

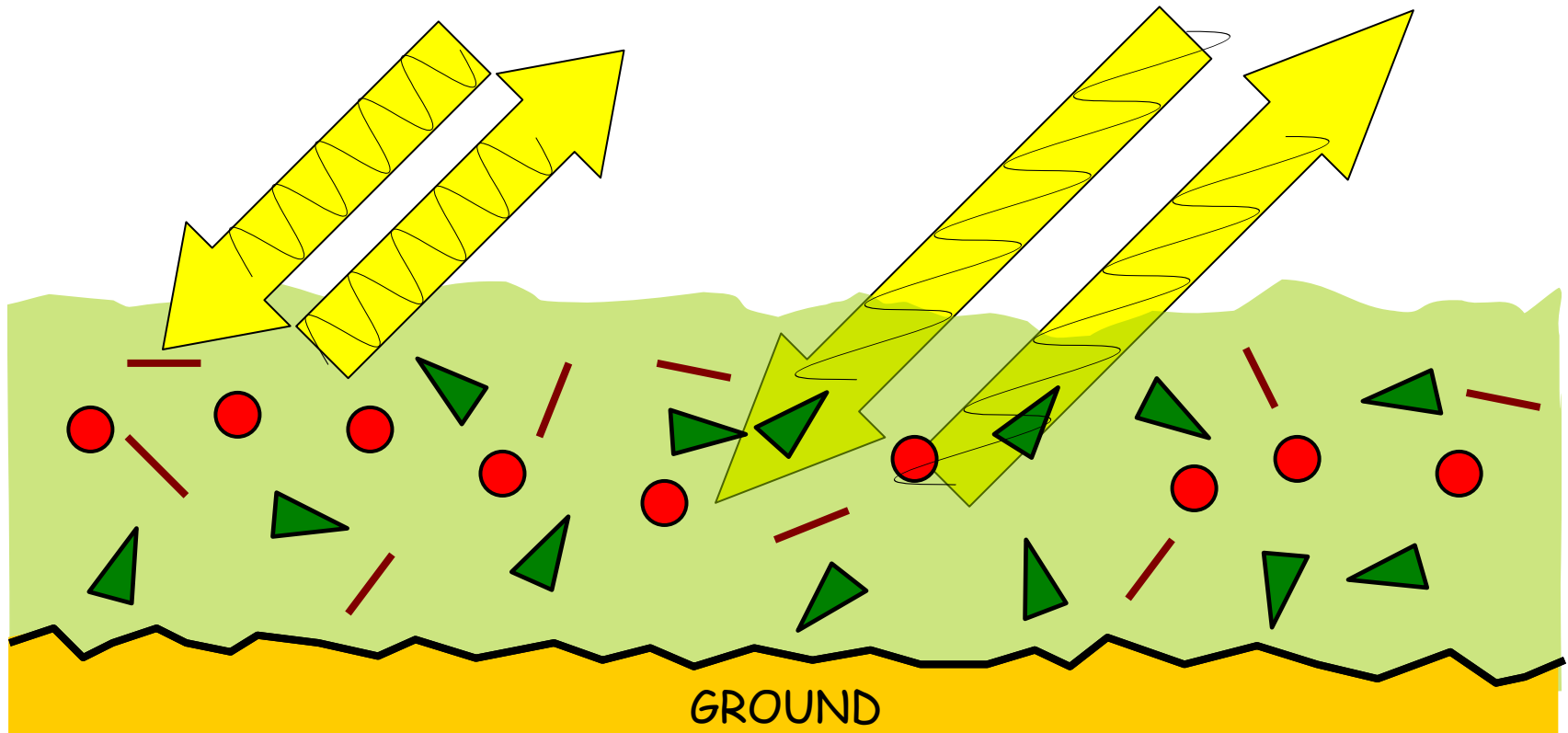
Impact of Polarimetric Dimensionality of Forest Parameter Estimation by Means of Polarimetric SAR interferometry

**Jun Su Kim, Seung-Kuk Lee, Konstantinos Papathanassiou,
and Irena Hajnsek**

German Aerospace Center

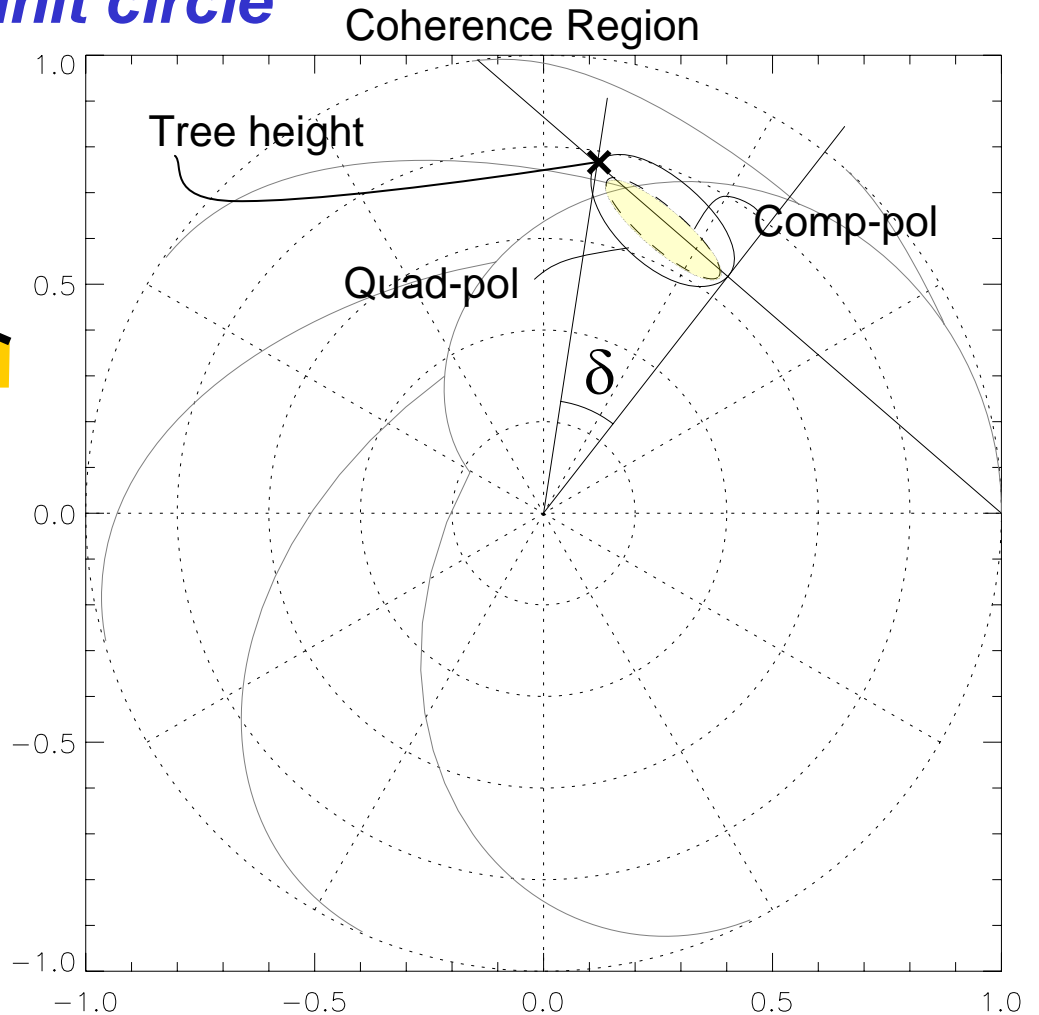
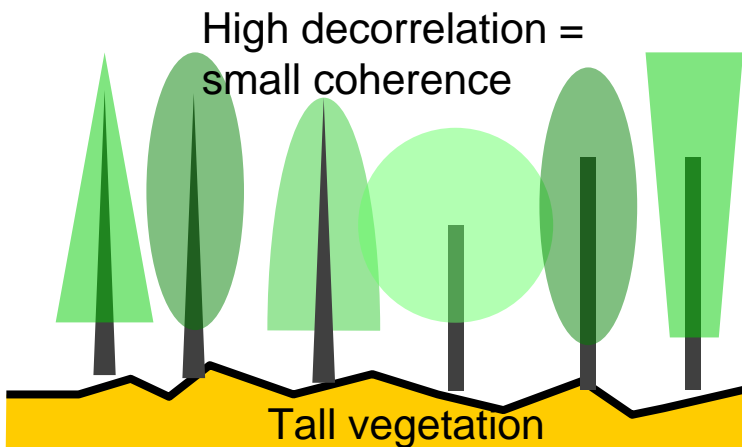
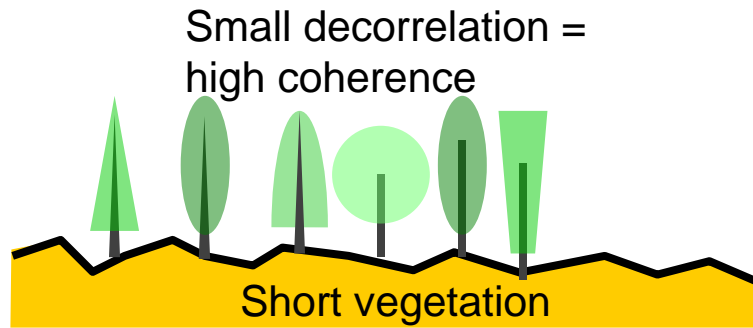
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Polarimetry and Interferometry



