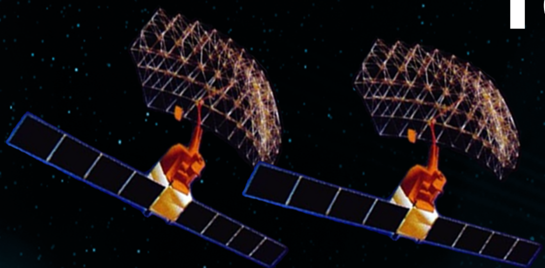
Institute of Electrics(IE),
Chinese Academy of Sciences(CAS)

Special considerations for TwinSAR-L baseline calibration method with known heights of point targets or reference DEM



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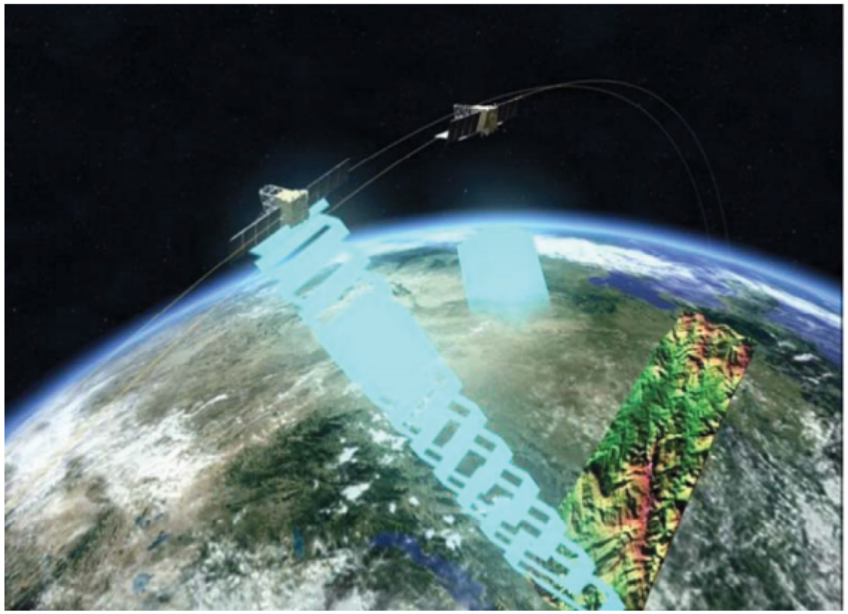
Science and Technology on Microwave Imaging Lab.

CEOS WGCV SAR Workshop 2019
18-22th November, 2019

Outline

- **TwinSAR-L System Overview**
  - TwinSAR-L interferometry Mode & parameter
  - InSAR height measurement principle
- **Distributed target baseline Calibration method overview**
- **Special considerations for TwinSAR-L**
  - Penetration depth
  - Signal to Noise Ratio
- **Summary**
- **Future work**

TwinSAR-L System Overview



Artists view of the TwinSAR-L satellites flying in close formation

Items	Value
Orbit Height(km)	607
Orbit semi major axis(km)	6978
Frequency(GHz)	1.26
Antenna length(m)	10
Orbit inclination(deg.)	97.8
Baseline calibration requirement(mm)	12
Relative height accuracy(m)	5

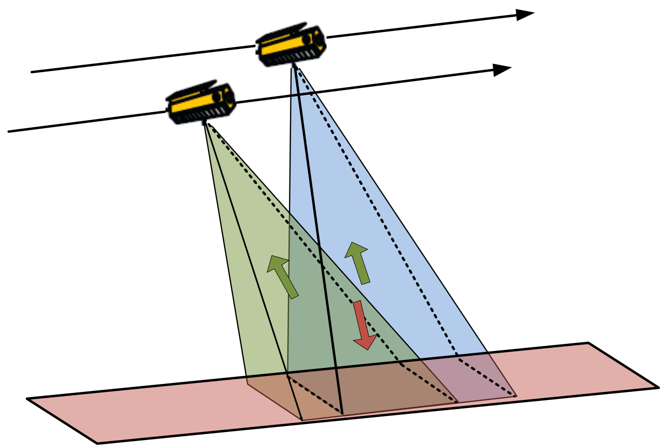
PARAMETERS OF THE SYSTEM

- TwinSAR-L(LT-1) mission was established in 2016 and will be launched in 2020.
- Multiple modes : **single-pass interferometry, multi-pass interferometry, multi polarization and wide swath imaging.**

Ref: C. Li et al., "Focusing the L-Band Spaceborne Bistatic SAR Mission Data Using a Modified RD Algorithm," IEEE TGRS.doi: 10.1109/TGRS.2019.2936255.

