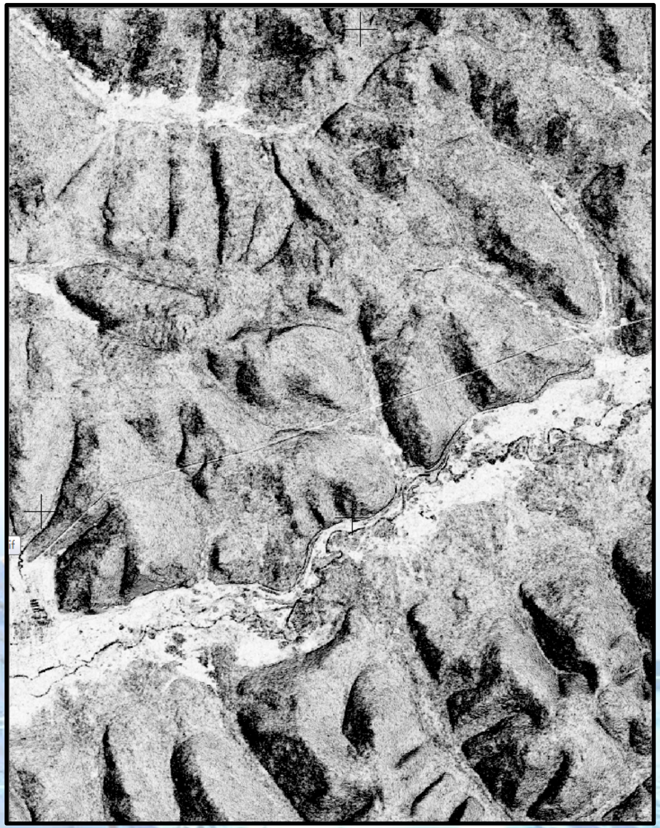


After correction

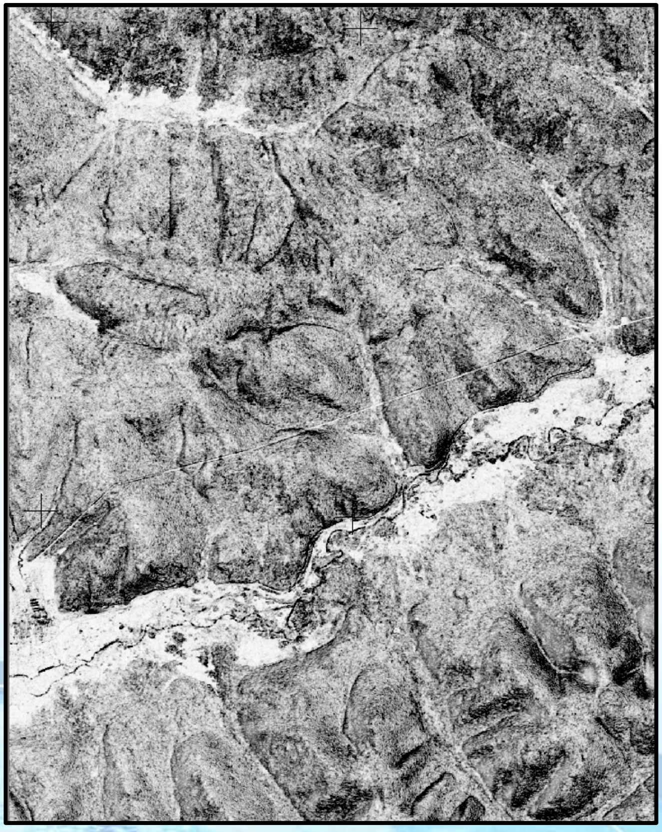
3.4 Result and Analysis

- The coherence correction results of space borne InSAR （Enlarged）

Range direction



Before correction

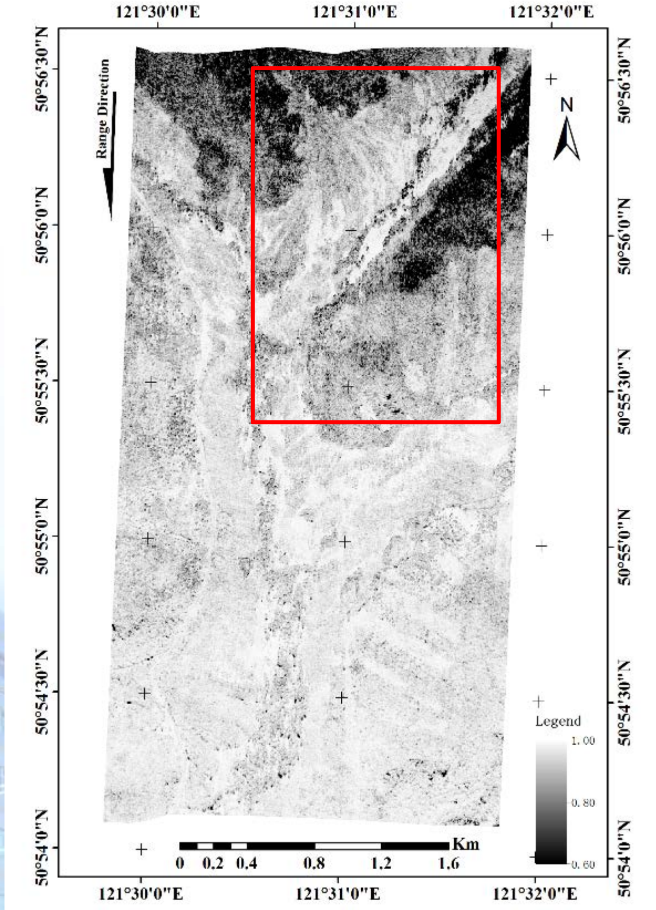


After correction

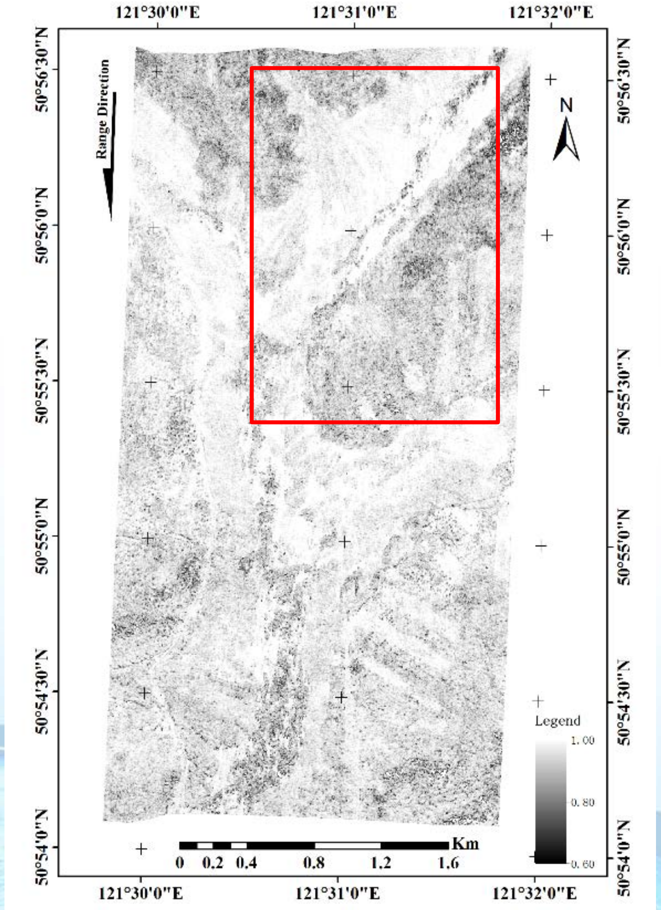
3.4 Result and Analysis

- The coherence correction results of Airborne InSAR

Range direction



Before correction



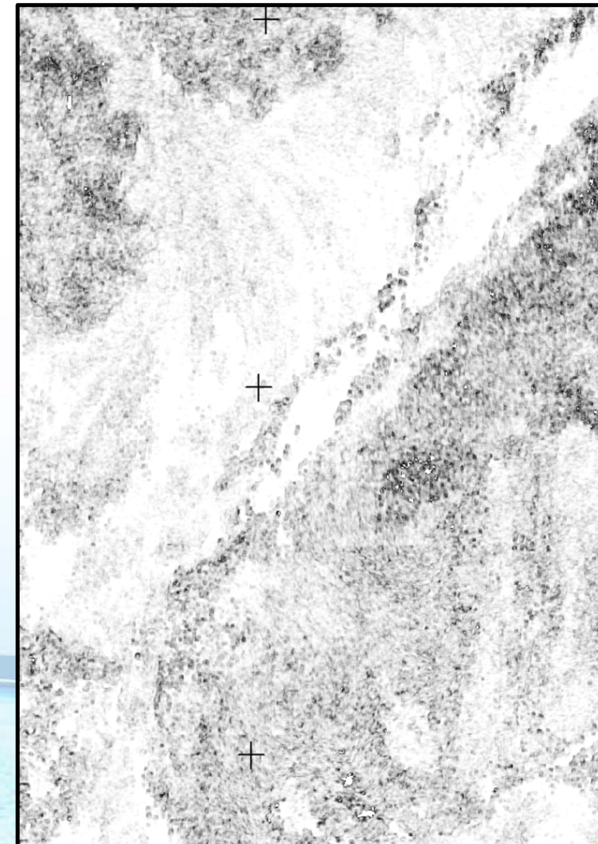
After correction

3.4 Result and Analysis

- The coherence correction results of Airborne InSAR （Enlarged）

Range direction

Before correction



After correction

3.4 Result and Analysis

- Application of the Coherence Terrain Correction

  - Improve the ability of InSAR to classify and identify. For example, the Interference Land Use (ILU) image:

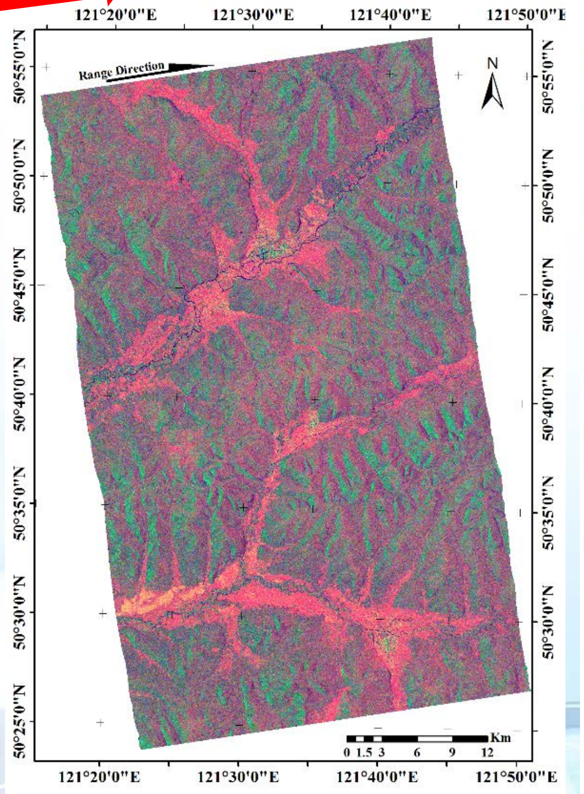
    ILU image:
    - ✓ R: InSAR Coherence
    - ✓ G: Average intensity
    - ✓ B: Intensity difference

  - Increasing the estimation accuracy of vegetation parameters based on the corrected coherent Image.