- Polarimetry is sensitive to dielectric structure / shape.
- Interferometry is sensitive to height / density.
- **Interferometric coherence depends on polarisation.**

Coherence Region -In Complex unit circle

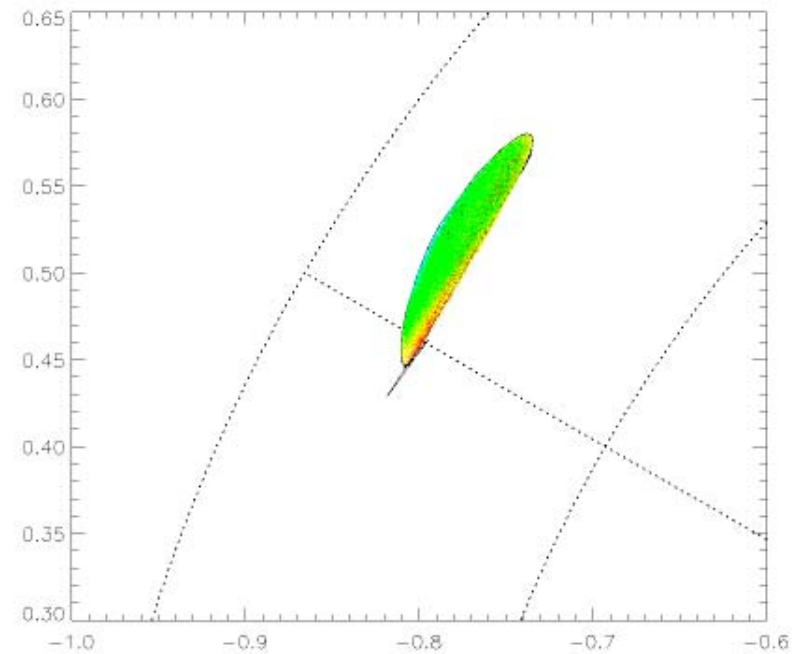
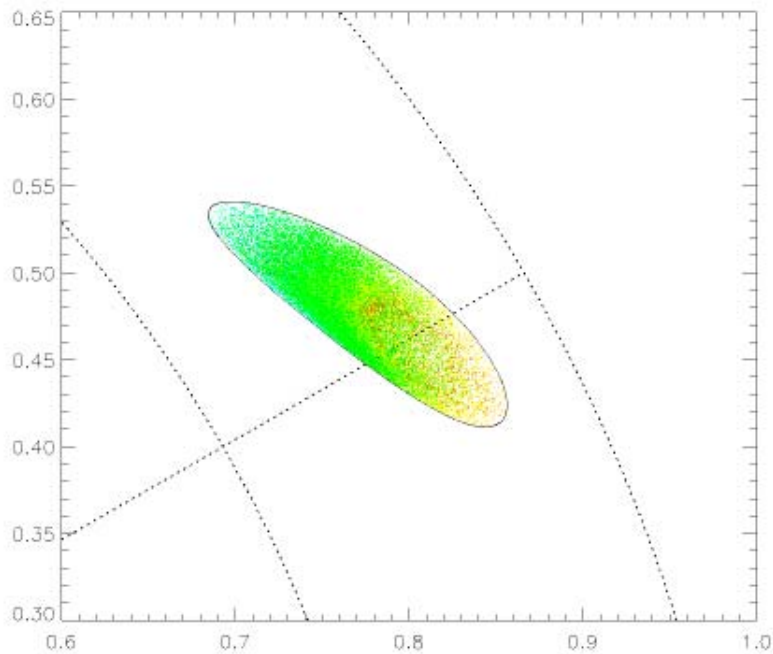




Structure of coherence region - α -angle dependency

➤ P-Band

➤ L-Band

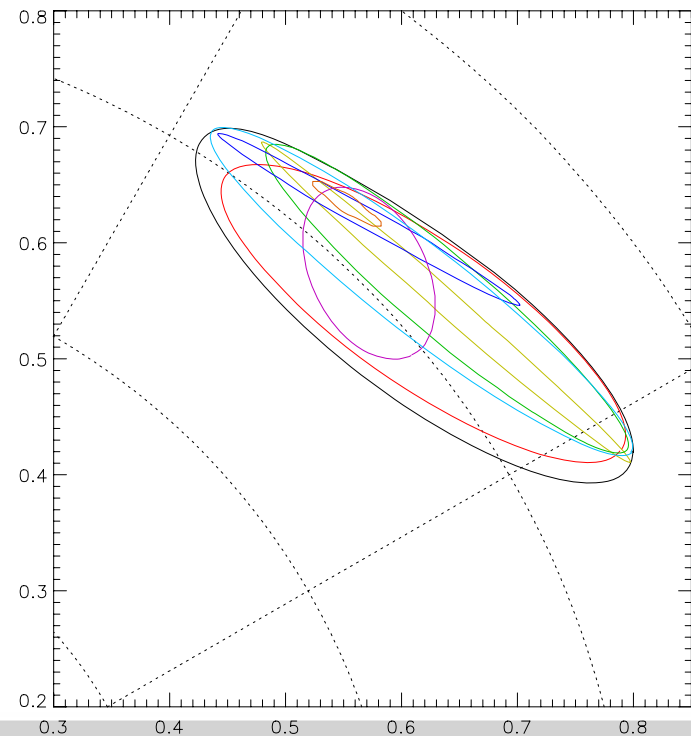
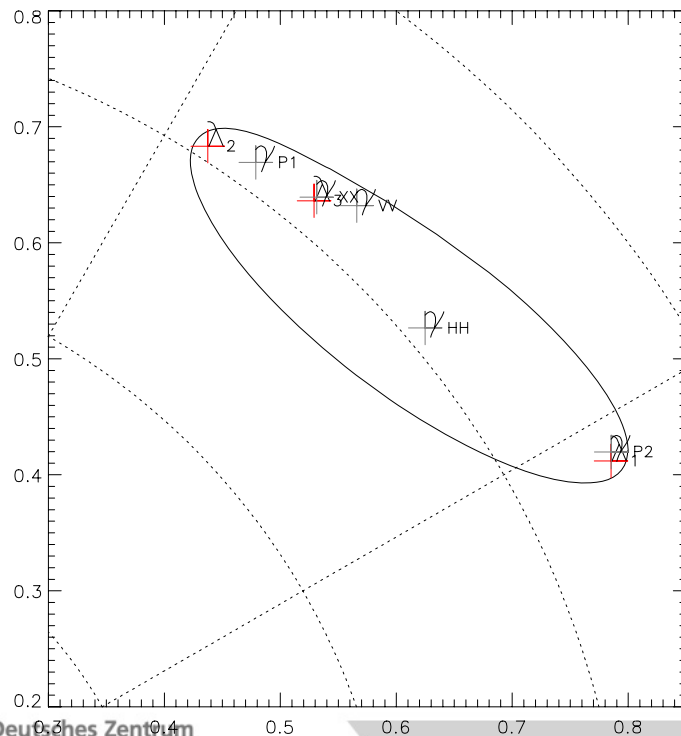