TwinSAR-L interferometry Mode:

- **the Helix satellite formation**



- **interferometry Mode parameter**

Items	Value
Ground range resolution(m)	3
Azimuth resolution(m)	3
Baseline length(km)	4~6
Incident angle (deg.)	20~46
Swath Width(km)	50

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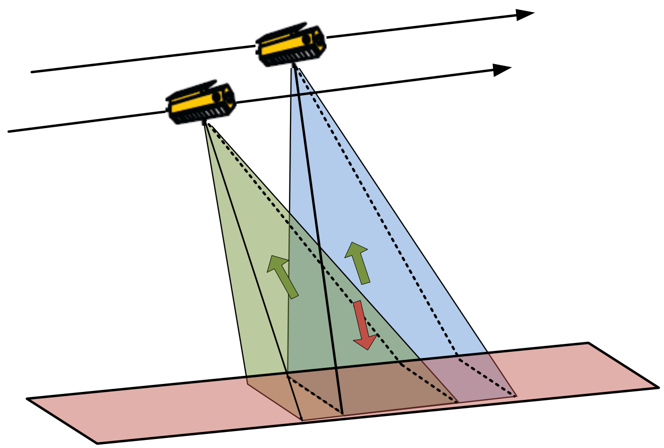

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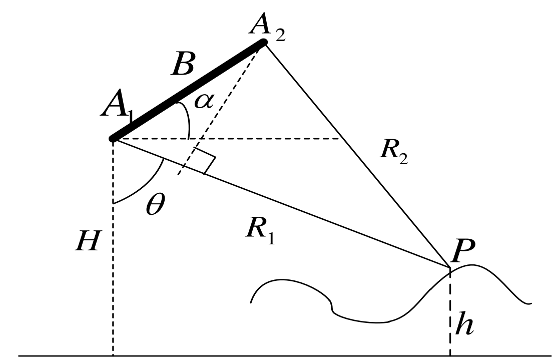
InSAR height measurement principle

$$cos(90^\circ - \theta + \alpha) = sin(\theta - \alpha) = \frac{B^2 + R_1^2 - R_2^2}{2B \cdot R_1}$$

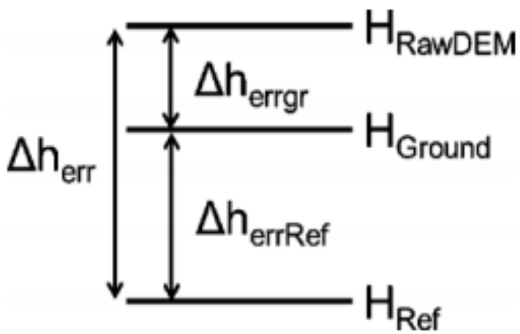
$$\phi = \frac{2\pi(R_1 - R_2)}{\lambda}$$

$$(R_1 - R_2) \simeq B \cdot cos(90^\circ - \theta + \alpha) = B \cdot sin(\theta - \alpha)$$

$$h = H - R_1 cos\theta$$



Distributed target baseline Calibration method overview

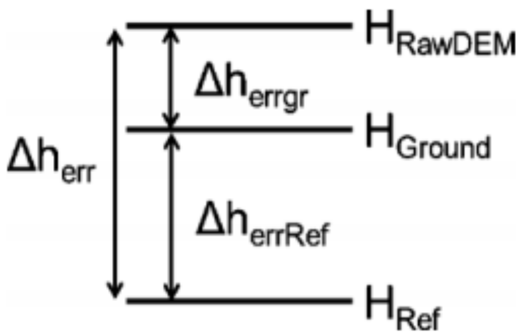


$$\Delta h_{err} = H_{RawDEM} - H_{Ref}$$

$$\Delta h_{errgr} = H_{RawDEM} - H_{Ground} = \frac{\Delta\emptyset}{2\pi} H_{amb}$$

$$\Delta h_{errRef} = H_{Ref} - H_{Ground}$$

Distributed target baseline Calibration method overview



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$$\Delta h_{errRef} = H_{Ref} - H_{Ground}$$

$$\Delta h_{err} = \frac{r \sin \theta_i}{B_{\perp}} \cdot B_{\parallel err} = \frac{H_{amb}}{\lambda} \cdot B_{\parallel err}$$

$$B_{||err} = \frac{\Delta \phi}{2\pi} \lambda - \frac{\Delta h_{errRef}}{H_{amb}} \lambda.$$

$$\vec{B}_{BIAS} = \vec{B}_{||err1} + k_1 \cdot \hat{B}_{\perp 1} = \vec{B}_{||err2} + k_2 \cdot \hat{B}_{\perp 2}$$

Ref: Antony J W , et al. Results of the TanDEM-X Baseline Calibration . IEEE J-STARS, 2013, 6(3):1495-1501.