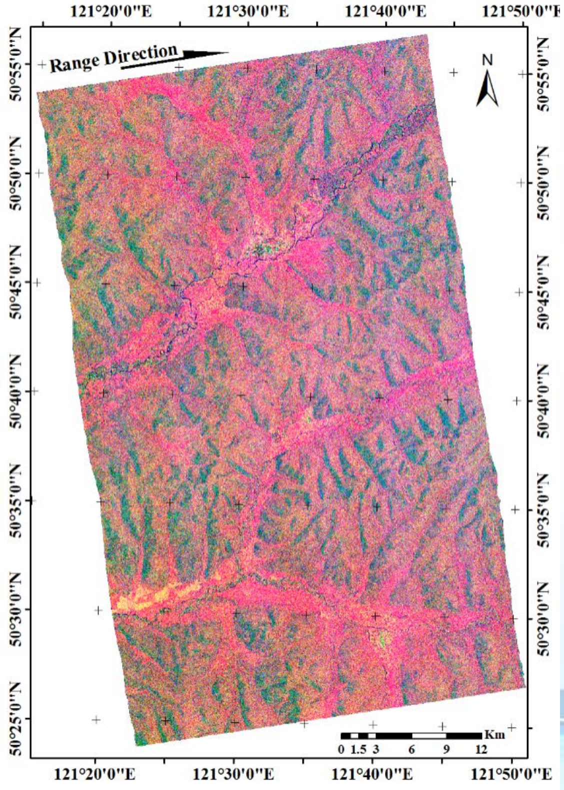
3.4 Result and Analysis

- The correction results of Space borne ILU image

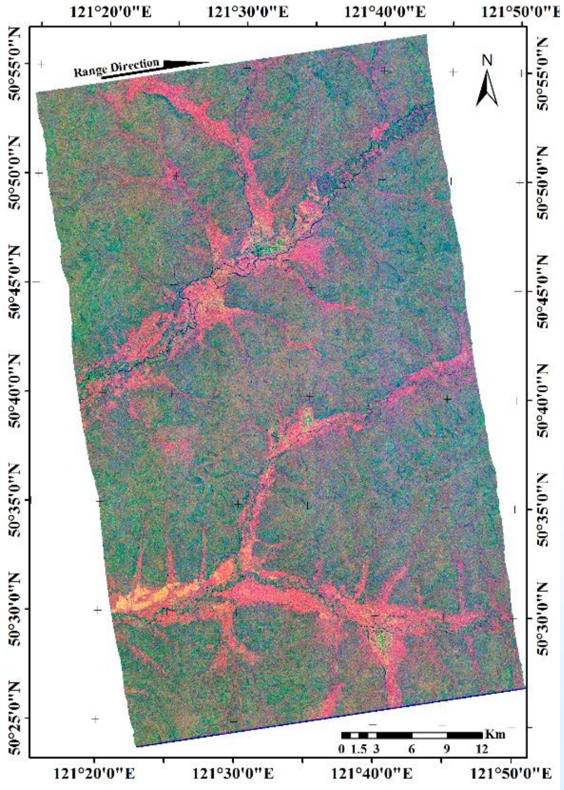
Range direction



Uncorrected intensity;
Uncorrected coherence.



Corrected intensity;
Uncorrected coherence.

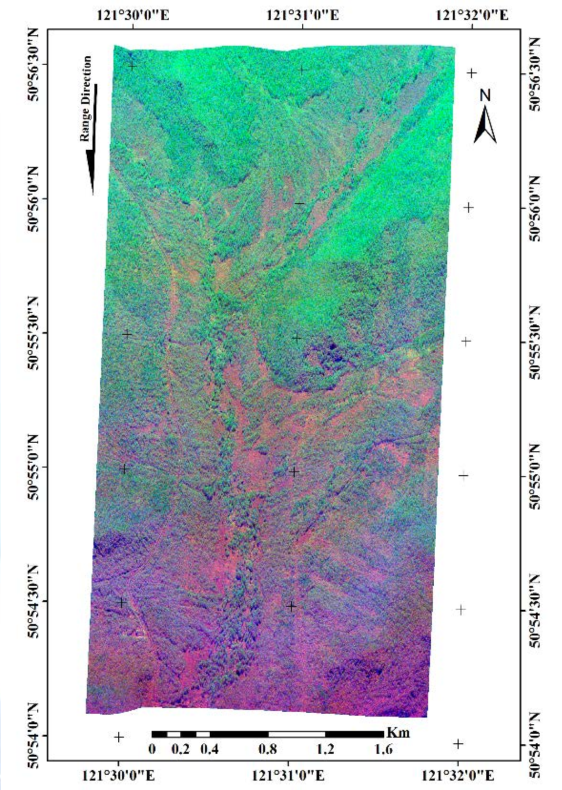


Corrected intensity;
Corrected coherence.

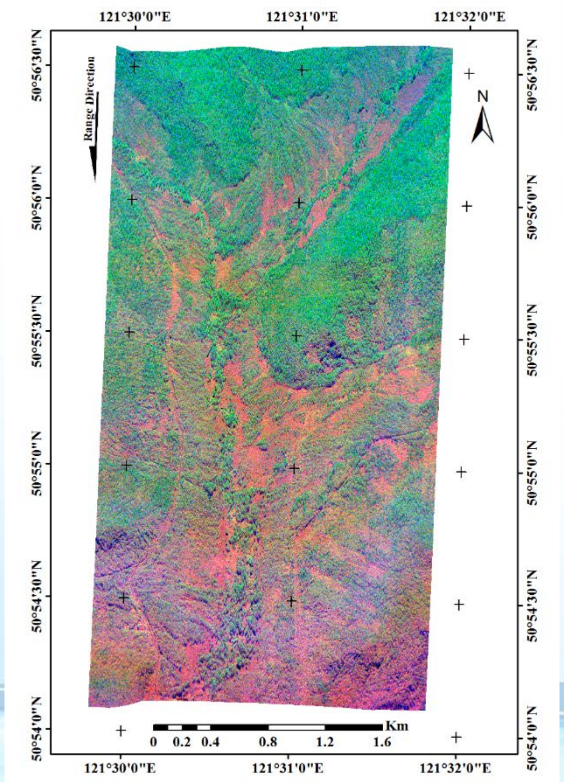
3.4 Result and Analysis

Range direction

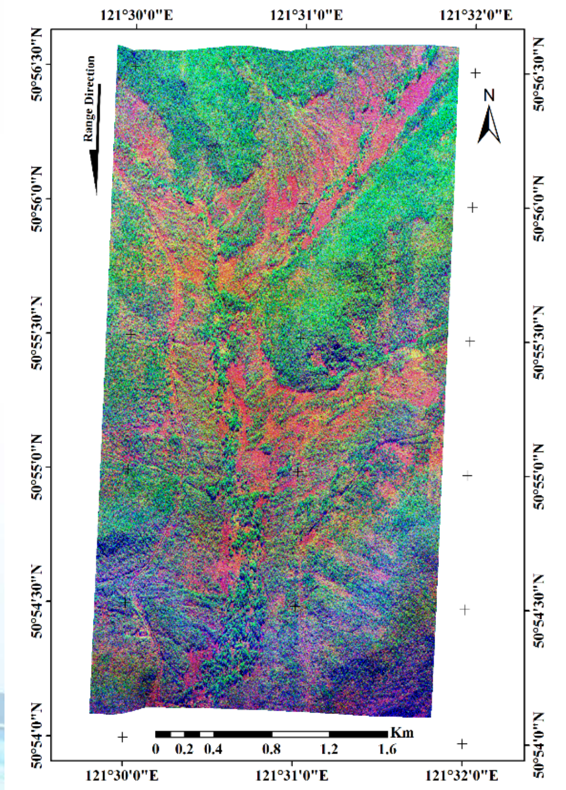
- The correction results of Airborne ILU image



Uncorrected intensity;
Uncorrected coherence.



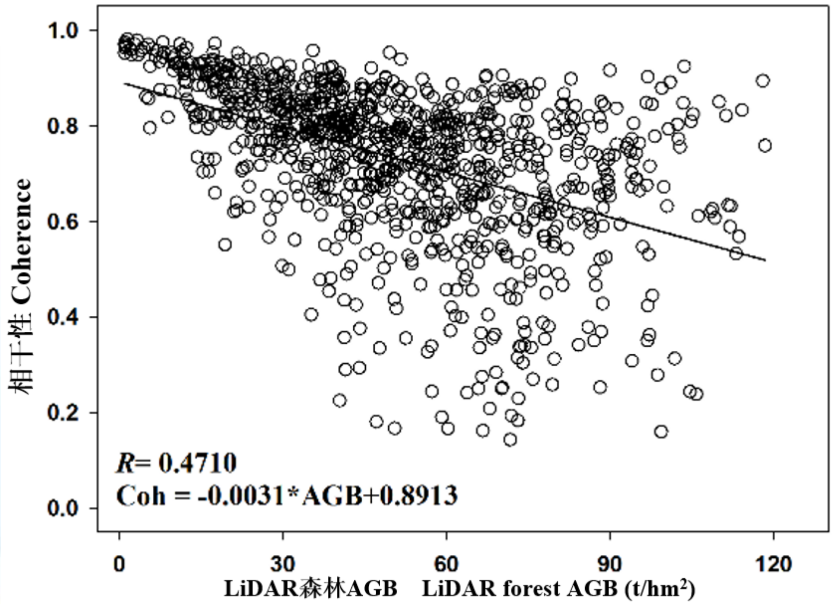
Corrected intensity;
Uncorrected coherence.