0 $\pi/12$ $\pi/6$ $\pi/4$ $\pi/3$ $5\pi/12$ $\pi/2$ Slide 4

Structure of Coherence region

-Important γ values and compact-pol

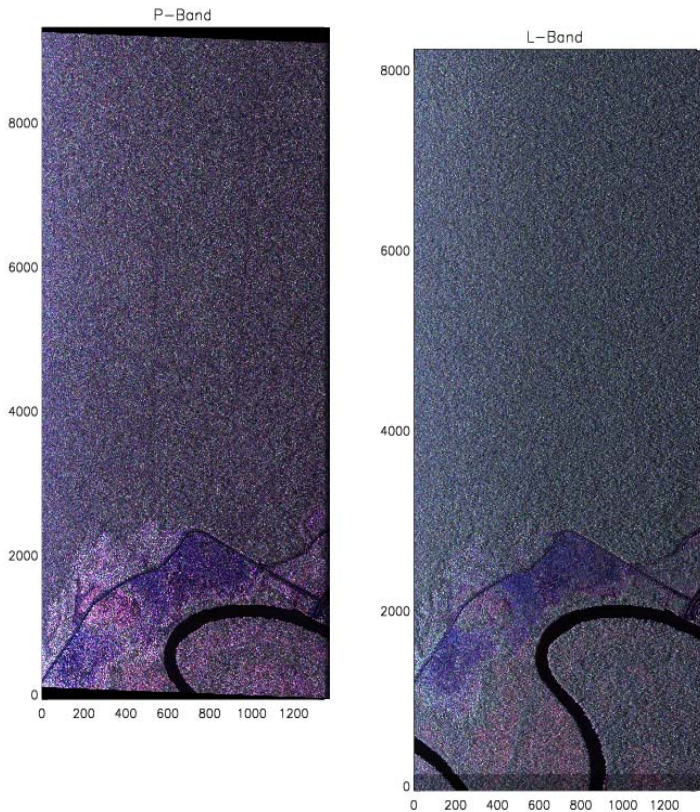
- Complex eigenvalues are placed in the coherence region and they are foci of boundary.
- Depending on the transmission basis, coherence region changes their shape and position.



Study Area and Datasets

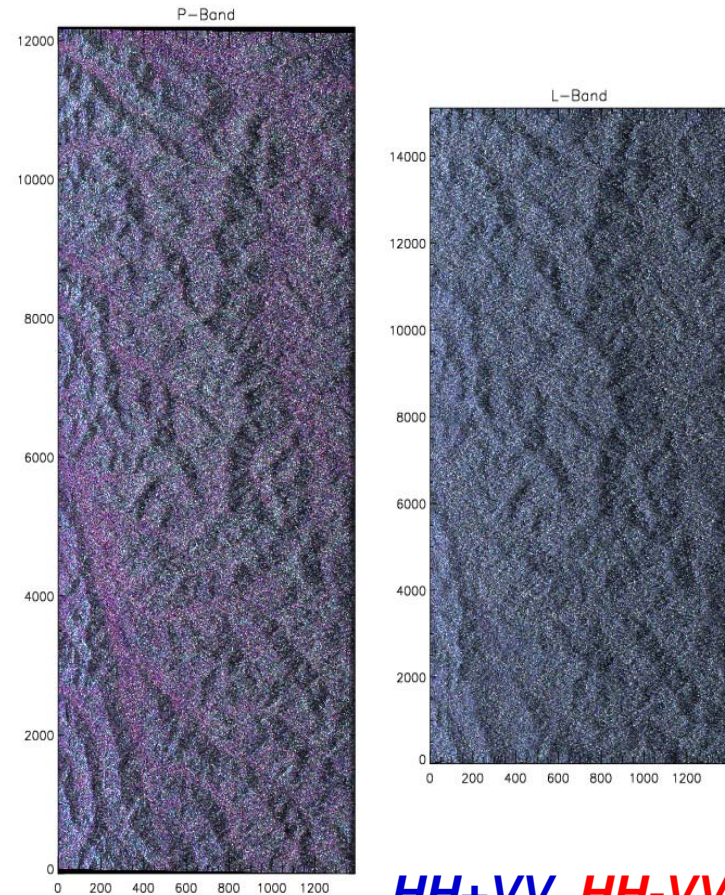
Mawas

- Flat terrain
- Homogeneous, and Sparse Peat Swamp forest with understory



Sungai Wain

- Hilly terrain,
- Heterogeneous, and Dense Dipterocarp forest

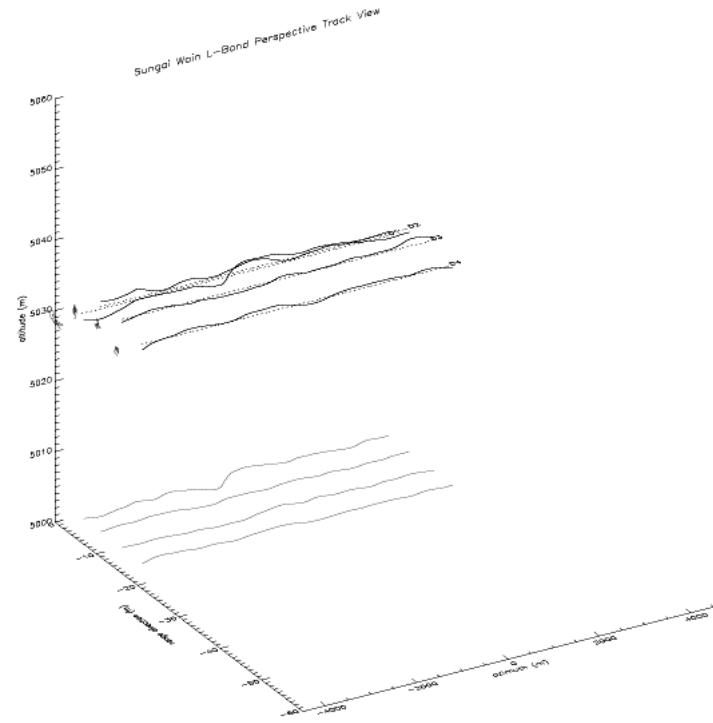
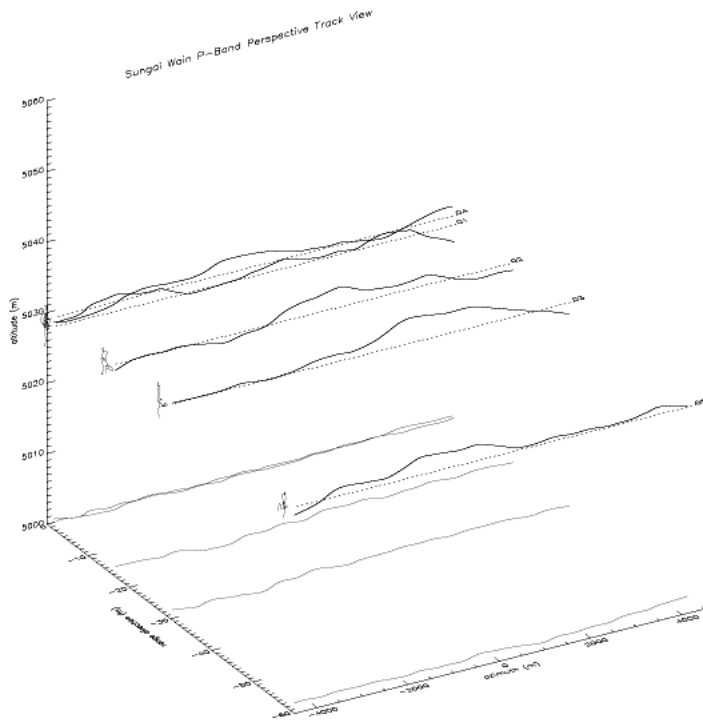


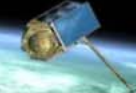
Study Area and Datasets - Interferometric parameters

P-Band

Sungai Wain

L-Band





The Dependency of δ/κ_ζ as a function of...