Two considerations for TwinSAR-L baseline calibration method with known heights from laser altimeter

Two considerations for TwinSAR-L baseline calibration method with known heights from laser altimeter

- **The height error caused by penetration depth**
- **The height error caused by Signal to Noise Ratio(SNR)**

Two considerations for TwinSAR-L baseline calibration method with known heights from laser altimeter

- **The height error caused by penetration depth**
- **The height error caused by Signal to Noise Ratio(SNR)**

↓

simulation

Simulation : penetration depth

Ulaby penetration depth model(while $\frac{\varepsilon''}{\varepsilon'} < 0.1$)

$$\delta_P = \frac{\lambda \sqrt{\varepsilon'}}{2\pi\varepsilon''}$$

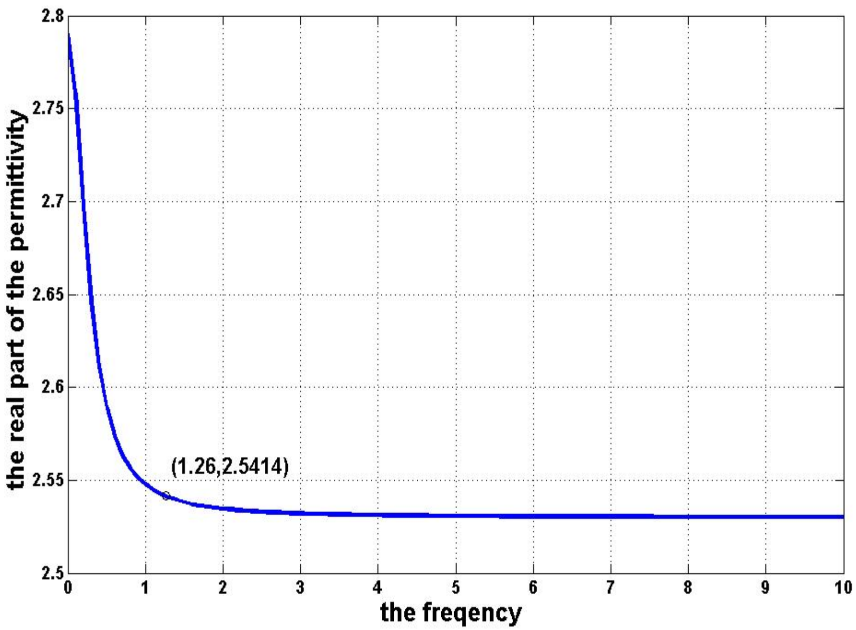
λ is wavelength and ε', ε'' are the real part and the imaginary part of the soil's permittivity

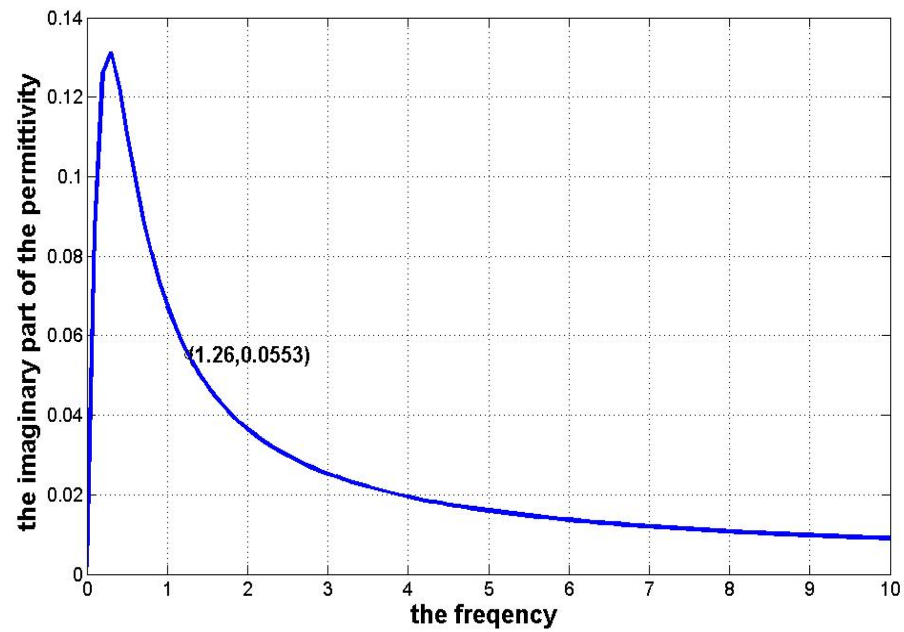
Ref: Ulaby F T , et al. Radar polarimetry for geoscience applications Norwood. MA: Artech House, 1990

Simulation : penetration depth

Permittivity model：

$$\varepsilon = \varepsilon' + i \cdot \varepsilon'' = \varepsilon_\infty + \frac{(\varepsilon_s - \varepsilon_\infty)}{1 - \frac{if}{f_0}} + ia'' \qquad f \in (0.245GHz, 6GHz)$$





Ref: Christian Matzler, C. Microwave permittivity of dry sand. IEEE TGRS 1998, 36(1):0-319.

Ulaby F T , et al. A Backscatter Model for a Randomly Perturbed Periodic Surface. IEEE TGRS, 1982, 20(4):518-528.