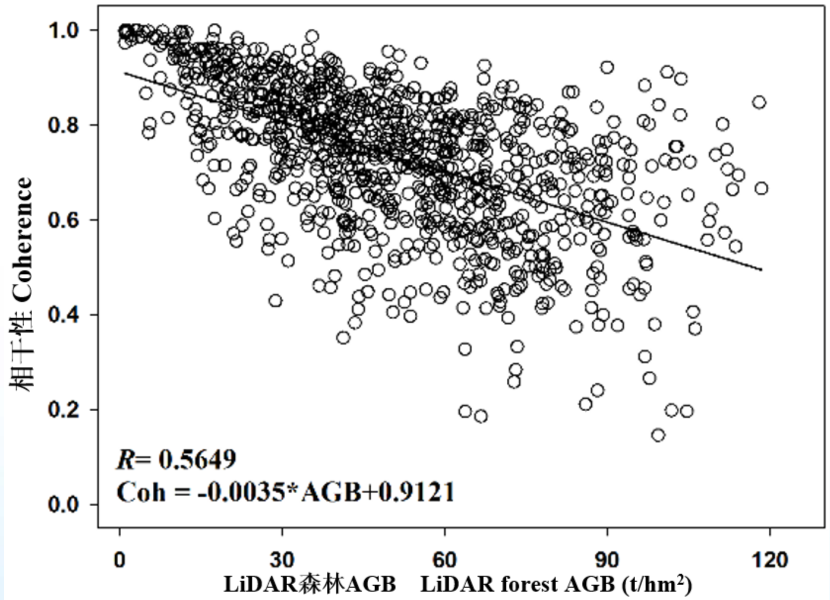


Corrected intensity;
Corrected coherence.

3.4 Result and Analysis

- The correlation between coherence (Space borne) and LIDAR forest AGB

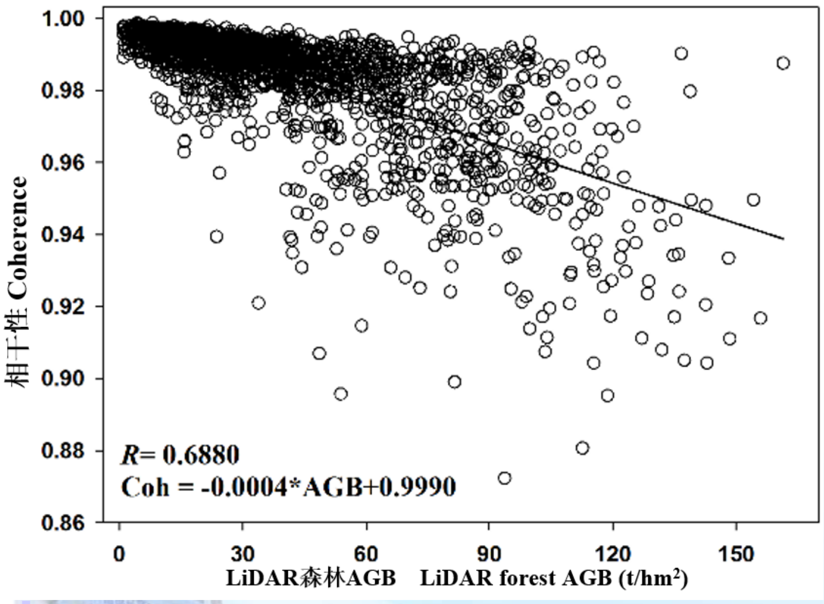


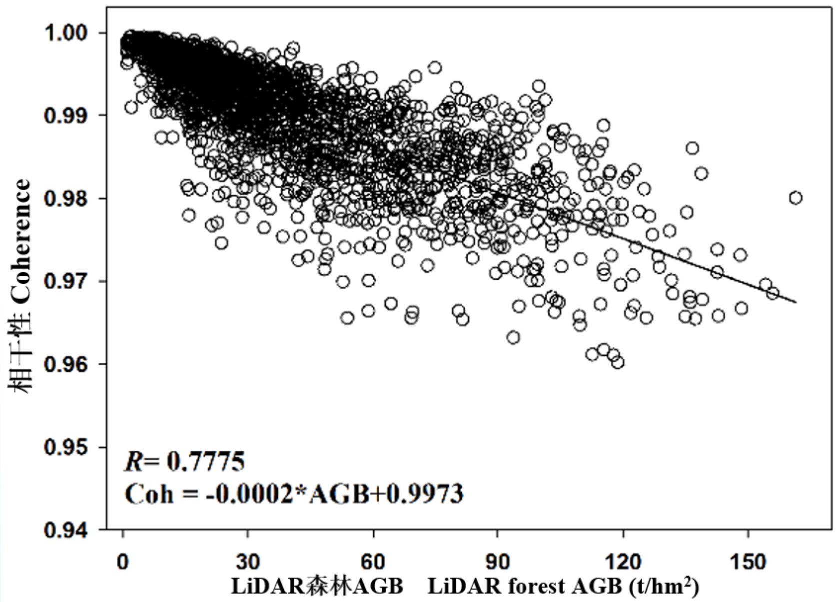


Before correction +0.09 After correction

3.4 Result and Analysis

- The correlation between coherence (Airborne) and LIDAR forest AGB





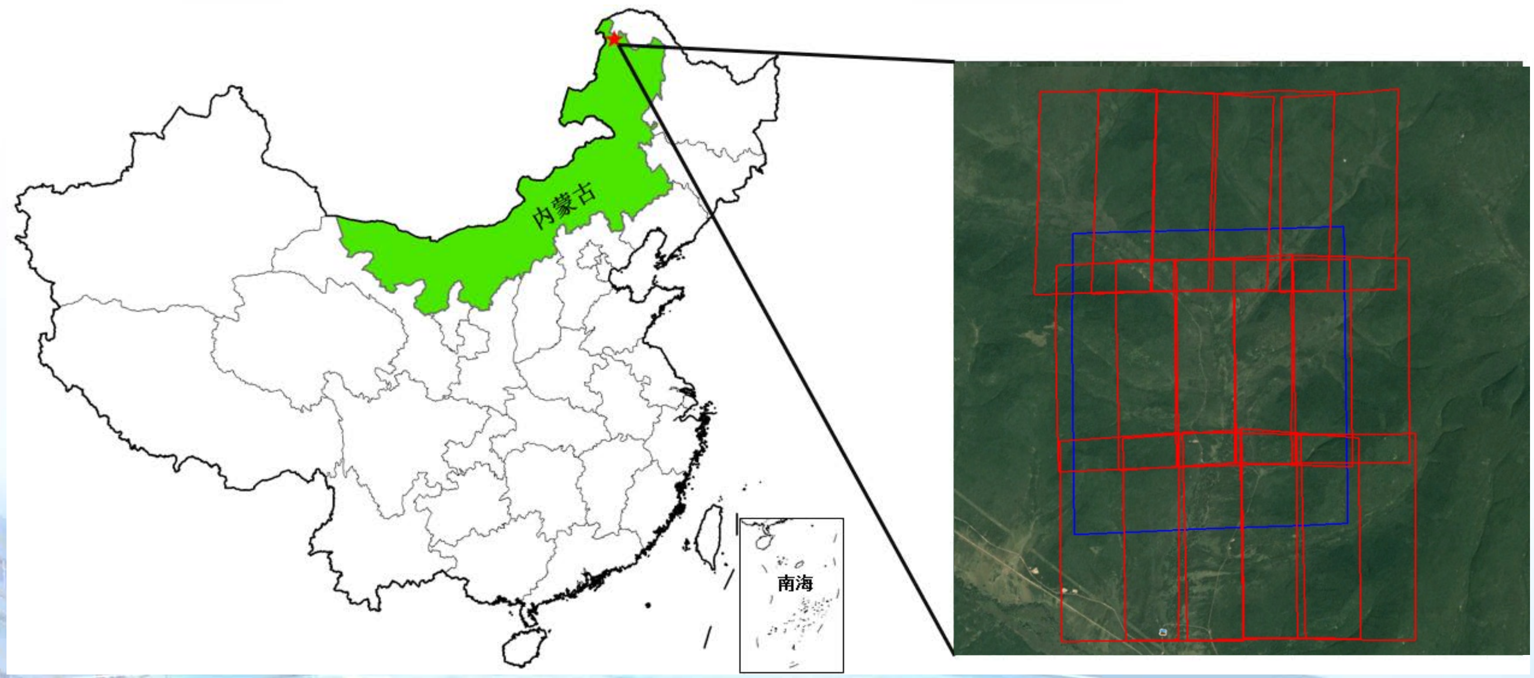
Before correction +0.09 After correction

Outlines

1. Background
2. Three-Stage Terrain Correction Method For PolSAR
3. Terrain Correction Method For InSAR coherence
4. The combined estimation approach of Forest AGB based on CASMSAR (X-InSAR, P-PolSAR)
5. Summary

4.1 Test Data

- DaXingAnLing test site in Inner Mongolia
  - China CASMSAR Multi-dimensional SAR System

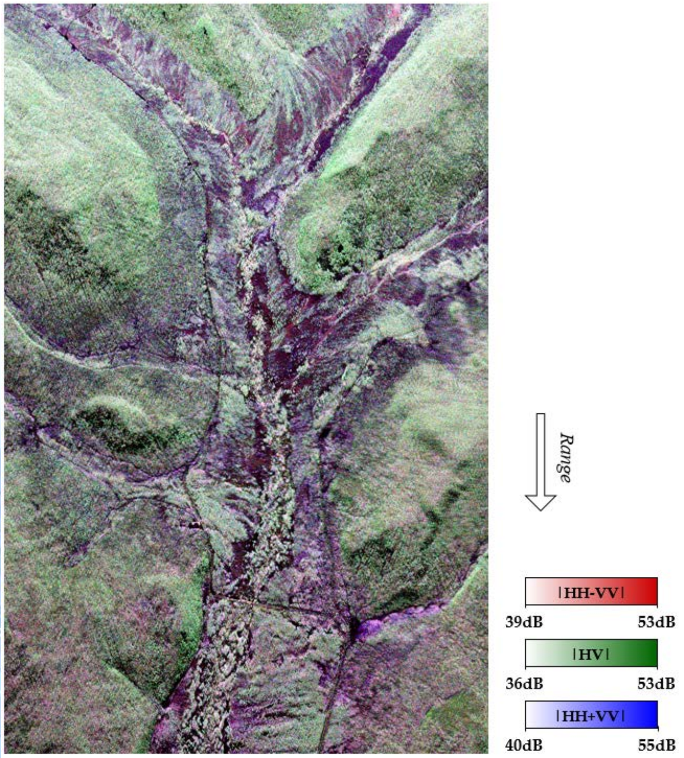


X-InSAR (15 images)

