Measurement for L-band SAR signal extinction in a forest canopy

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1. Background

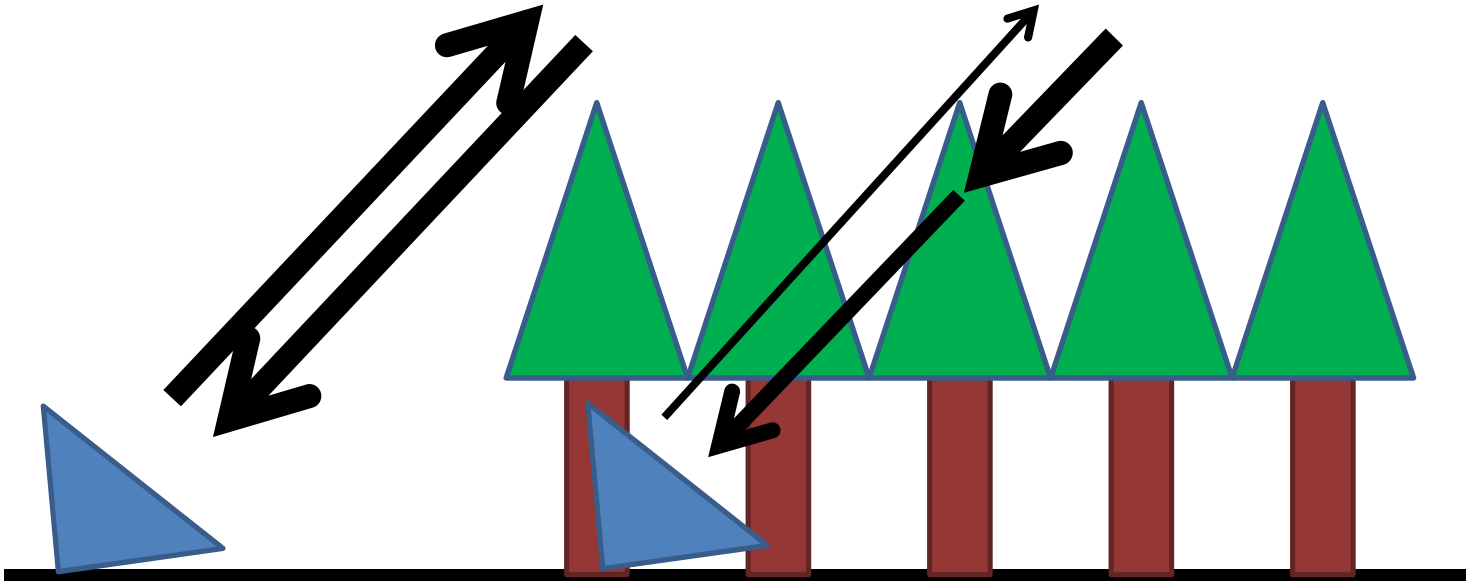
Motivation

- How much L-band SAR penetrate in a forest canopy?
- Extinction factor (σ) is important for tree height estimaton with InSAR
  Water Cloud model (σ^0-biomass relation)
- σ estimation example from InSAR (L-band) & LiDAR data (Indirect method)*
  Average : 0.18-0.21 dB/m, Max ~0.7 dB/m (@Finland)

→ **"Direct measurement of σ", "Applying tree height measurement with InSAR"**

Method

- Deploy CR under trees, measure σ.
- Estimate tree height with measured σ and InSAR technique.