- 1. **Wavelength (λ)**
- 2. **(Spatial) Baseline (B)**
- 3. **Polarization Configuration (A)**
 - 1. Quad Polarisation (Quad)
 - 2. Compact Pol

Tx: Linear (45 deg)	Rx: H,V	(L1)
Tx: Linear (-45 deg)	Rx: H,V	(L2)
Tx: Circular Right	Rx: H,V	(CR)
Tx: Circular Left	Rx: H,V	(CL)
 - 3. Dual Pol

HH and VH	(DH)
VV and HV	(DV)
HH and VV	(HV)
- 4. **Incidence angle (θ)**
- 5. **Terrain slope (α)**

Dependency on (Spatial) Baseline

Mawas P-Band

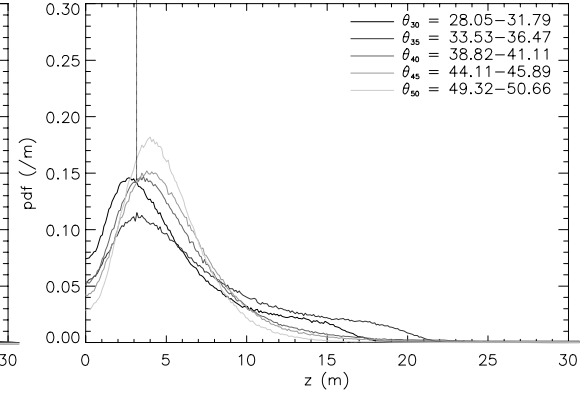
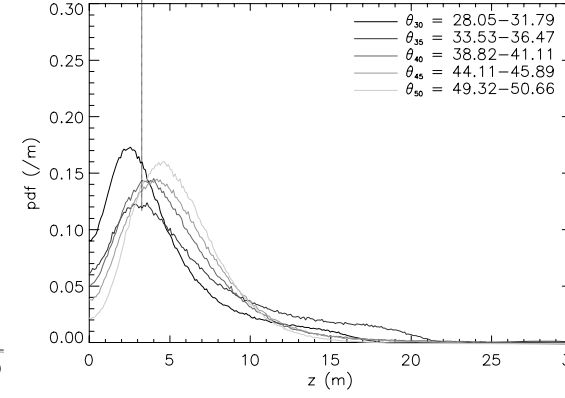
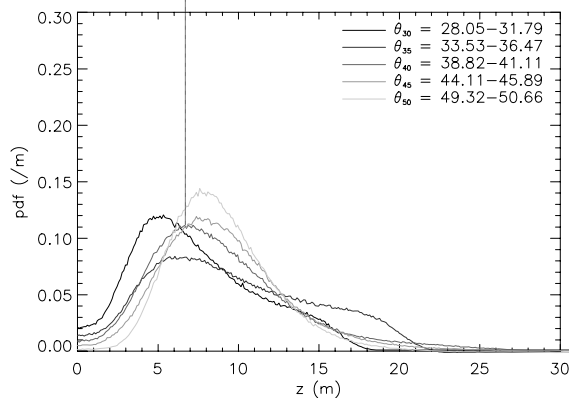
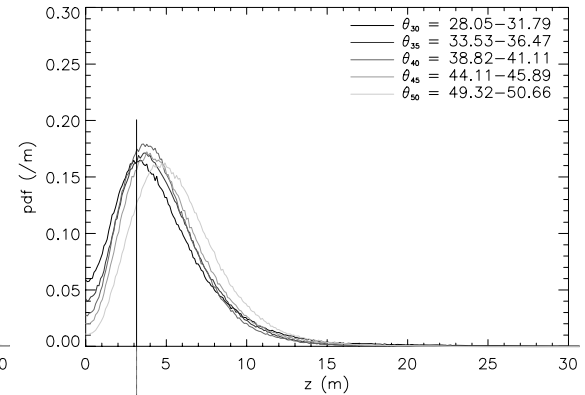
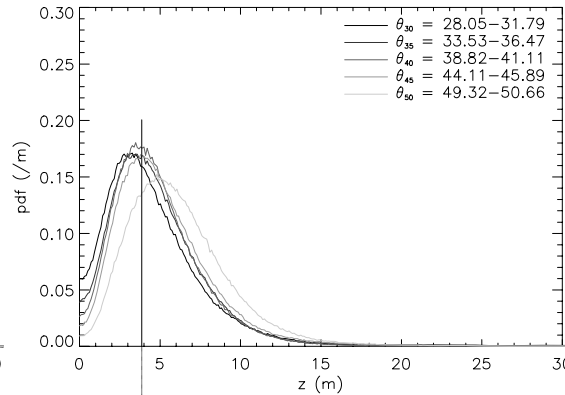
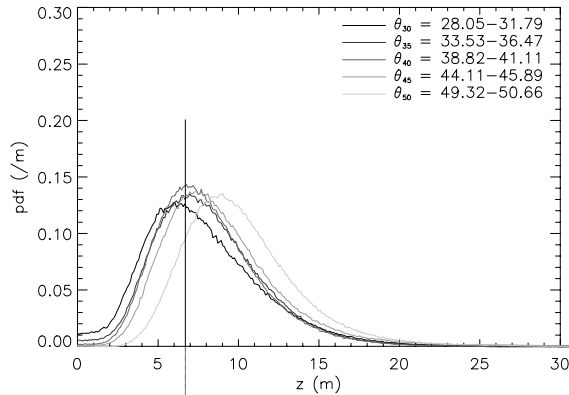
Quad-pol