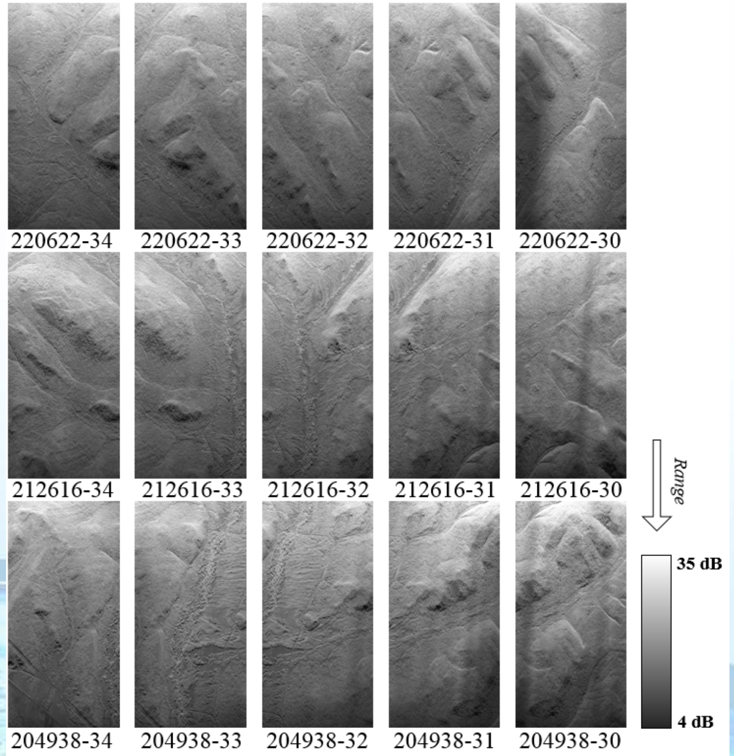
P-PolSAR(1 image)

4.1 Test Data

- China CASMSAR Multi-dimensional SAR System
  - P-band PolSAR
  - X-band HH InSAR