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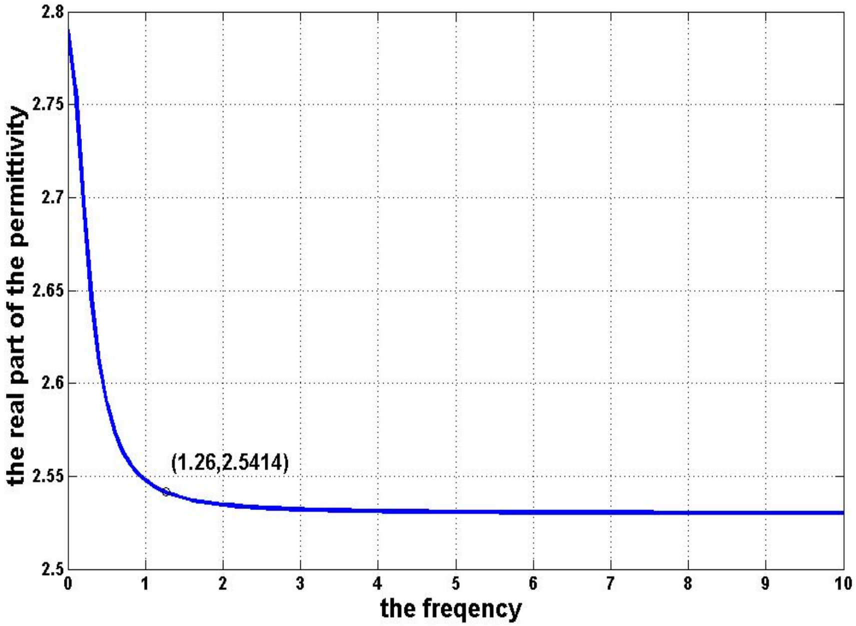

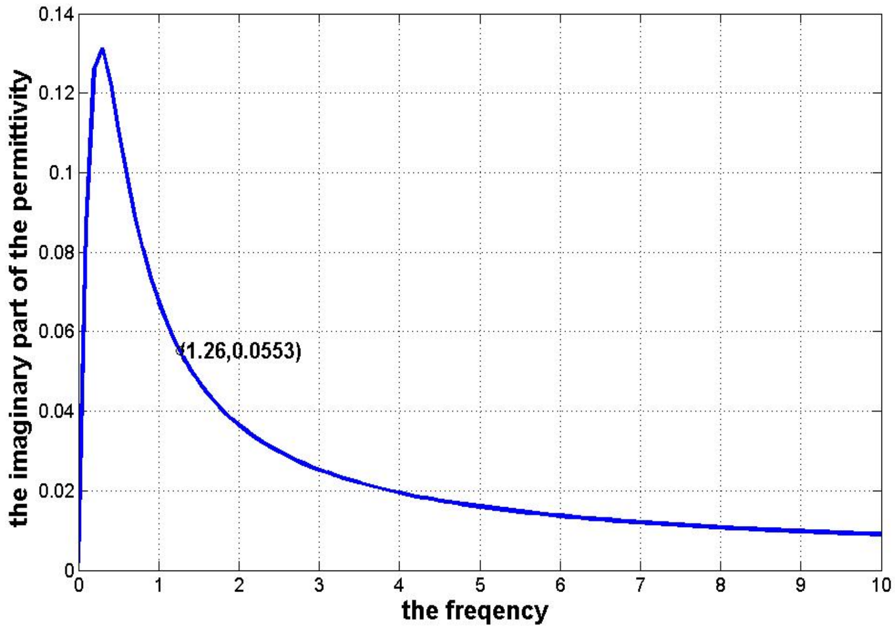

According to the figures：the permittivity in L band is（2.5414，0.0553）

Simulation : penetration depth

Ulaby penetration depth model(while $\frac{\varepsilon''}{\varepsilon'} < 0.1$)

$$\delta_P = \frac{\lambda \sqrt{\varepsilon'}}{2\pi\varepsilon''}$$

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the permittivity of dry sand in L band is (2.5414 , 0.0553)

put the data into the model:

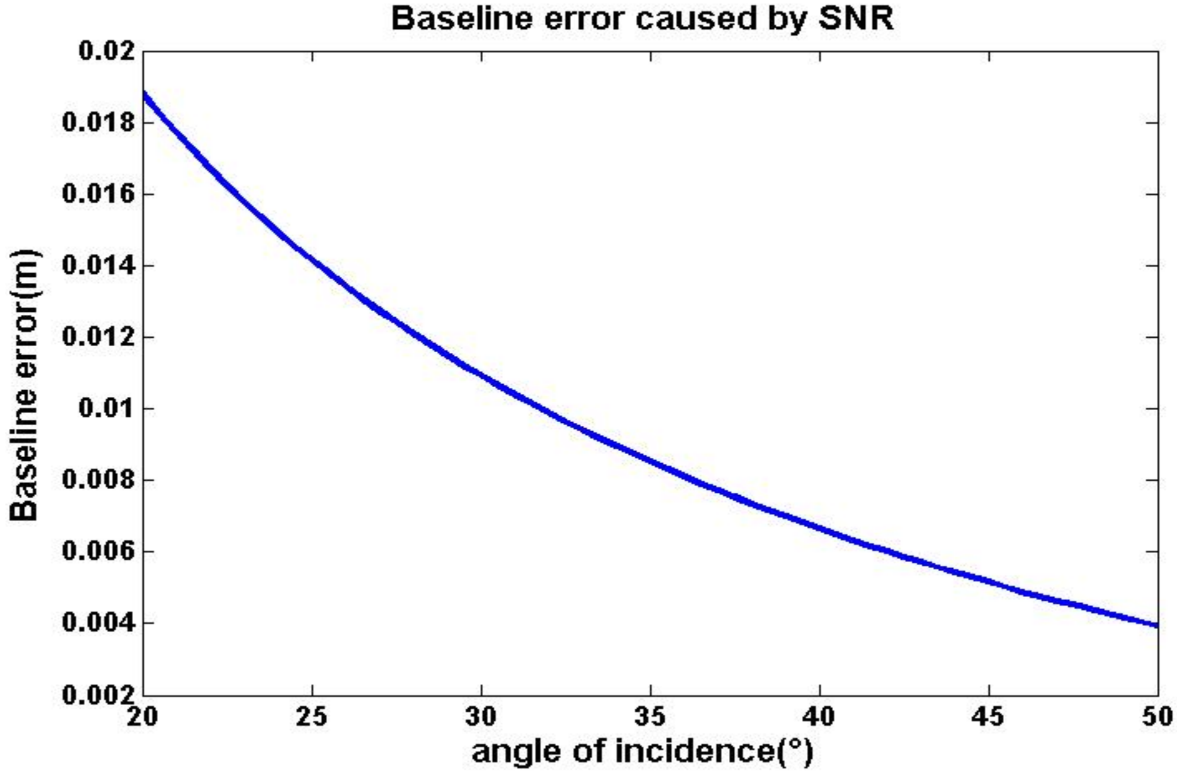
δ_1=1. 0924m (**penetration depth in L band**)

Height error is 1.0924m(required 5m)

Simulation : penetration depth

Height error is 1.0924m(required 5m)

$$B_{\parallel err} = \frac{B_{\perp}}{r \sin \theta_i} \cdot \Delta h_{err}$$



Baseline error :3.9mm to 18.8mm(required 12mm)

Simulation : penetration depth

Parameter			Test result			
			bare land	grassland	cement court	sand land
land surface parameter	humidity (%)		1.24	15.53	0.11	0.25
	average temperature (°c)		32	32	34	28
	average wind speed(m/s)		3.94	4.22	6.43	5.32
	rms height (cm)		2.23	-	0.082	-
	correlation length (cm)		50.2	-	5.68	-
	Relative complex permittivity	1.34GHz	4.85,0.0196	-	-,-	2.98,0.068
		3.2GHz	4.86,0.021	-	-,-	2.96,0.073
		10GHz	4.75,0.023	-	-,-	2.89,0.078
		16 GHz	4.69,0.025	-	-,-	2.86,0.081

the permittivity of dry sand in L band is (2.98 , 0.068)
the permittivity of dry sand in X band is (2.89 , 0.078)

the experimental data provided by CRIRP in 2009 (Institute of radio propagation in China)

Simulation : penetration depth

Parameter			Test result			
			bare land	grassland	cement court	sand land
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Put the data into the Ulaby penetration depth model:

$\boldsymbol{\delta_1 = 0.9046m}$ (**penetration depth in L band**)

$\boldsymbol{\delta_2 = 0.1041m}$ (**penetration depth in X band**)

Baseline error (L): 3.3mm to 15.6mm (required 12mm)
Baseline error (X): 0.37mm to 1.8mm (required 12mm)

Simulation : backscattering coefficient

γ - f backscattering coefficient model

$$\sigma_{\gamma-f}^{0} = \gamma \cdot a f^{b} \cdot sin(\psi + c)$$

f is the frequency(GHz);ψ is depression angle; a, b, c and γ are Coefficients based on statistical methods

The relevant parameters under various terrains :