* J. Praks, et al., IEEE TGRS, vol. 50, No. 10, pp 3831-3843, 2012

1. 2. Measurement for L-band SAR signal extinction with CR

~ Data ~

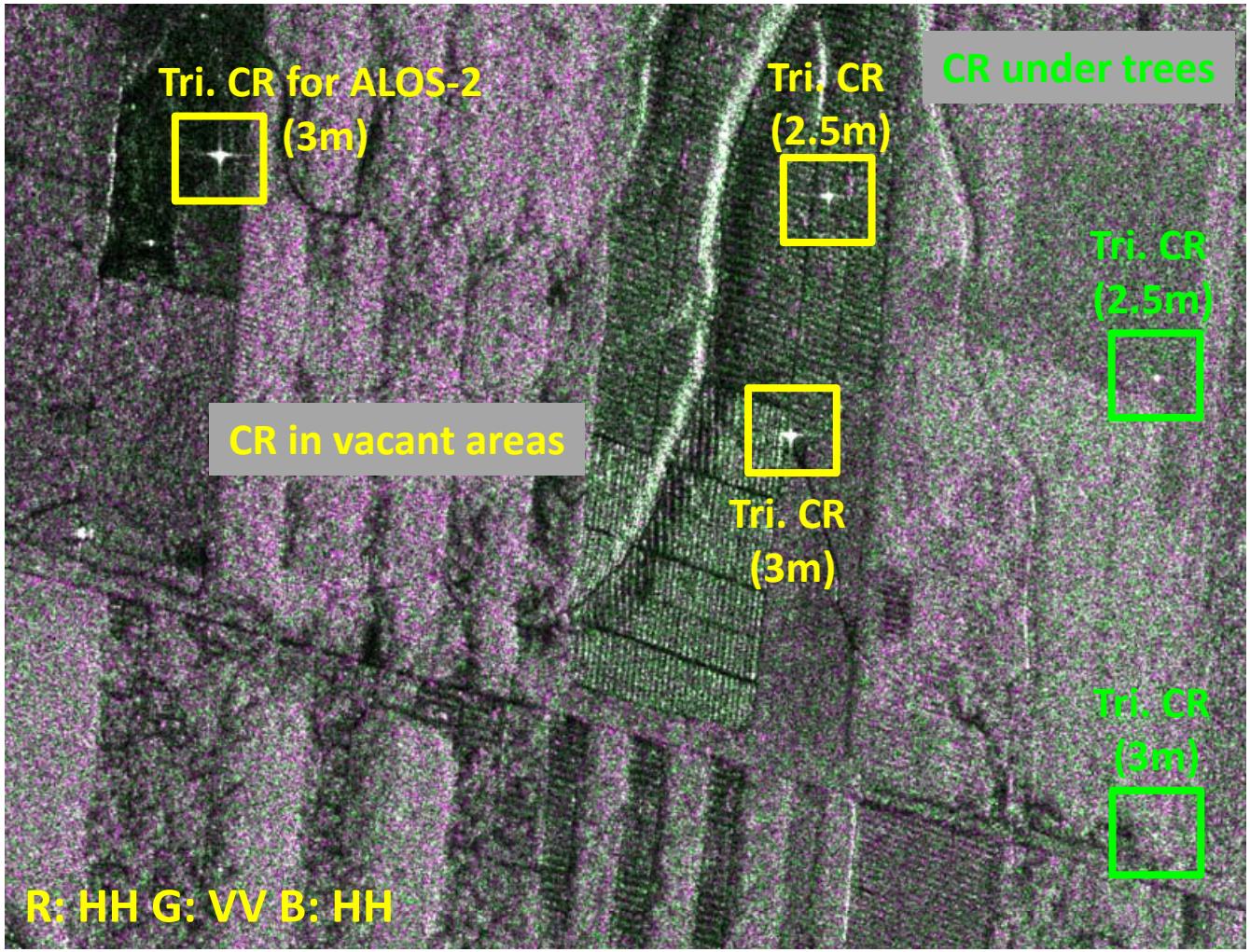
@ Tomakomai National forest

Pi-SAR-L2	Data 1	Data 2
Obs. date	Oct. 10, 2013	Oct. 11, 2013
Flight direction	South→North（PALSAR-D）	East→West
Obs. ID	L203001、L203003	L203101、L203102、L203103、L203105、L203106

Forest data	Broad leaf	Aka-ezomatsu
Average tree height	9.2 m	9.5m
Biomass	62.9 tons/ha	110.5 tons/ha
Deployed CR	2.5 m	3 m

Observed CRs

(L203003)



CR under trees are observed

CR managed to be observed with 110.5 tons/ha forest

Measured extinction factor (σ)

ID	Broad leaf	Aka-ezomatsu
Biomass	62.9 tons/ha	110.5 tons/ha
σ	**0.30 dB/m (S→N , HH)** **0.42 dB/m (S→N , VV)** 0.43 dB/m (E→W , HH) 0.42 dB/m (E→W , VV) (Small azimuth dependency)	**0.75dB/m (S→N , HH)** **0.65dB/m (S→N , VV)** 1.05 dB/m (E→W ,HH) 1.07 dB/m (E→W ,VV) (Large azimuth dependency)
Photos		

Extinction factor: 0.3～1.07

Consistent with the result estimated from LiDAR & InSAR data.