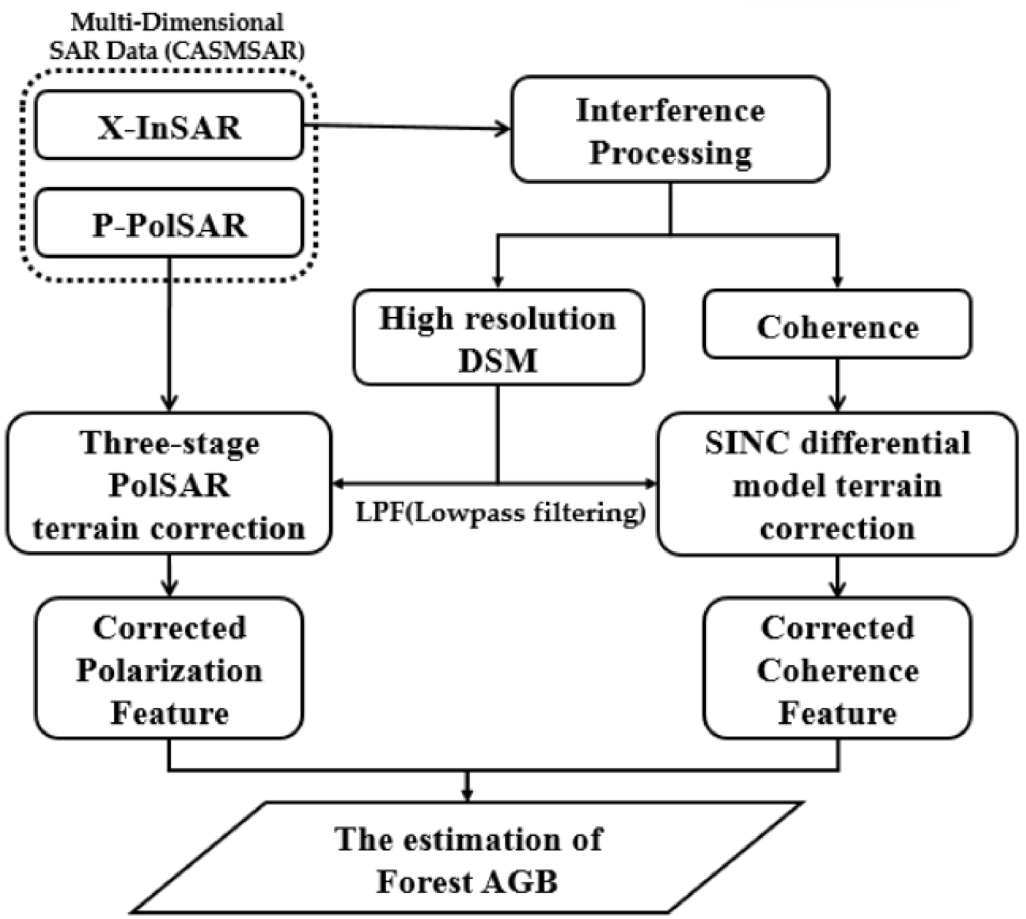
P-PolSAR PauliRGB



X-InSAR intensity image

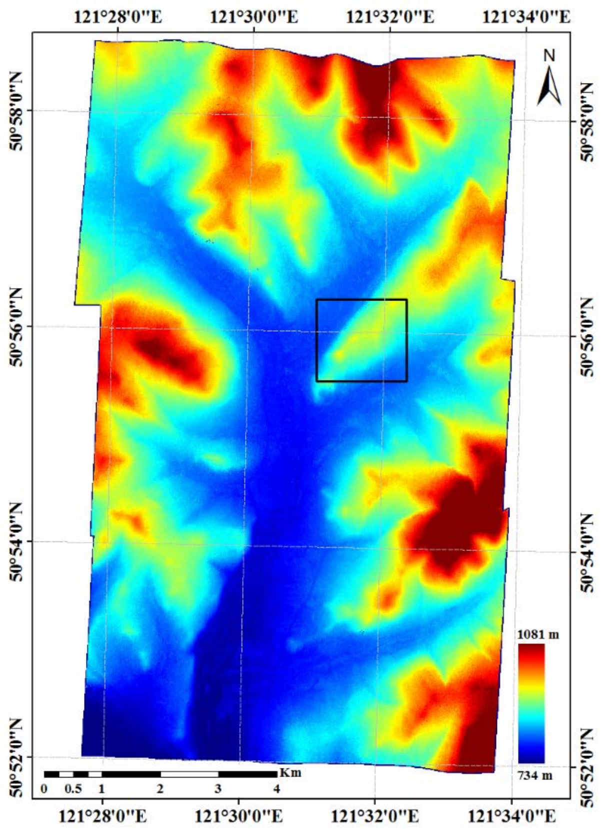
4.2 Methods

- Flow chart of combined estimation approach

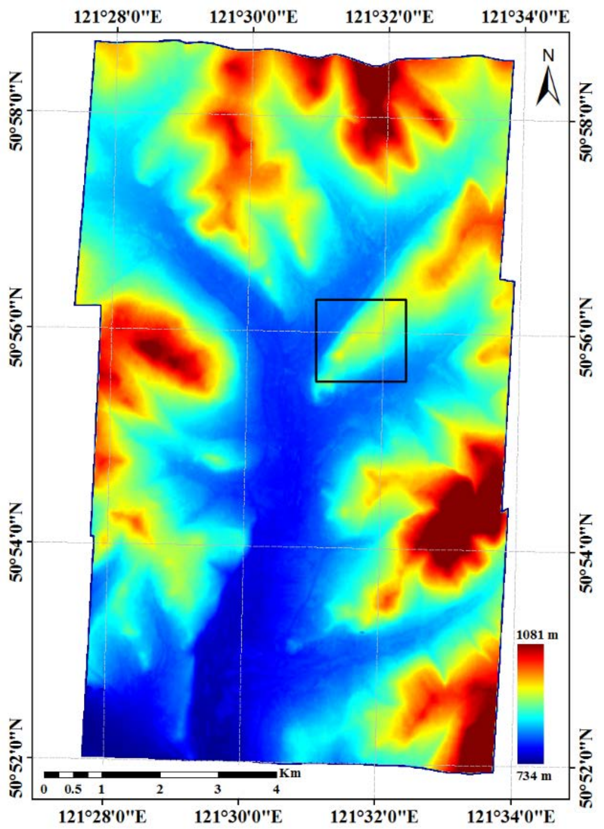


4.3 Result and Analysis

- X-InSAR interference processing result：DSM



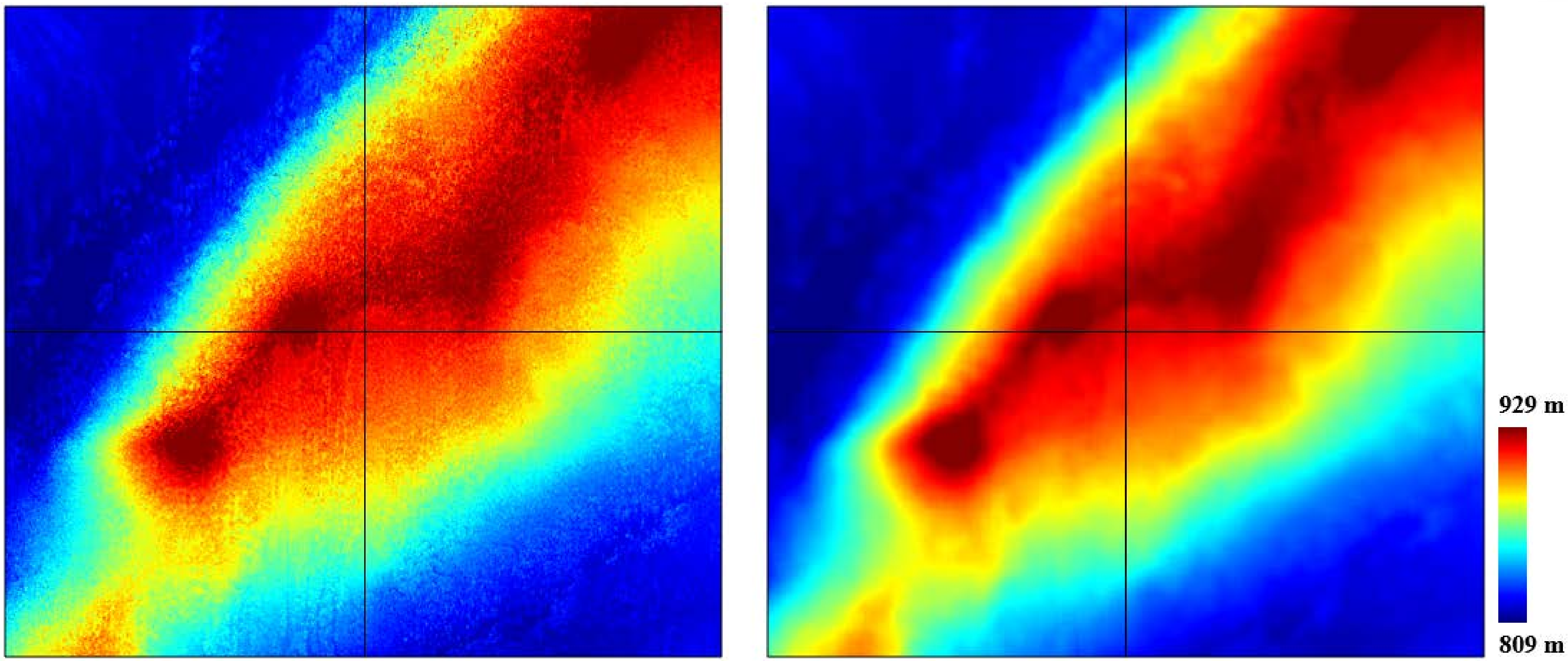
Original InSAR DSM



Lowpass filtered InSAR DSM

4.3 Result and Analysis

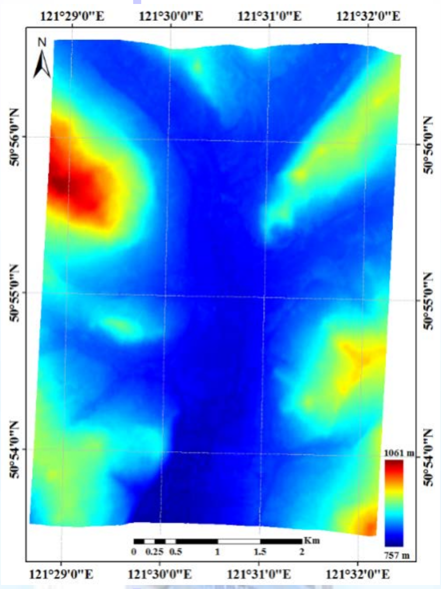
- X-InSAR interference processing result：DSM （Enlarged）



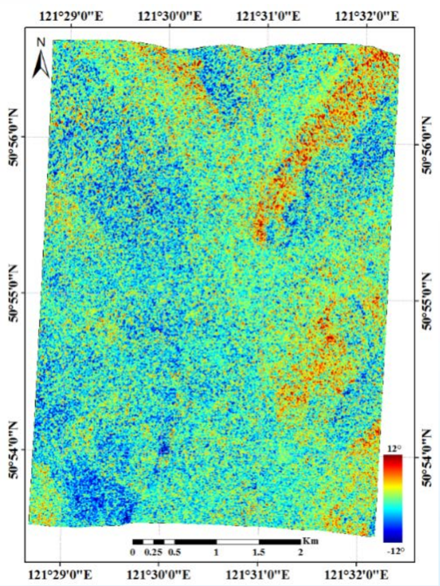
Original InSAR DSM ⇨ Lowpass filtered InSAR DSM

4.3 Result and Analysis

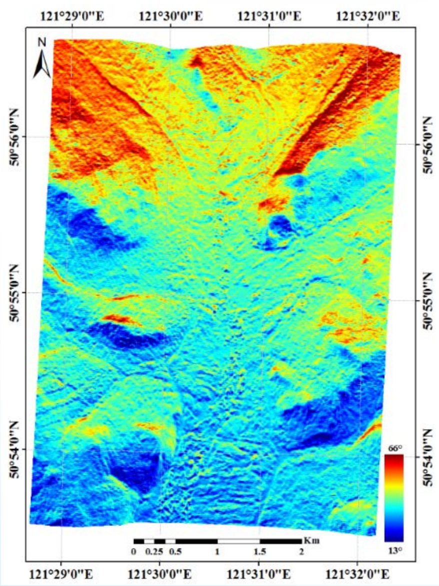
- Terrain correction results of P-PolSAR