Right Circular

Dual-pol Vertical

B=16m

B=32m



Dependency on Wavelength

Sungai Wain $\kappa_{\xi} \sim 0.1$

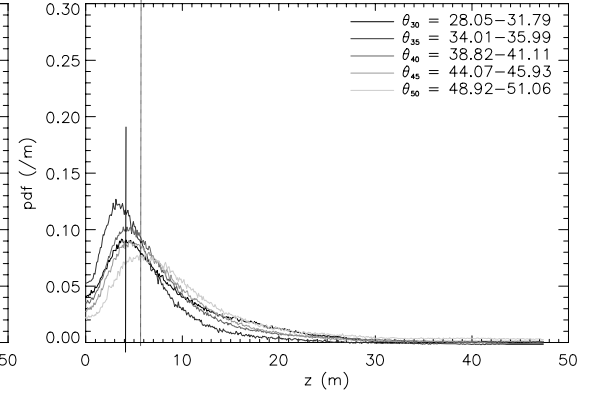
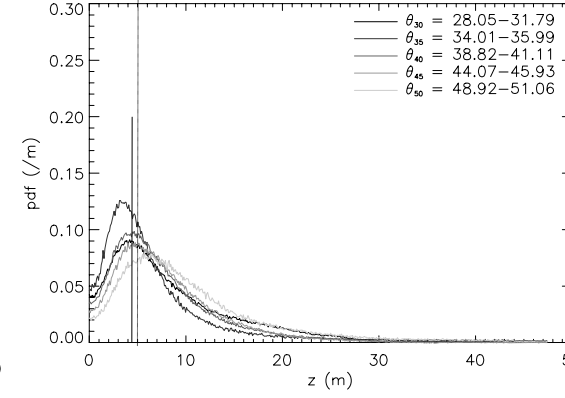
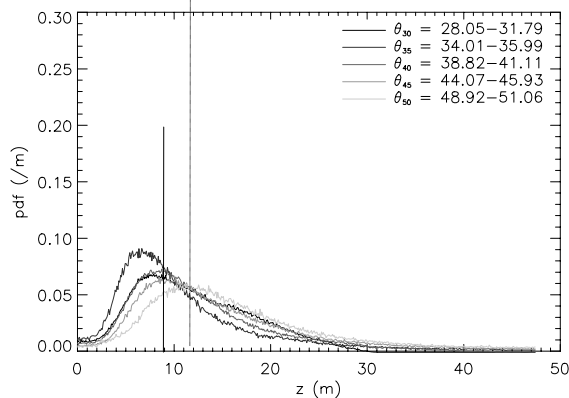
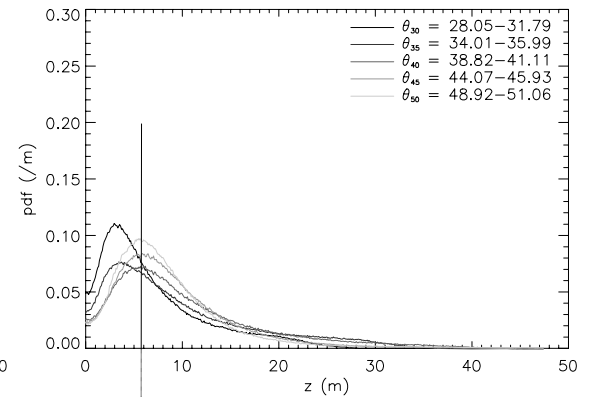
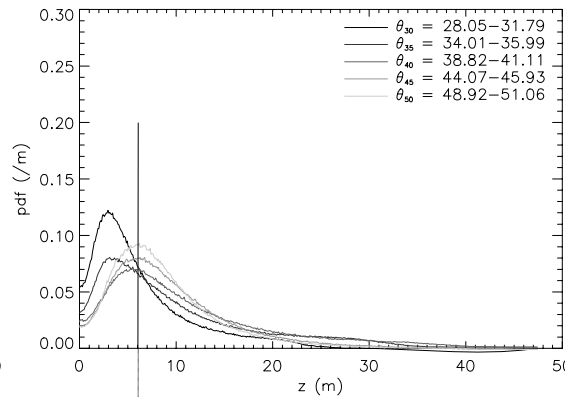
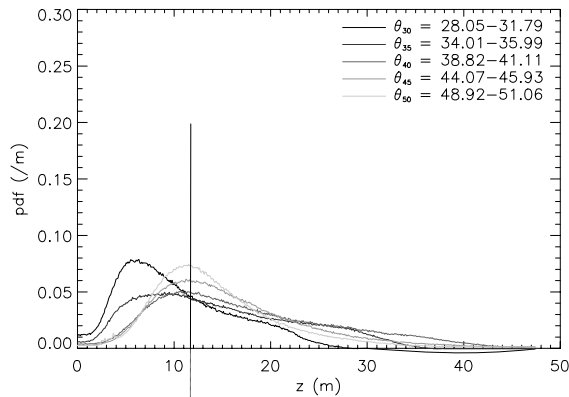
Quad-pol

Right Circular

Dual-pol Vertical

P-Band

L-Band



Dependency on Spatial Baseline

Mawas

	P-Band					
	16m			32m		48m
	02/05	05/08	08/11	02/08	05/11	02/11
Quad	7.50	7.20	7.10	7.10	7.00	7.30

δ/κ_ξ independent of baseline

δ/κ_ξ decreases with wavelength

Dependency on Spatial Baseline

Sungai Wain

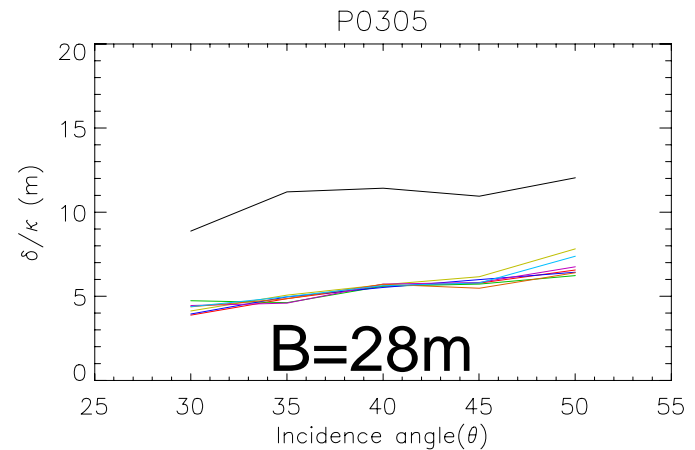
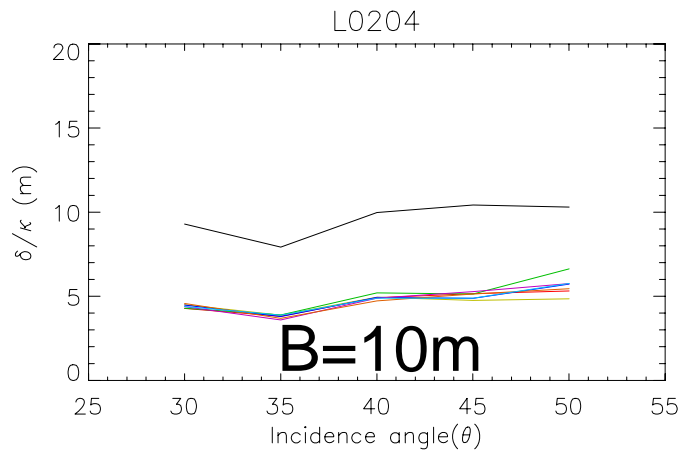
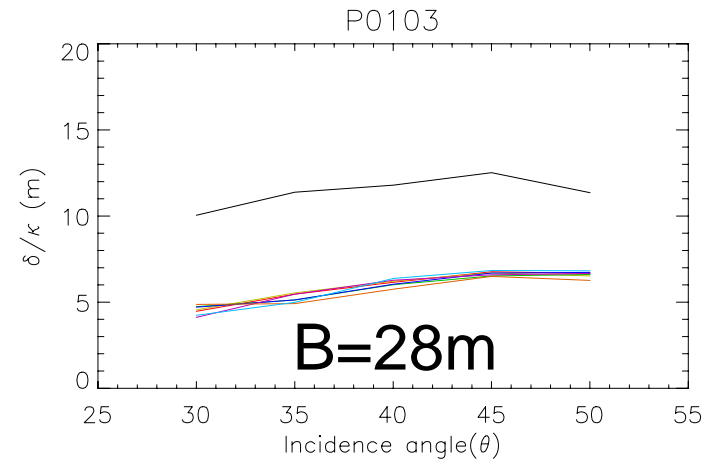
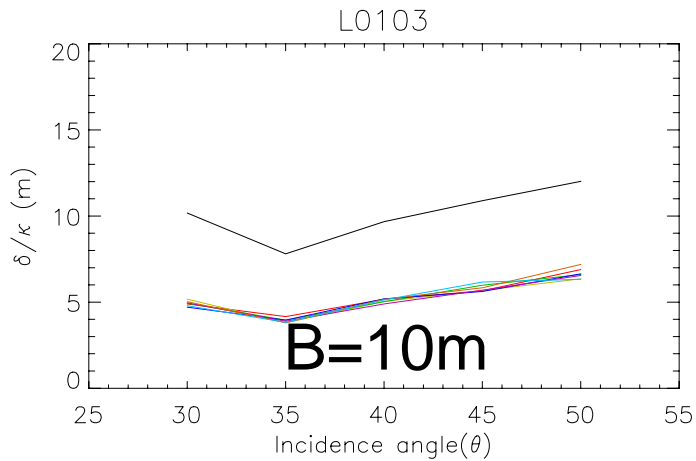
	P-Band								
	14m			28m			42m	56m	
	01/02	02/03	02/04	01/03	03/04	03/05	02/05	01/05	04/05
Quad	12.30	12.80	13.30	10.85	10.90	9.85	8.55	6.50	6.40