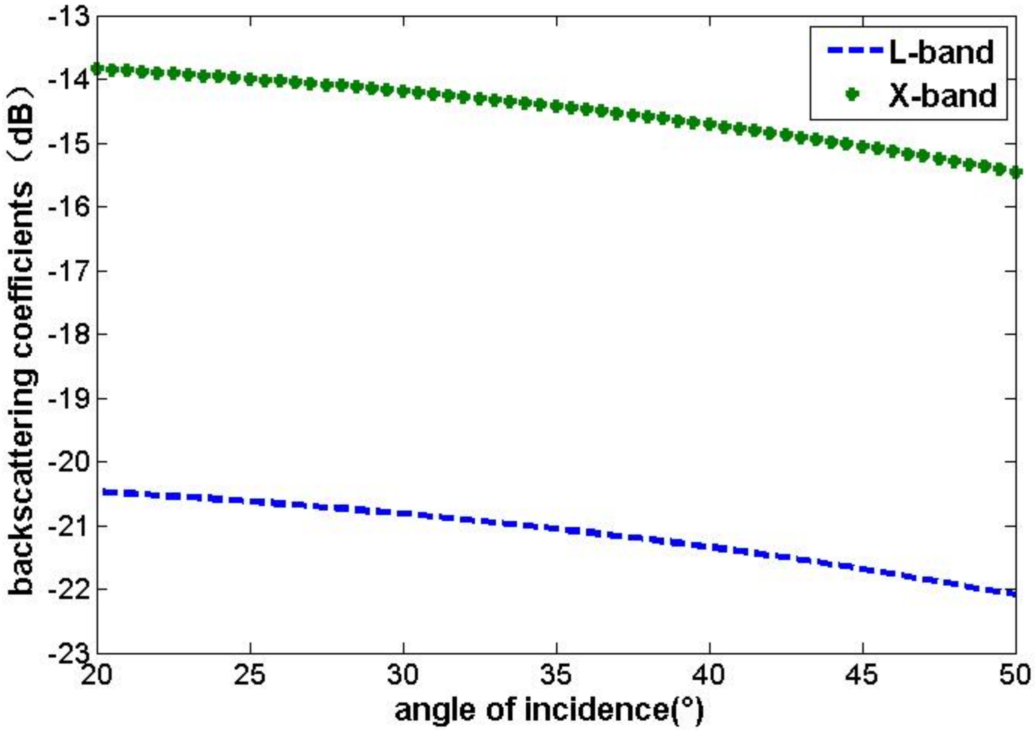
terrains	γ	a	b	c
sand land	0.1	0.08	0.75	0.50
farmland	0.0316	0.18	0.60	0.55
hill	0.1	0.25	0.20	1.20
Urban	0.316	0.35	0.18	0.70

Simulation : backscattering coefficient

γ - f backscattering coefficient model:

$$\sigma_{r-f}^{0} = \gamma \cdot af^{b} \cdot sin(\psi + c)$$

γ - f backscattering coefficient Simulation result:



Simulation : backscattering coefficient

Height error caused by the Signal to Noise Ratio :

Signal to Noise Ratio:

$$SNR(dB) = \sigma^0(dB) - NE\sigma^0(dB)$$

Correlation:

$$\gamma = \frac{1}{1 + SNR^{-1}}$$

Phase Noise:

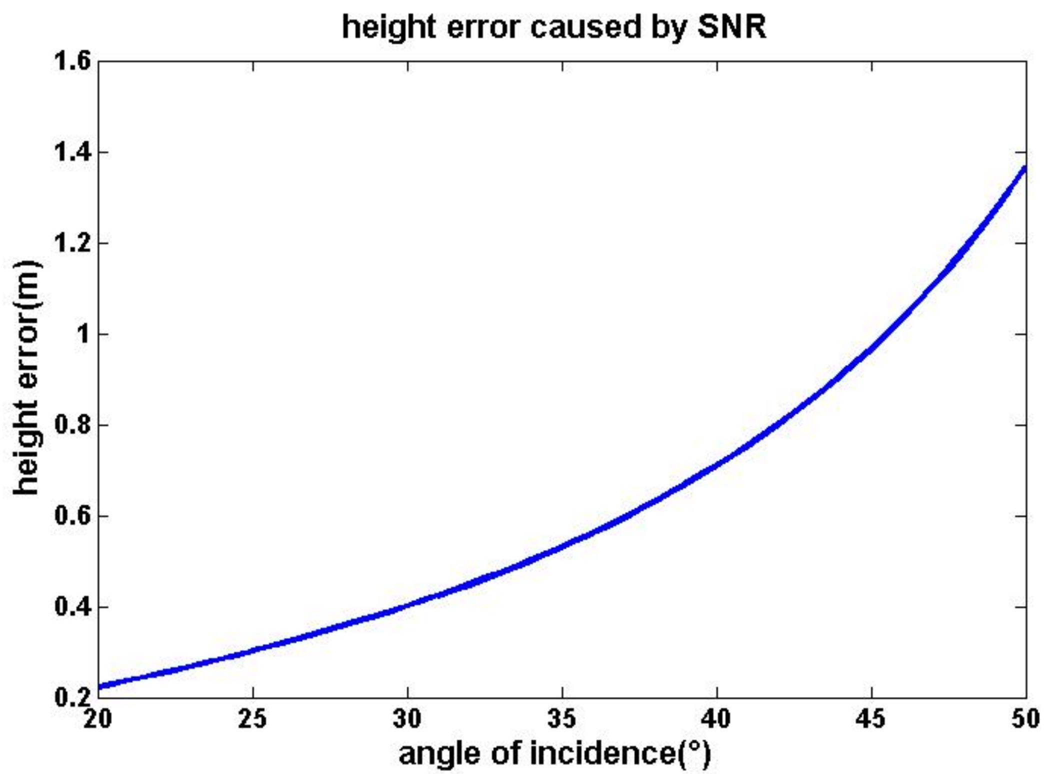
$$\sigma_\phi = \frac{1}{\sqrt{2N}} \frac{\sqrt{1-\gamma^2}}{\gamma}$$