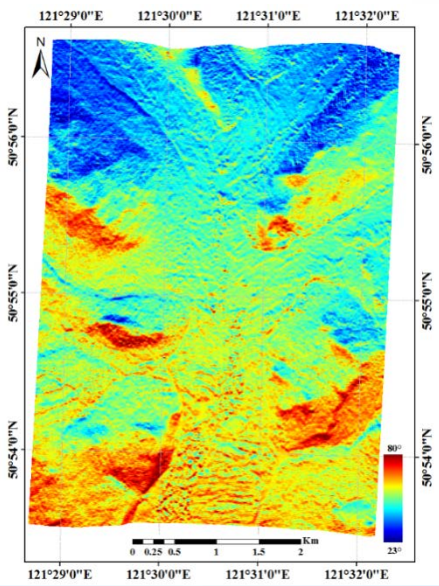
Filtered InSAR DSM



POA shift angle



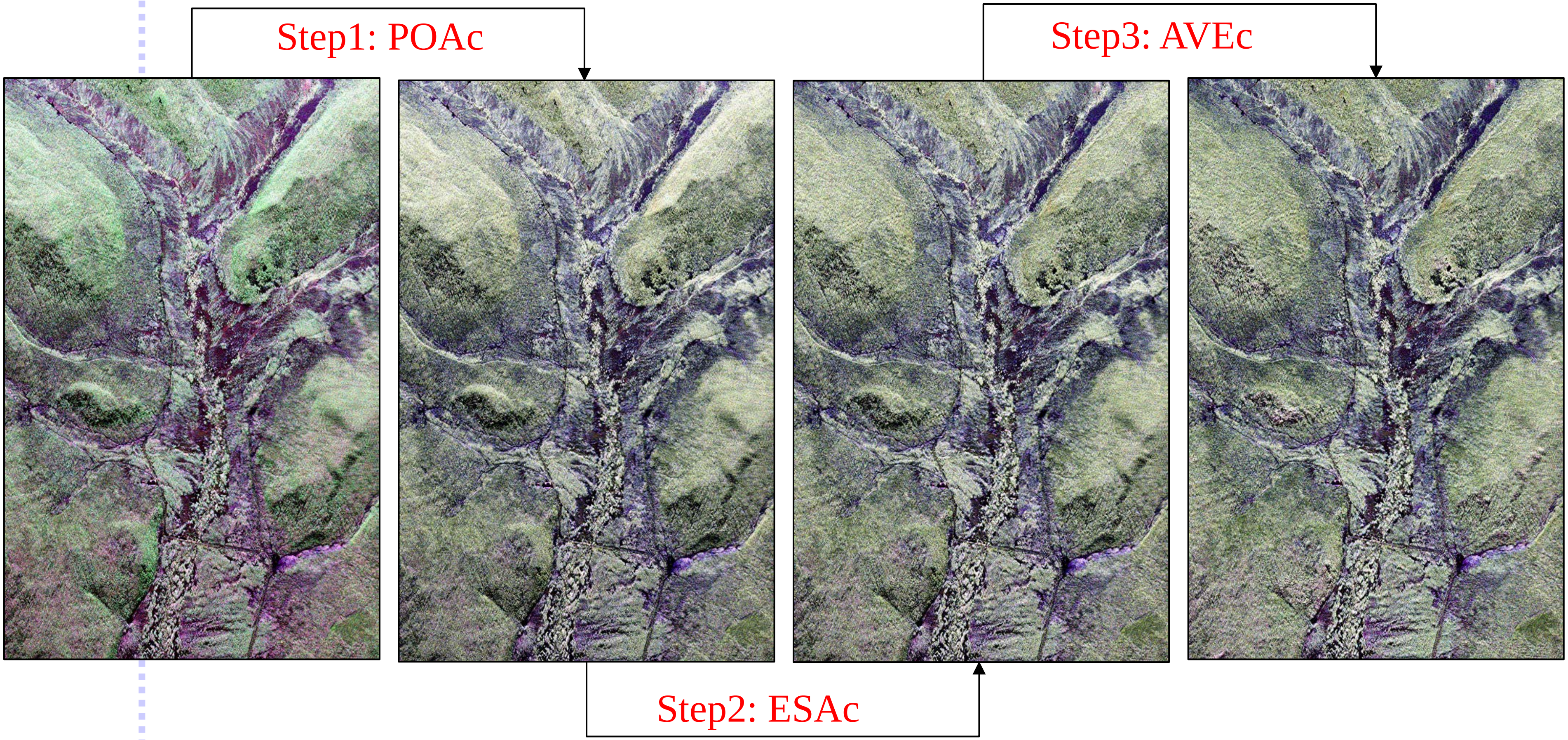
Projection angle



Local incidence angle

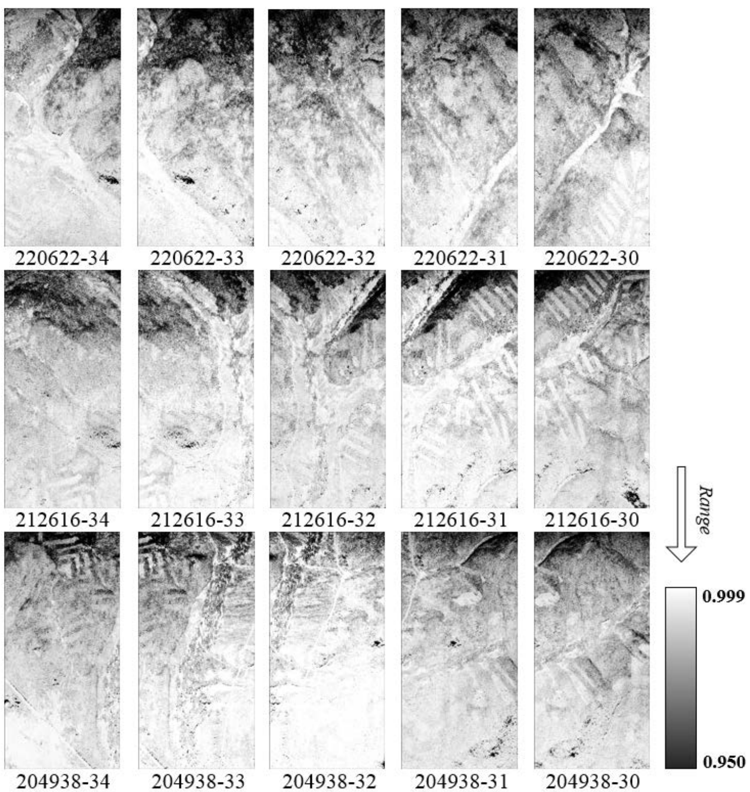
4.3 Result and Analysis

- Terrain correction results of P-PolSAR

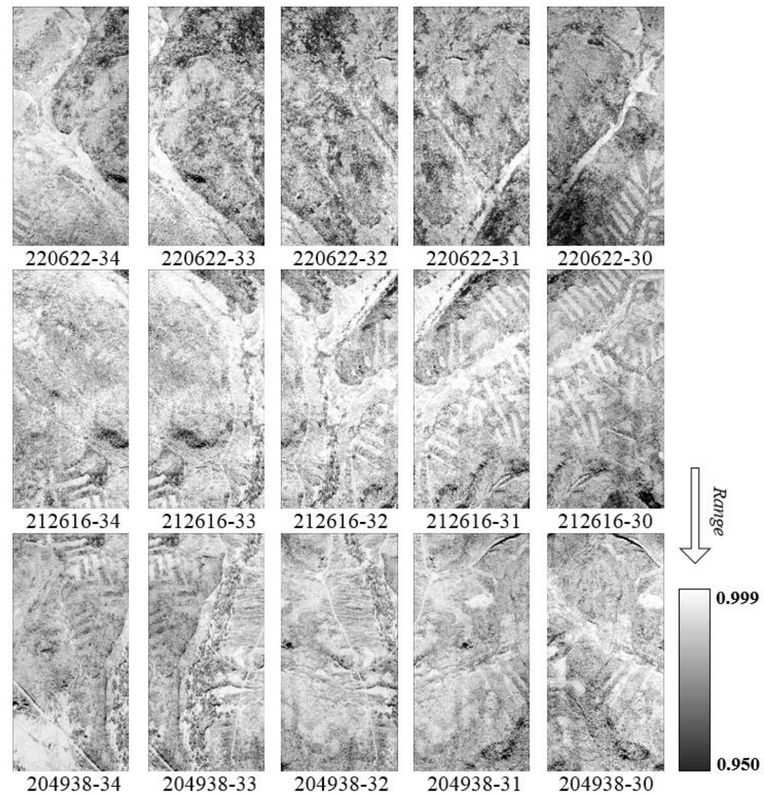


4.3 Result and Analysis

- Terrain correction results of X-InSAR coherence



Before correction

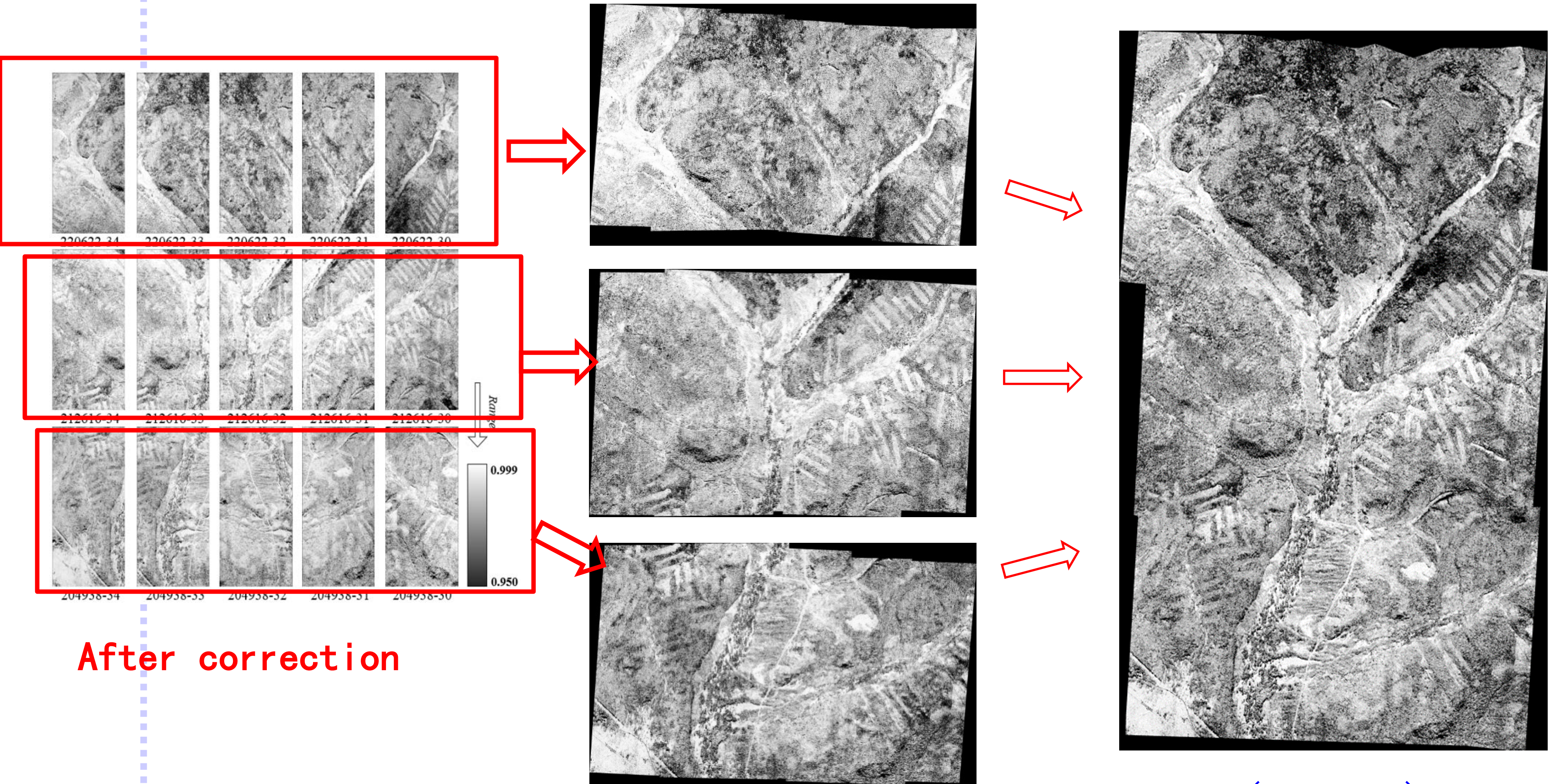


After correction

NRSCC esa

4.3 Result and Analysis

- Terrain correction results of X-InSAR coherence (Mosaic)

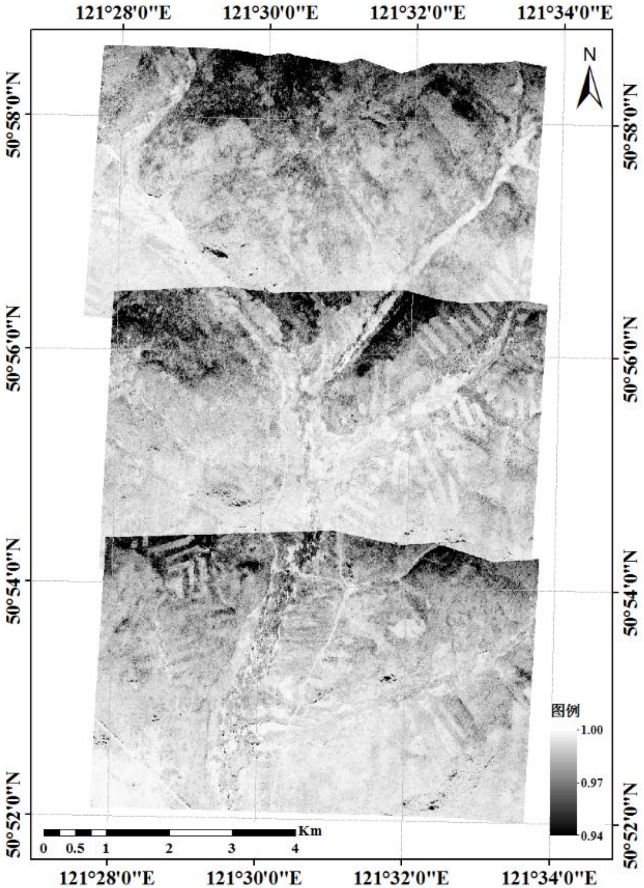


After correction

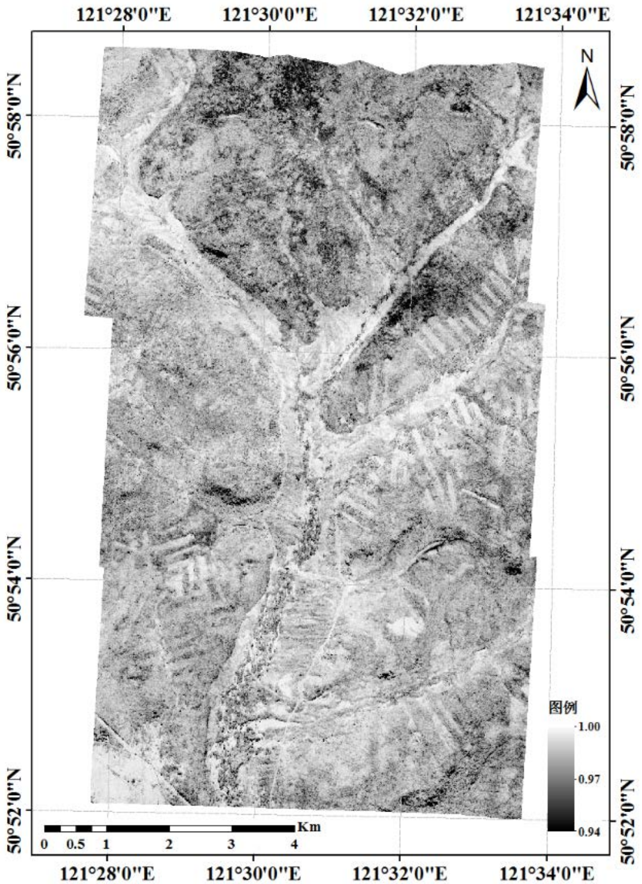
(15 images)

4.3 Result and Analysis

- Terrain correction results of X-InSAR coherence (Mosaic)