Dependency on Baseline

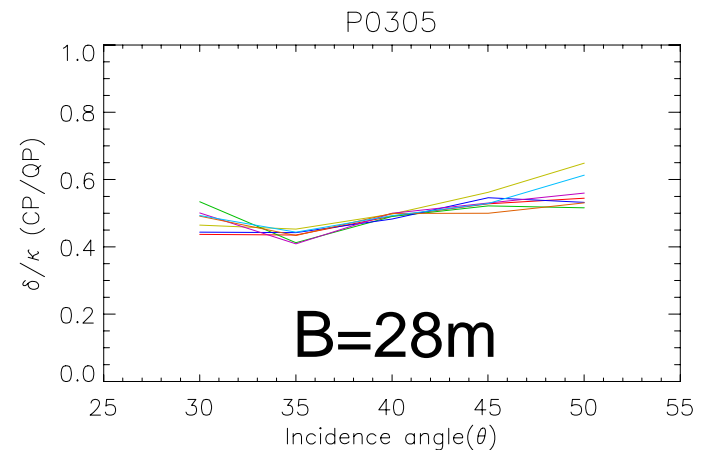
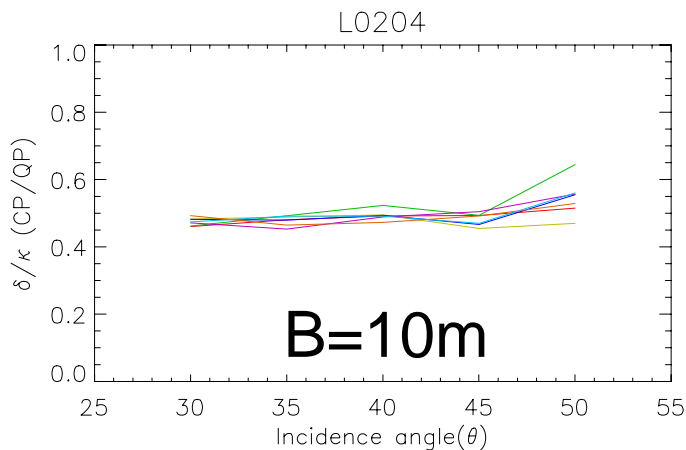
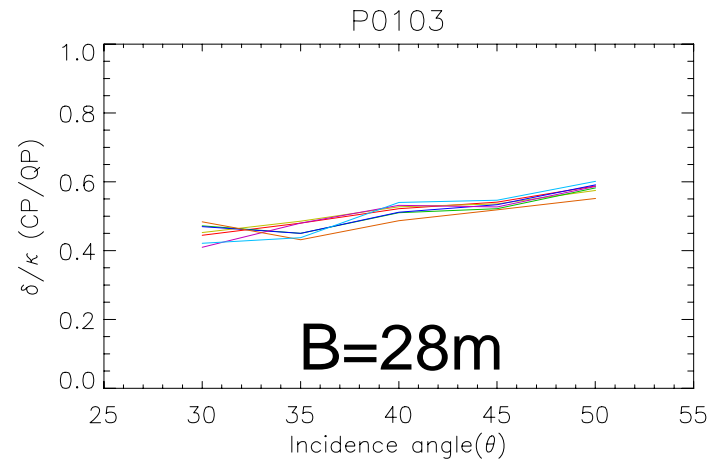
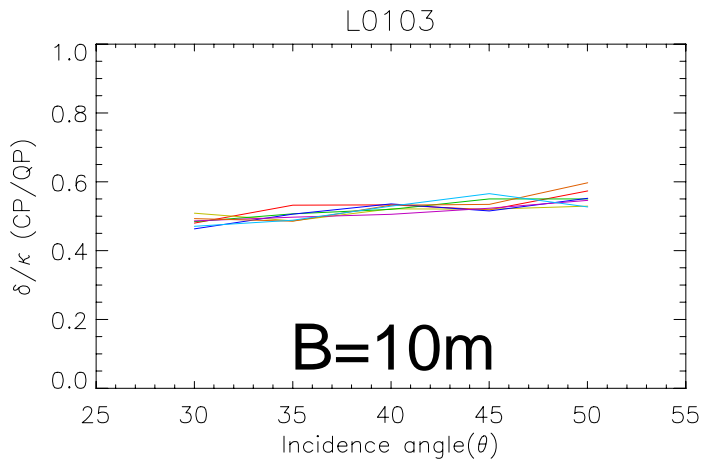
Sungai Wain

	L-Band					
	5m			10m		15m
	01/02	02/03	03/04	01/03	02/04	01/04
Quad	12.20	9.65	9.70	9.80	9.75	9.40

Dependency on Incidence Angle



Dependency on Incidence Angle



Dependency on Incidence Angle

Mawas

P-Band		30
16m	02/05	5.90(52.5
	05/08	6.10(50.8
	08/11	6.10(52.5
32m	02/08	5.20(44.2
	05/11	4.90(49.0
48m	02/11	3.00(50.0

)

L-Band		30
6m	02/05	5.10(54.9
12m	05/08	9.30(39.8
18m	02/08	6.60(57.6

)

)

)

)

Dependency on Incidence Angle

Sungai Wain

P-Band		30
14m	01/02	7.80(51.3)
	02/03	7.70(53.2)
	02/04	8.40(50.0)
28m	01/03	6.70(47.8)
	03/04	5.90(54.2)
	03/05	5.70(47.4)
42m	02/05	5.30(47.2)
56m	01/05	4.40(45.5)
	04/05	4.40(47.7)

Dependency on Incidence Angle

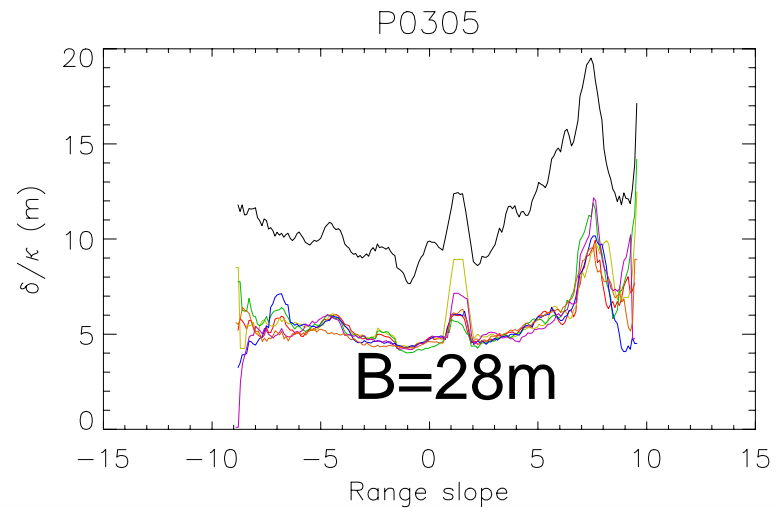
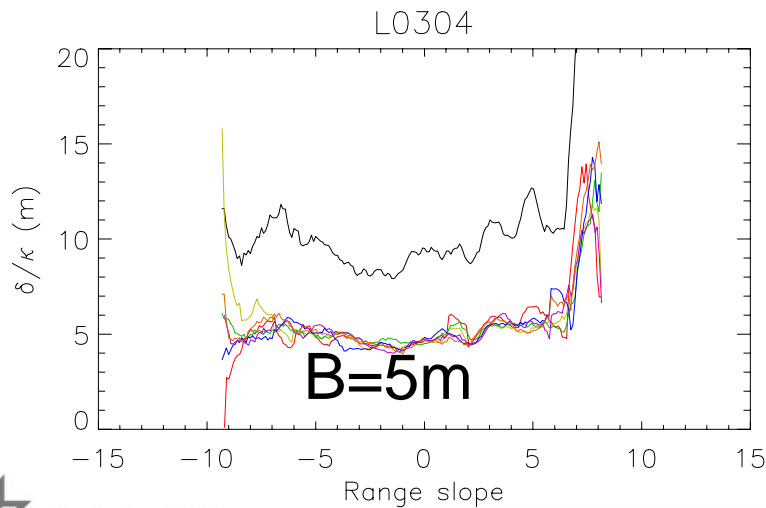
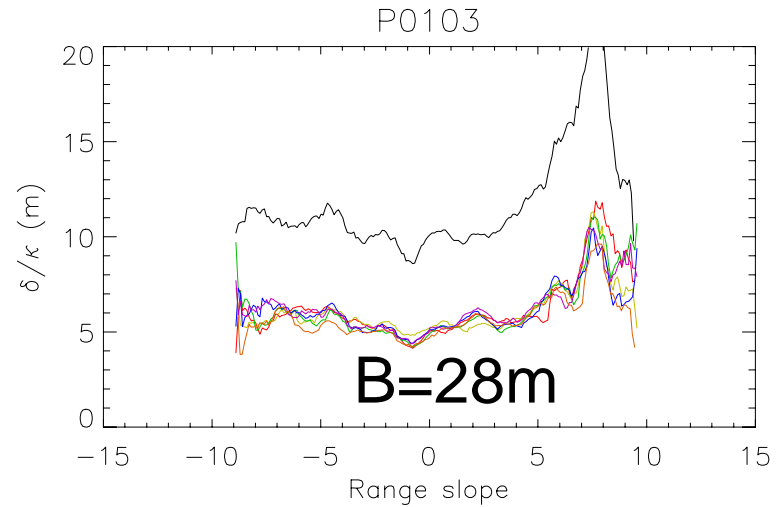
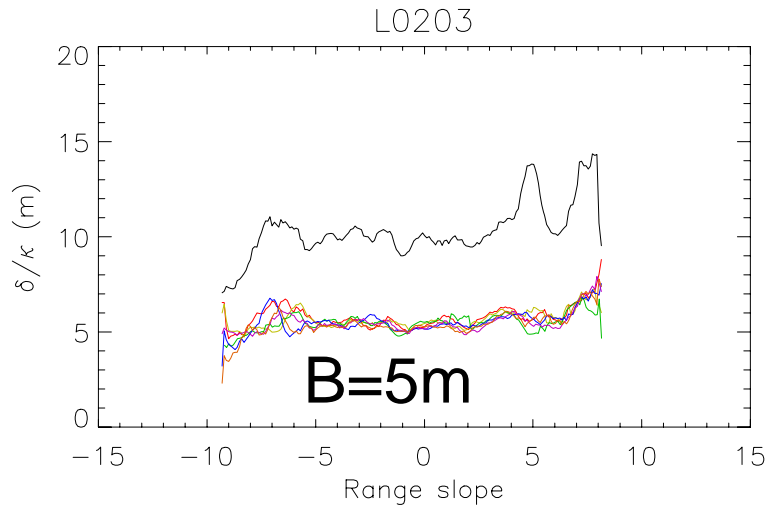
Sungai Wain