Azimuth dependency is observed for regularly planted Aka-ezomatsu site.

3. Tree height estimation by PALSAR/InSAR

Coherence
(Intensity)

$$|\gamma|_{Obs.} = |\gamma|_{processor}\,|\gamma|_{azimuth}\,|\gamma|_{noise}\,|\gamma|_{spatial}\,|\gamma|_{volume}\,|\gamma|_{temporal}$$

Cause of de-correlation

$|\gamma|_{spatial}$: Non-parallel orbits of two repeat pass. ≤ 1

Well represented by a theory

$|\gamma|_{volume}$: **Volume scattering component** ≤ 1

Some theories suggested, based on a forest structure

$|\gamma|_{temporal}$: Status change of scatterers between two flights ≤ 1

Difficult to describe a theory.

One of a theory for Volume de-correlation

~ Exponential extinction in a canopy ~

$$\gamma_{volume}(\vec{w}) = \exp^{i\varphi_0} \frac{\int_0^{h_v} \exp^{\frac{2\sigma(\vec{w})z}{\cos\theta}} \exp^{ik_z z'} dz}{\int_0^{h_v} \exp^{\frac{2\sigma(\vec{w})z}{\cos\theta}} dz}$$

$$= \exp^{i\varphi_0} \frac{p_1(\vec{w})\left(\exp^{p_2(\vec{w})h_v} - 1\right)}{p_2(\vec{w})\left(\exp^{p_1(\vec{w})h_v} - 1\right)}$$

$$p_1 = \frac{2\sigma(\vec{w})}{\cos\theta}$$

$$p_2 = \frac{2\sigma(\vec{w})}{\cos\theta} + ik_z$$

$$k_z = \frac{4\pi B_\perp}{\lambda R \sin\theta}$$

σ : Extinction factor (dB/m)

θ : Incident angle

h_v : Volume thickness（Tree height）

λ : Wave length

$\vec{w}$: Scattering vector

R : Range distance

$B_\perp$: Orbit interval

hv is estimated from γ_{volume} and σ

PALSAR data

- 4 pairs with highest coherence
- Exclude winter time
- Surface phase is corrected in the vacant area data.

	FBD 34.3° (HH,HV)		PLR 21.5° (HH,HV,VH,VV)	
Obs. direction	Ascending		Descending	
Obs. date	8/18-10/3, 2007	7/8-8/23, 2009	5/30-8/30, 2010	8/30-10/15, 2010
Obs. interval (day)	46	46	92	46
Orbit interval (m)	321.9	1137.51	307.9m	385.8
kz	0.032	0.112	0.053	0.067
ID	FBD1	FBD2	PLR1	PLR2

Coherence (Intensity & phase)