Before correction

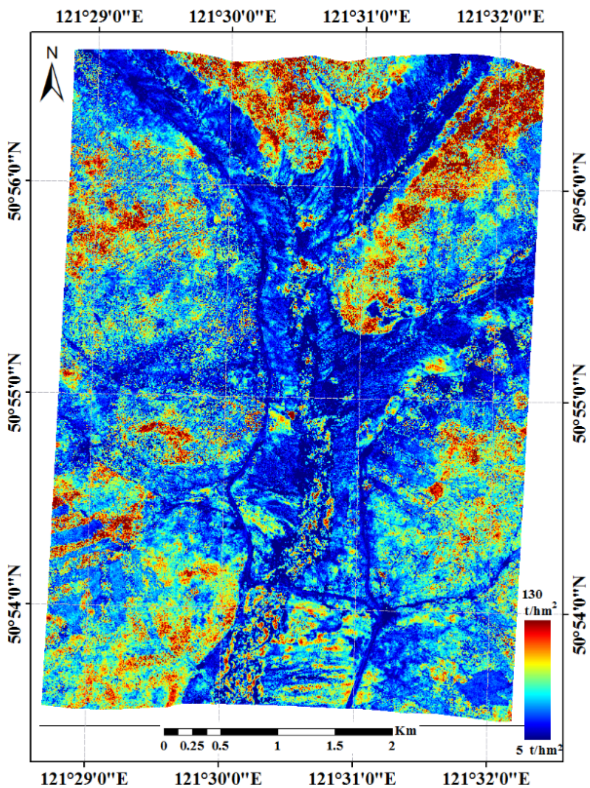


After correction

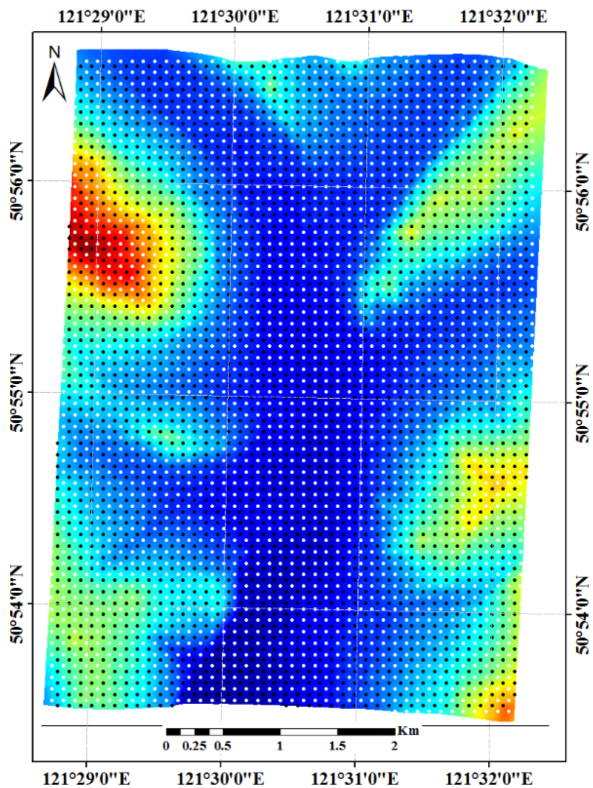
4.3 Result and Analysis

- Forest AGB combined estimation Modeling

Model： AGB = a + b·HH + c·HV + d·VV + e·Coherence



LiDAR forest AGB

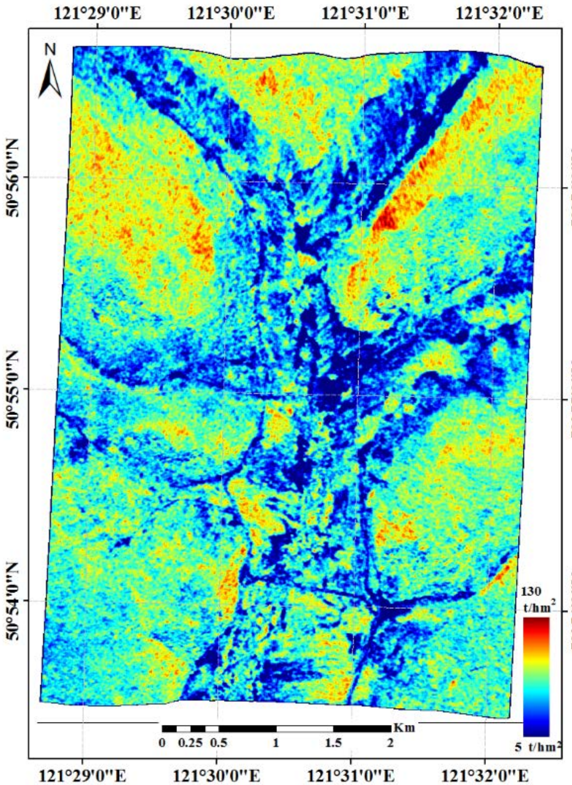


Training samples(white point：2188)
Validation samples(black point:2107) （30m*30m）