L-Band		30
5m	01/02	8.00(60.0)
	02/03	8.60(47.7)
	03/04	7.70(53.2)
10m	01/03	8.30(54.2)
	02/04	9.20(43.5)
15m	01/04	10.30(44.7)

)

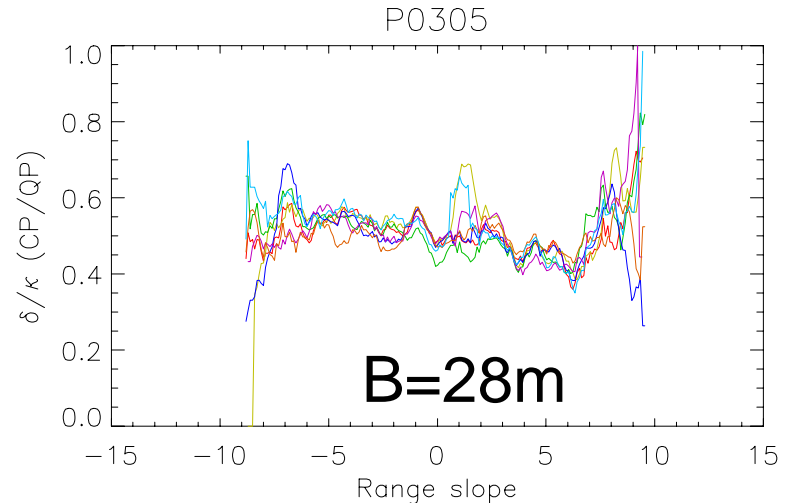
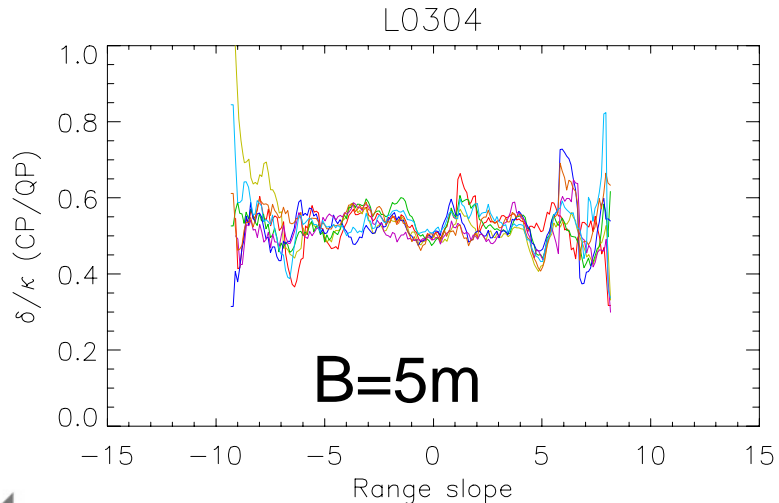
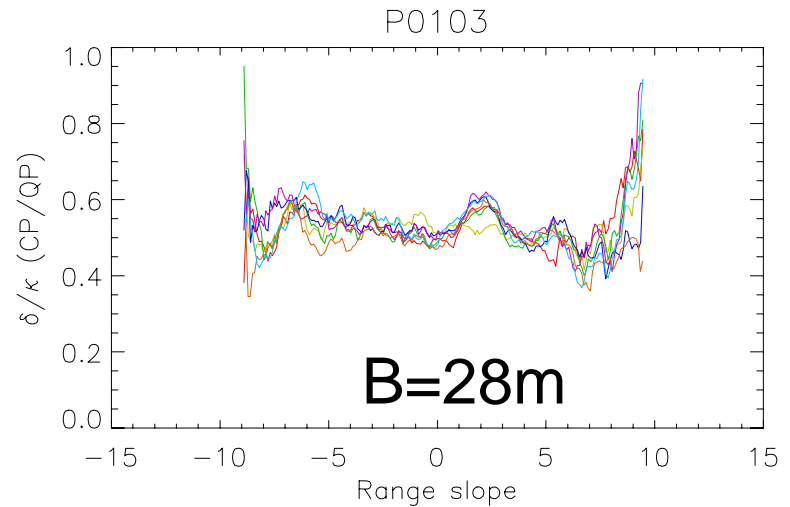
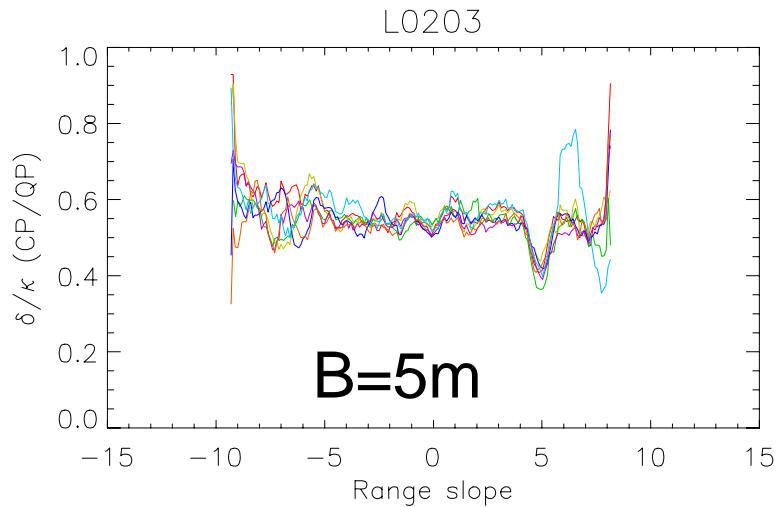