Height error:

$$h_{err} = \frac{h_{amb}}{2\pi}\sigma_\phi = \frac{\lambda r \sin(\theta_i)}{2\pi B_\perp}\sigma_\phi$$

Baseline error:

$$B_{\| err} = \frac{\lambda h_{err}}{h_{amb}}$$



Height error : 0.22m to 1.37m (required 5m)
Baseline error : 3.8mm to 4.9mm (required 12mm)

Simulation : backscattering coefficient

The modified Morchin backscattering coefficient model:

$$\sigma^0 = \frac{A\sigma_c^0 sin\theta_g}{\lambda} + ucot^2\beta_0 \exp[-\frac{tan^2(B-\theta_g)}{tan^2\beta_0}]$$

$u = \frac{\sqrt{f_0}}{4.7}, f_0(GHz) is$ the frequency; θ_g is depression angle; the terrain is sand land; if $\theta_g < \theta_c, \sigma_c^0 = (\frac{\theta_g}{\theta_c})^k$ else if $\theta_g > \theta_c, \sigma_c^0$=1; $h_e \approx 9.3\beta_0^{2.2}$; k=1; A, B, β_0 are Coefficients based on statistical methods:

The relevant parameters under various terrains :

terrains	A	B	β_0	σ_c^0
sand land	0.00126	$\pi/2$	0.14	θ_g/θ_c
farmland	0.004	$\pi/2$	0.2	1
hill	0.0126	$\pi/2$	0.4	1
mountain	0.04	1.24	0.5	1

Simulation : backscattering coefficient

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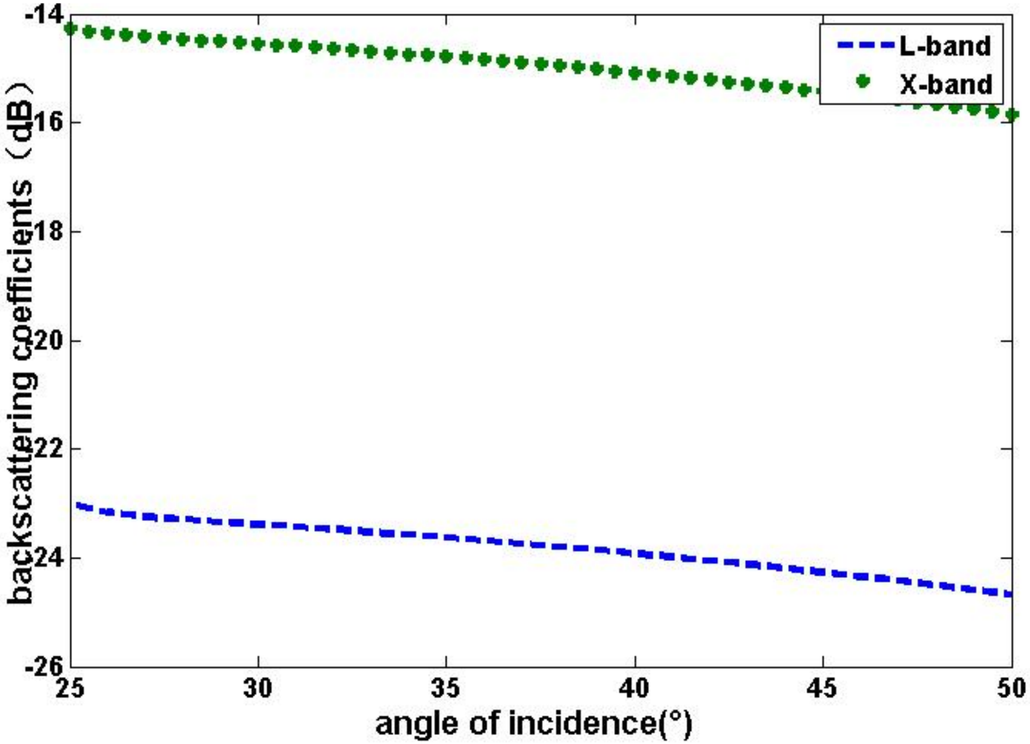
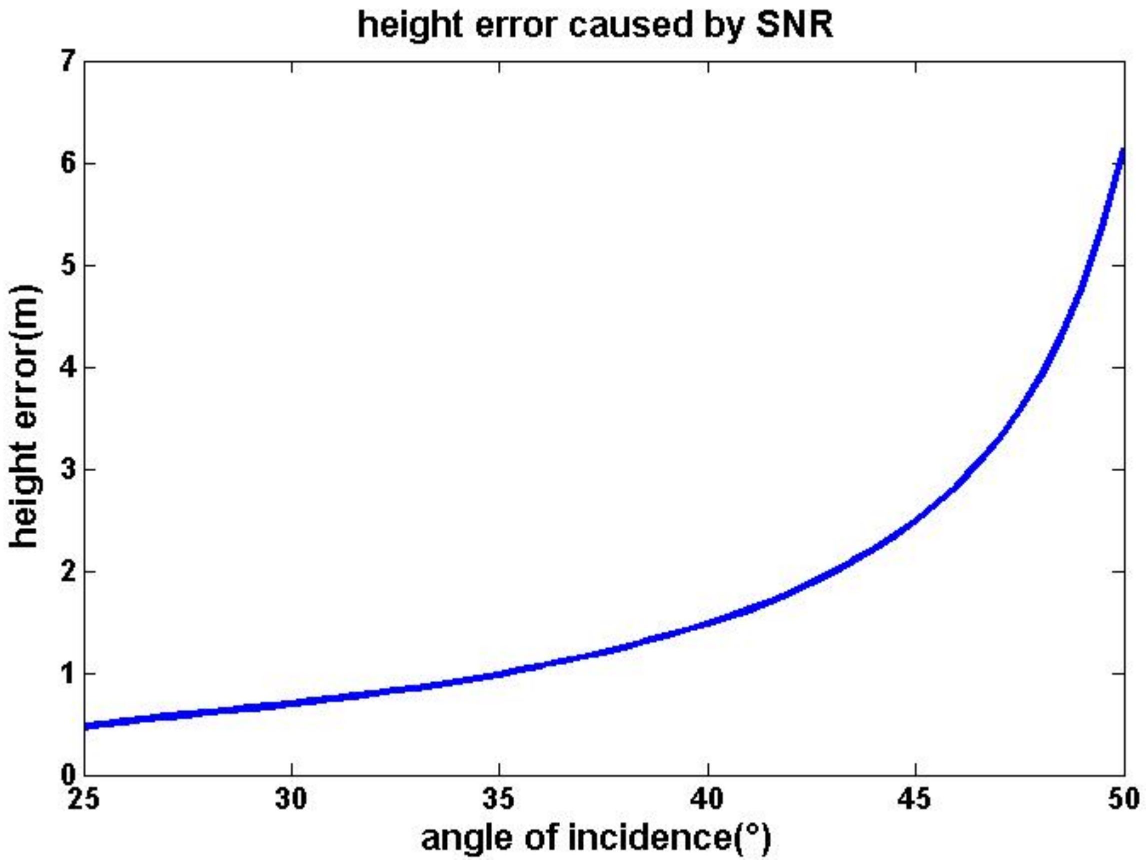
The modified Morchin backscattering coefficient Simulation :