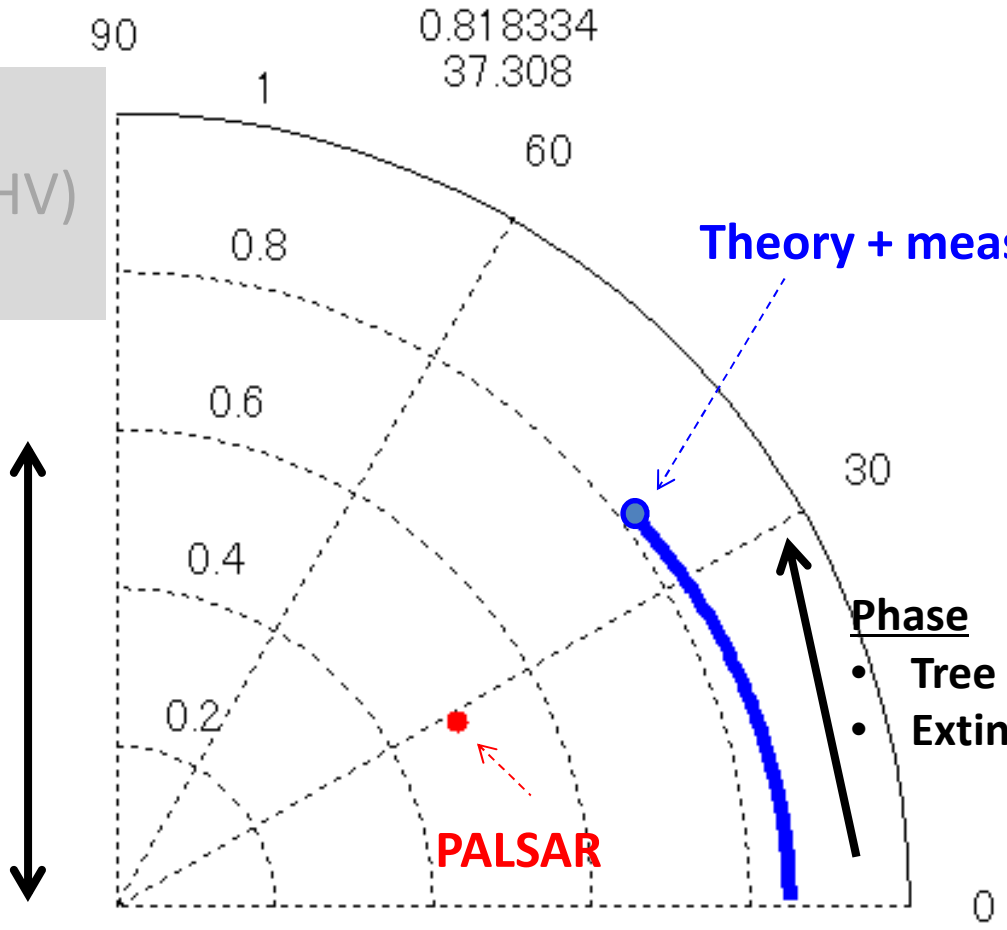
Tree ID	Obs. mode	Polari-zation	Coherence				Tree height (m) (Measured)	Tree height (m) (Estimated from phase)	Difference (%)
			PALSAR		Theory + measured σ				
			Int.	Phase	Int.	Phase			
Broad leaf	FBD1	HH	0.60	5.9°	0.96	10.5°	9.2	5.6	-39.1
	FBD2	HH	0.49	28.2°	0.82	37.3°		7.3	-20.7
	PLR1	HH	0.34	15.9°	0.91	17.2°		**8.5**	**-7.6**
		VV	0.33	26.6°	0.91	18.3°		12.5	35.9
	PLR2	HH	0.38	17.9°	0.88	21.5°		**7.9**	**-14.1**
		VV	0.41	14.8°	0.88	22.9°		6.4	-30.4
Aka-ezomatsu	FBD1	HH	0.81	14.5°	0.96	13.4°	9.5	**10.2**	**7.4**
	FBD2	HH	0.57	79.4°	0.83	47.5°		14.6	53.7
	PLR1	HH	0.53	9.5°	0.91	21.7°		4.8	-49.5
		VV	0.49	12.9°	0.91	21.0°		6.4	-32.6
	PLR2	HH	0.65	18.9°	0.89	27.2°		7.1	-25.3
		VV	0.66	22.3°	0.89	26.3°		**8.3**	**-12.6**

Intensity: Difference observed

Phase : Tree height estimation with **7～14 % accuracy for several sites.**

Coherence value on complex plane

Site : Broad leaf
Mode : FBD (HH, HV)
Polarization : HH-HH



Intensity
- **Tree height**
- **Extinction factor**
- **Temporal de-correlation**
- Spatial de-correlation

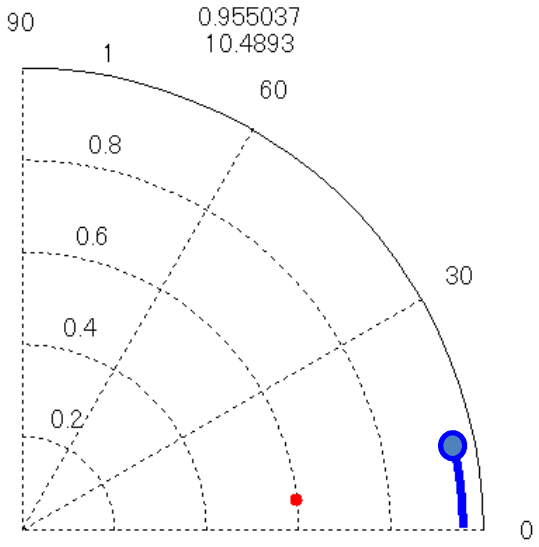
Phase
- **Tree height**
- **Extinction factor**

Intensity: Difference observed(→No temporal de-correlation considered)
Phase : Tree height estimation with **7～14 % accuracy for several sites.**
(→No temporal de-correlation dependency)
→**Implying tree height estimation with coherence phase only**.