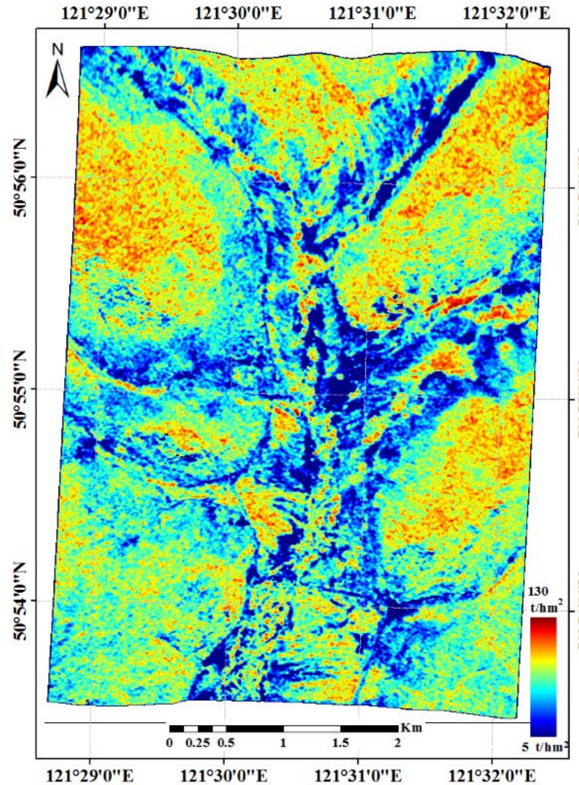
4.3 Result and Analysis

- Forest AGB estimation results: P-PolSAR

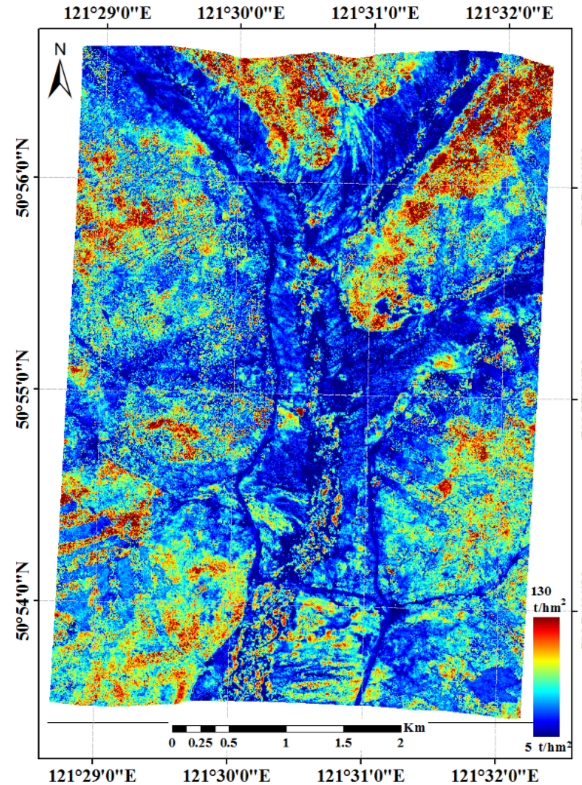
Model： AGB = a + b·HH + c·HV + d·VV



Uncorrected P-PolSAR



Corrected P-PolSAR

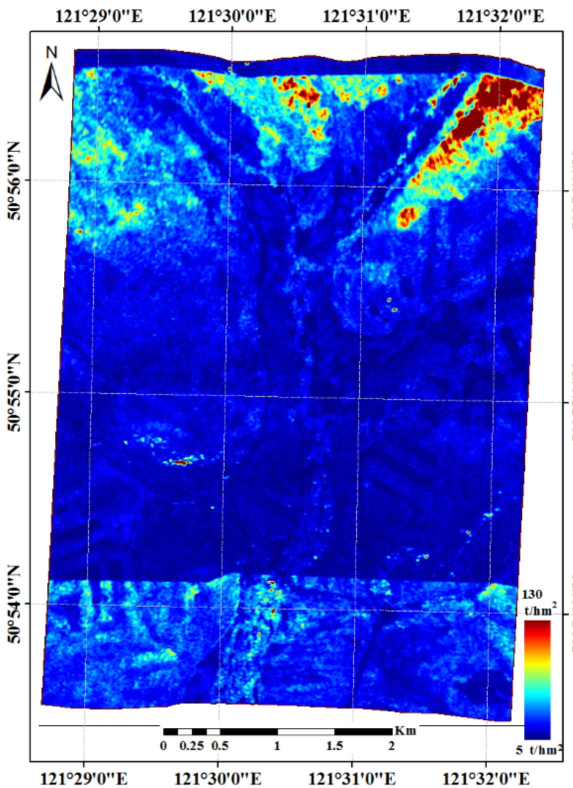


LiDAR forest AGB

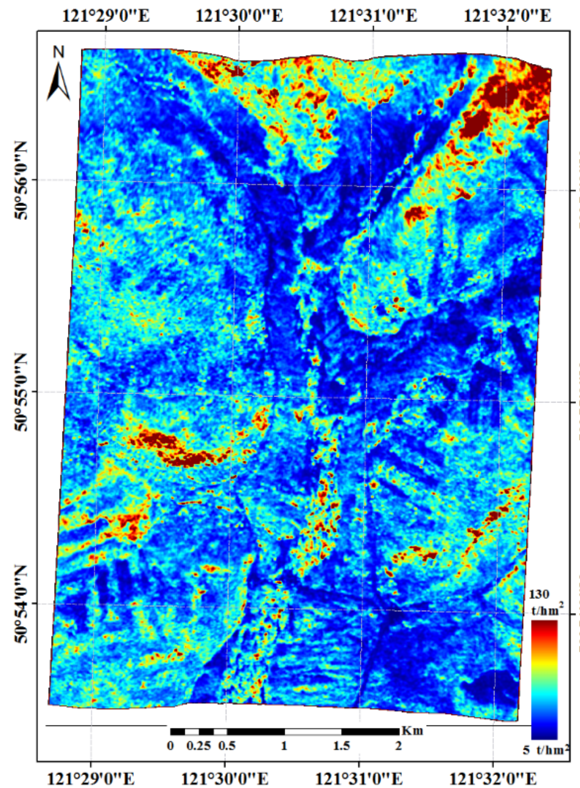
4.3 Result and Analysis

- Forest AGB estimation results: X-InSAR

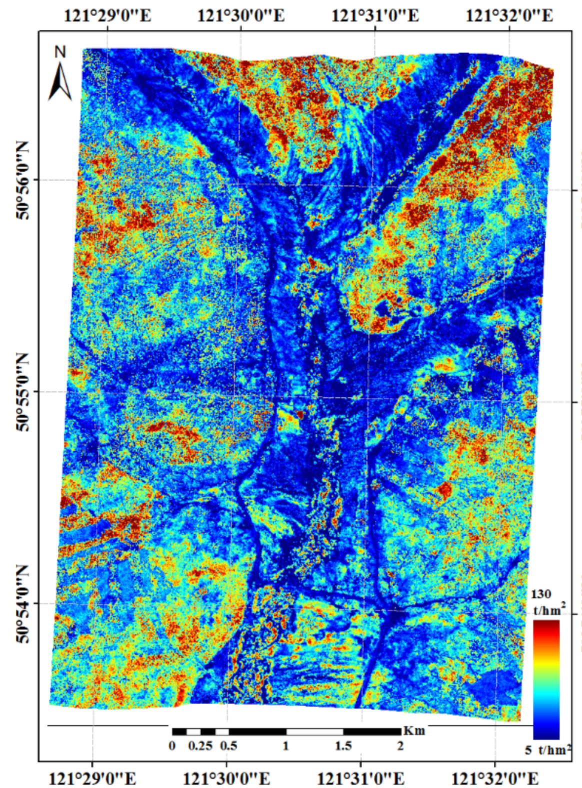
Model： AGB = a + e·Coherence



Uncorrected coherence



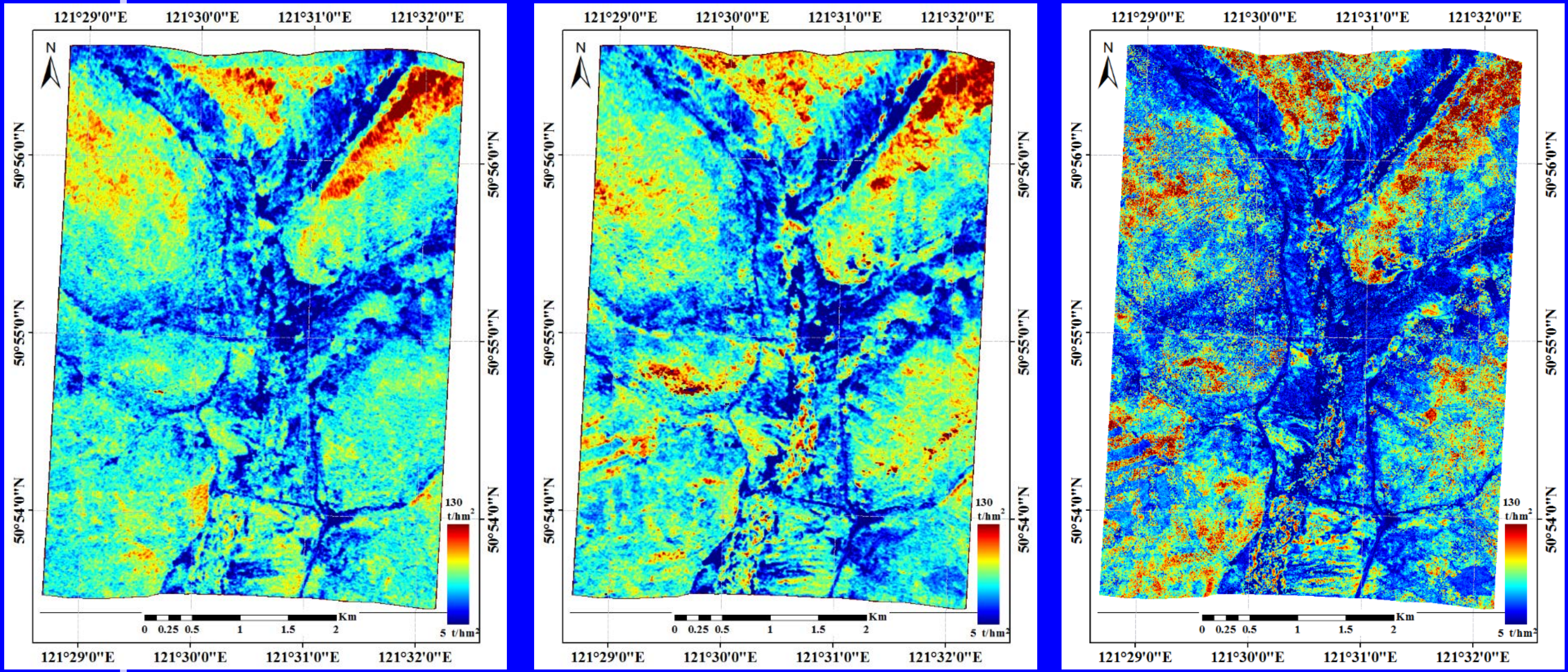
Corrected coherence



LiDAR forest AGB

- Forest AGB estimation results: P-PolSAR + X-InSAR

Model： AGB = a + b·HH + c·HV + d·VV + e·Coherence

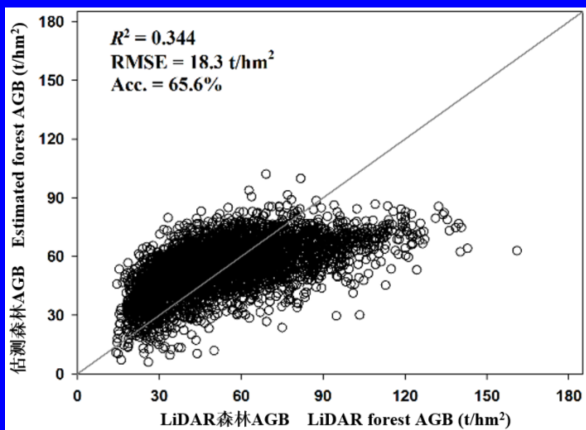


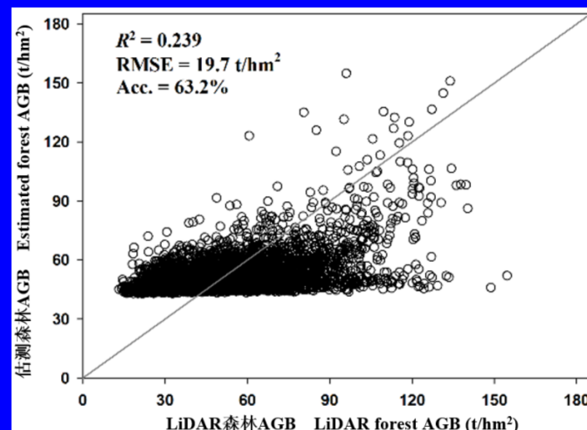
- Forest AGB estimation accuracy

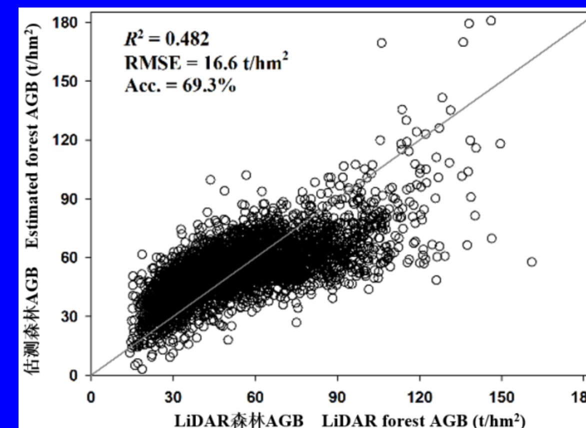
+3.7%

+6.1%

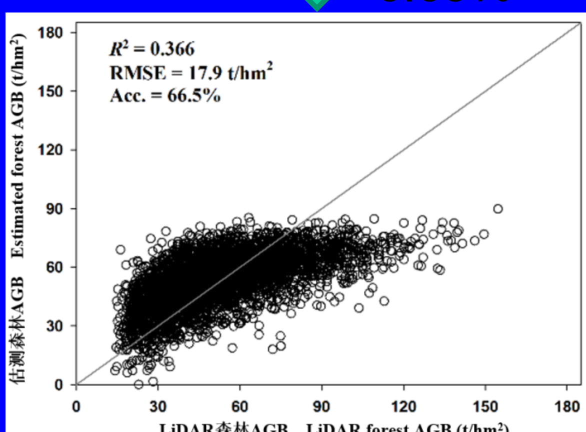
P-PolSAR | X-InSAR | P-PolSAR+X-InSAR

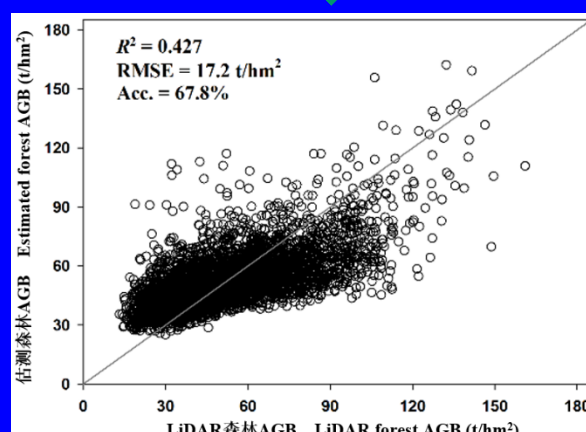


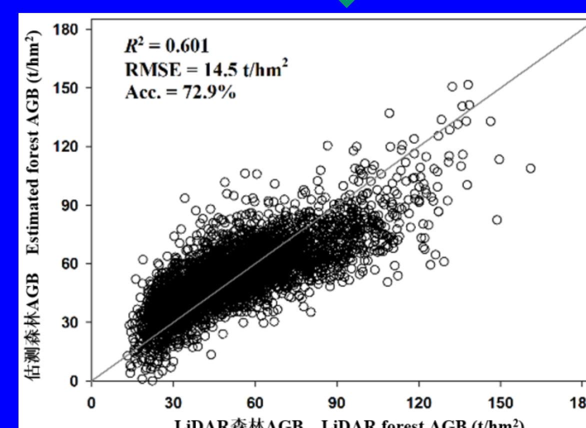




+0.09% | +5.6% | +3.6%







+6.4%

+5.1%

Outlines

1. Background
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3. Terrain Correction Method For InSAR coherence
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5. Summary

5. Summary

Aiming at the terrain problem of multi-dimensional SAR data applied to forest AGB estimation:

- One three-stage terrain correction methods for PolSAR data was proposed

  Three-stage method has advanced features in systematic comprehensive correction and self-adaptive parameter settings. And it is suitable for PolSAR matrix data.

- SINC differential correction method for InSAR coherence was developed

  It can effectively improve the image quality of ILU image & improve the correlation between coherence and forest AGB.

- Combined estimation approach for forest AGB based on X-band InSAR and P-band PolSAR data.

  It shows that the terrain effect of multi-dimensional SAR data can be effectively removed by proposed method. And the accuracy of forest AGB estimation can be improved.

Thank you for your attentions !