Simulation : backscattering coefficient

Height error caused by the Signal to Noise Ratio :



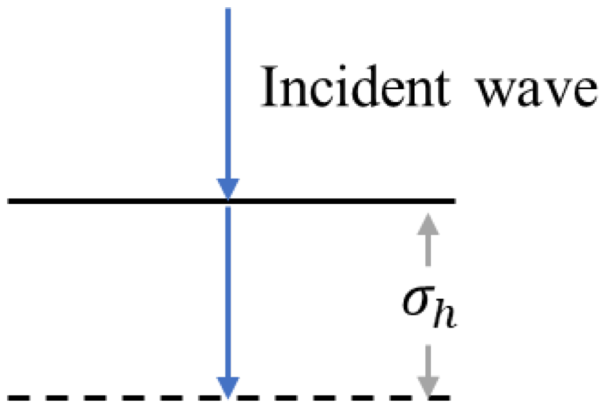
Height error : 0.47m to 6.13m(required 5m)
Baseline error : 6mm to 24mm(required 12mm)

Summary

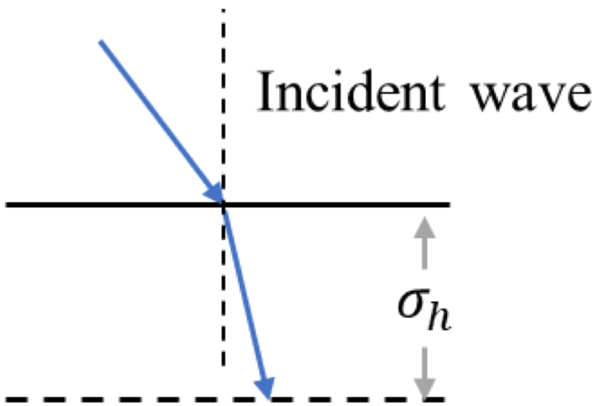
- **Height error caused by penetration depth in L band is around 1.0m(required 5m) and Baseline error ranges from 3.9mm to 18.8mm (required 12mm)**
- **Height error caused by SNR in L band in γ - f backscattering coefficient model ranges from 0.22m to 1.37m (required 5m) and Baseline error ranges from 3.8mm to 4.9mm (required 12mm)**
- **Reference DEM is replaced by point targets for the baseline calibration of TwinSAR-L.**

Future work

- **Validation with The L-Band ALOS-2 satellite data.**
- **The refraction at the interface will be considered.**



Refraction at the interface isn’t considered



Refraction at the interface is considered

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Thank you for your attention!