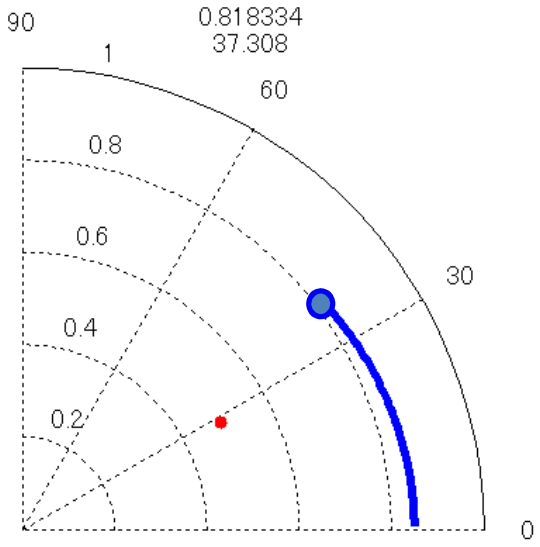
FBD
HH-HH

Broad leaf

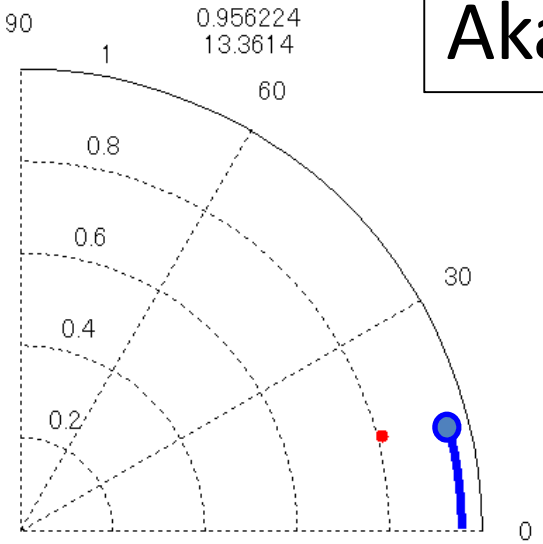
FBD1

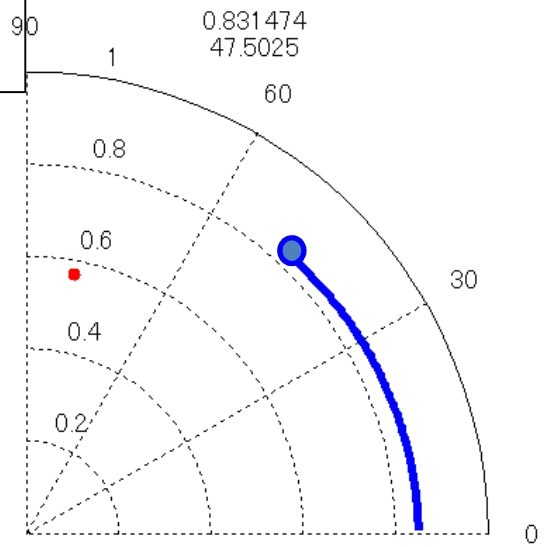


FBD2



Aka-ezomatsu



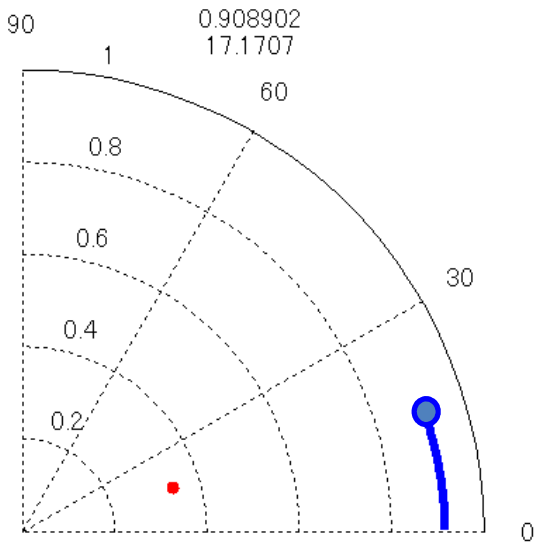


* : PALSAR　　: Theory + measured σ

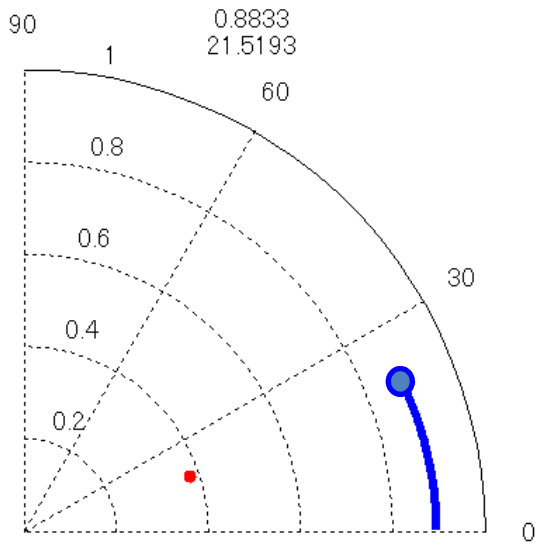
PLR
HH-HH

Broad leaf

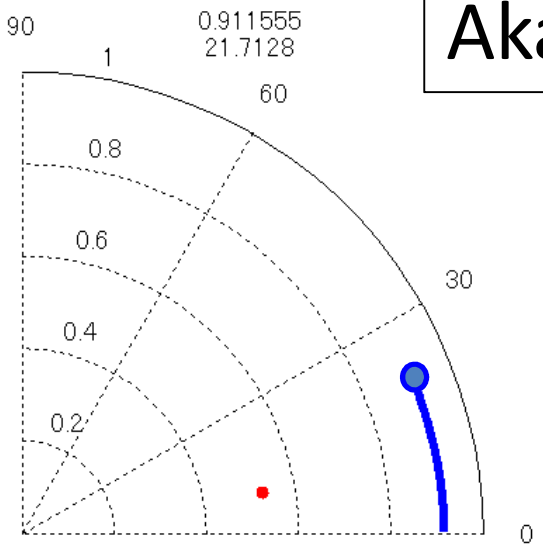
PLR 1

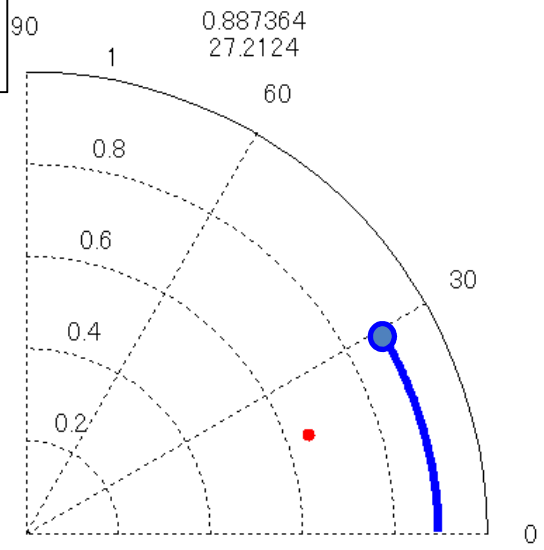


PLR2



Aka-ezomatsu



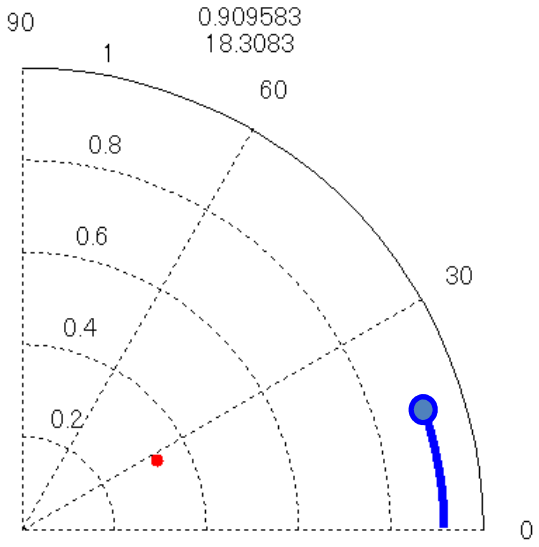


* : PALSAR　　: Theory + measured σ

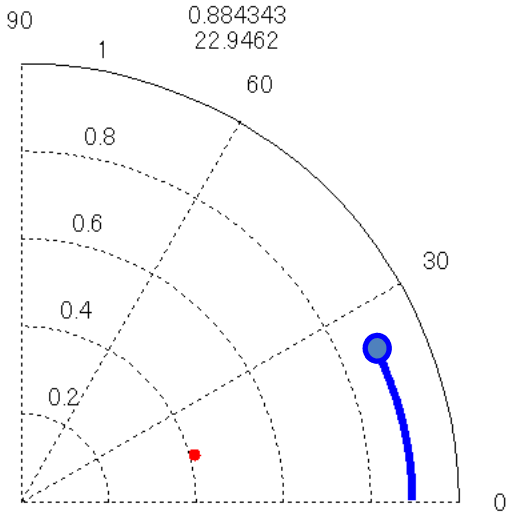
PLR
VV-VV

Broad leaf

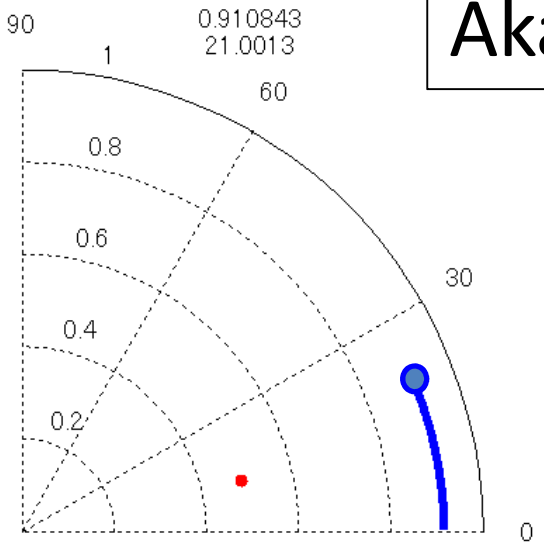
PLR 1

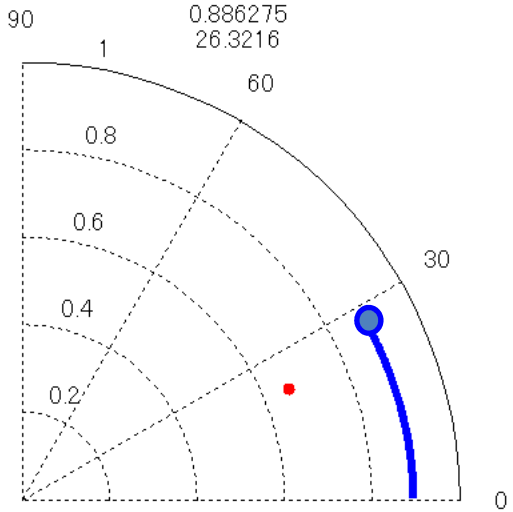


PLR2



Aka-ezomatsu





* : PALSAR　　: Theory + measured σ

4. Summary & future

- L-band SAR signal extinction estimation from CR deployed under trees
  - ✓ **Extinction factor**
    0.40 dB/m (@ biomass = 62.9 tons/ha, height=9.2m)
    0.88 dB/m (@ biomass = 110.5 tons/ha, height=9.5m)
    Consistent with the result estimated from LiDAR & InSAR data.
    Azimuth dependency is observed for regularly planted site.
  - ✓ This method is applicable for a forest site with biomass < ~100 tons/ha
- Coherence (PALSAR obs. vs Theory + measured σ)
  - ✓ Intensity : Difference observed (→No temporal de-correlation considered
  - ✓ Phase : Tree height estimation with **7～14 % accuracy for several sites.**
    (→No temporal de-correlation dependency)
    → **Implying tree height estimation with coherence phase only**
- Future
  Possible to estimate σ from SAR data?