Dependency on Terrain Slope



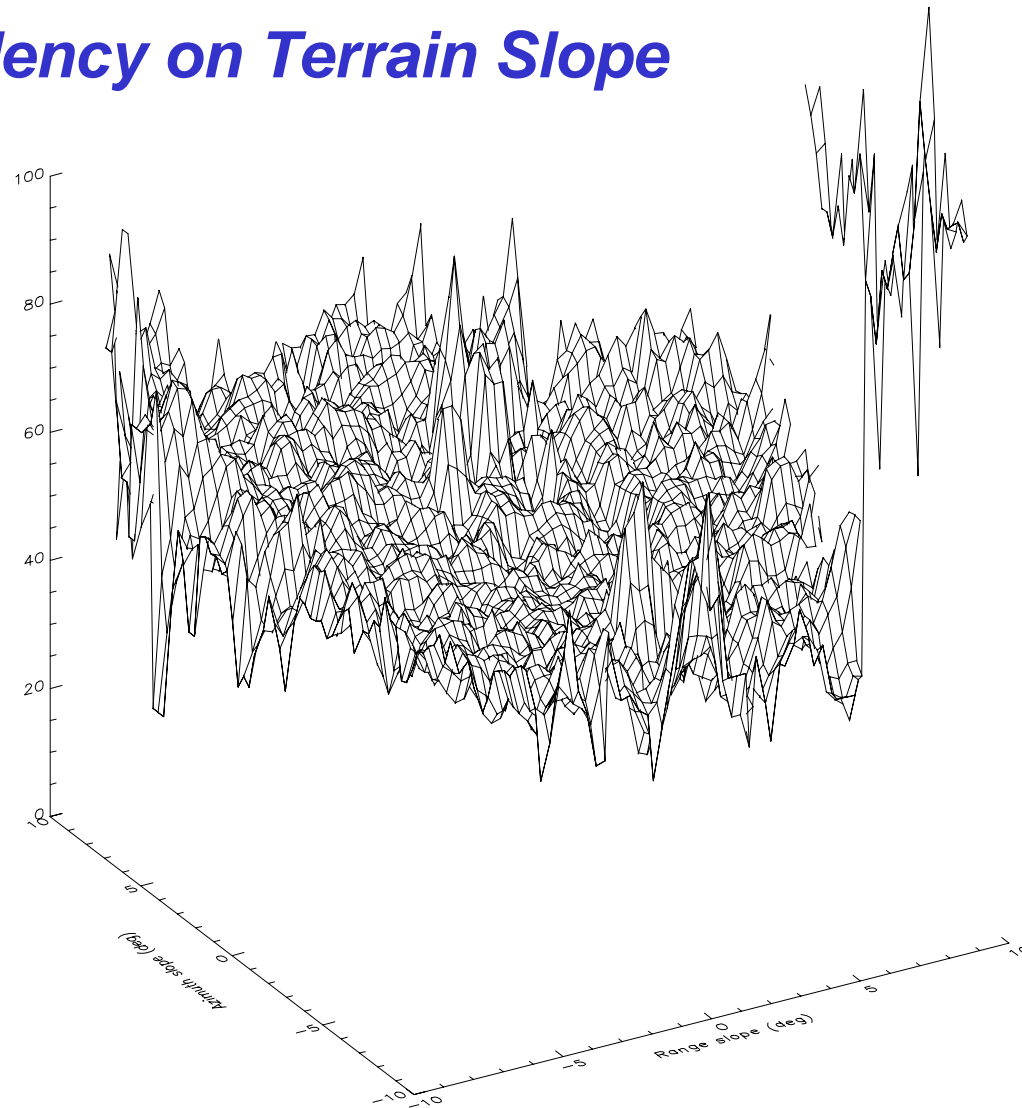


Dependency on Terrain Slope





Dependency on Terrain Slope





Conclusions ... from the analysis of the two tropical data sets

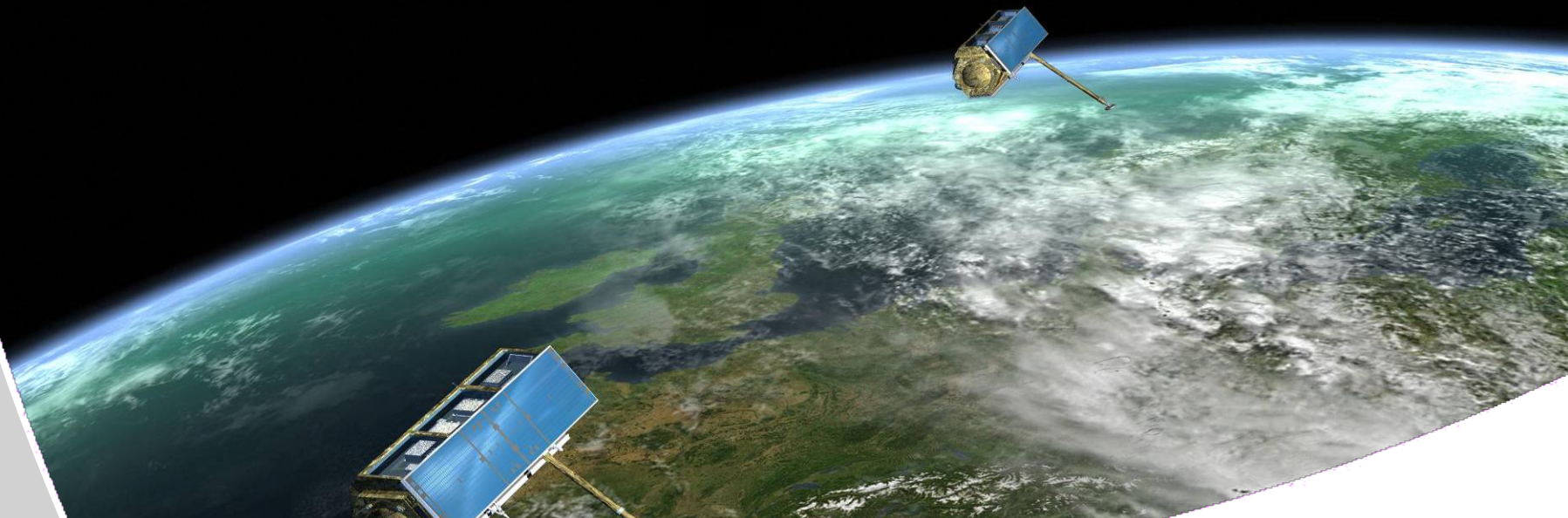
- δ/κ_ζ is widely independent on spatial baseline.
The baseline dependency observed in Sungai Wain is probably due to terrain induced decorrelation effects.
- δ/κ_ζ increases with wavelength: at P-band about 20-30% longer than at L-band
- δ/κ_ζ degrades significantly (40-50%) in any partial polarimetric scenario.

Quad-pol L-band performs better than Compact-Pol P-band !!!

Surprising:

There is no big difference between Compact/Hybrid configurations and Dual-Pol configurations. This is probably due to the very weak dihedral scattering component in both test sites.

- δ/κ_ζ increases with incidence angle -> wider ground scattering dynamic in far range.
- The performance of partial-polarimetry degrades in the presence of even weak slopes ($\alpha > 2-3^\circ$)
- Compact-polarimetry works better when ground is flat. (Sungai Wain shows smaller CP/QP ratio than Mawas)



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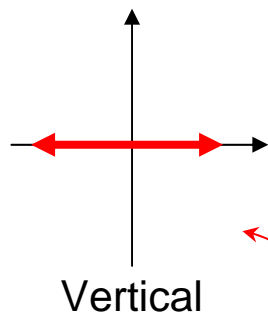
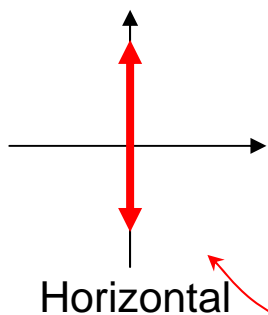
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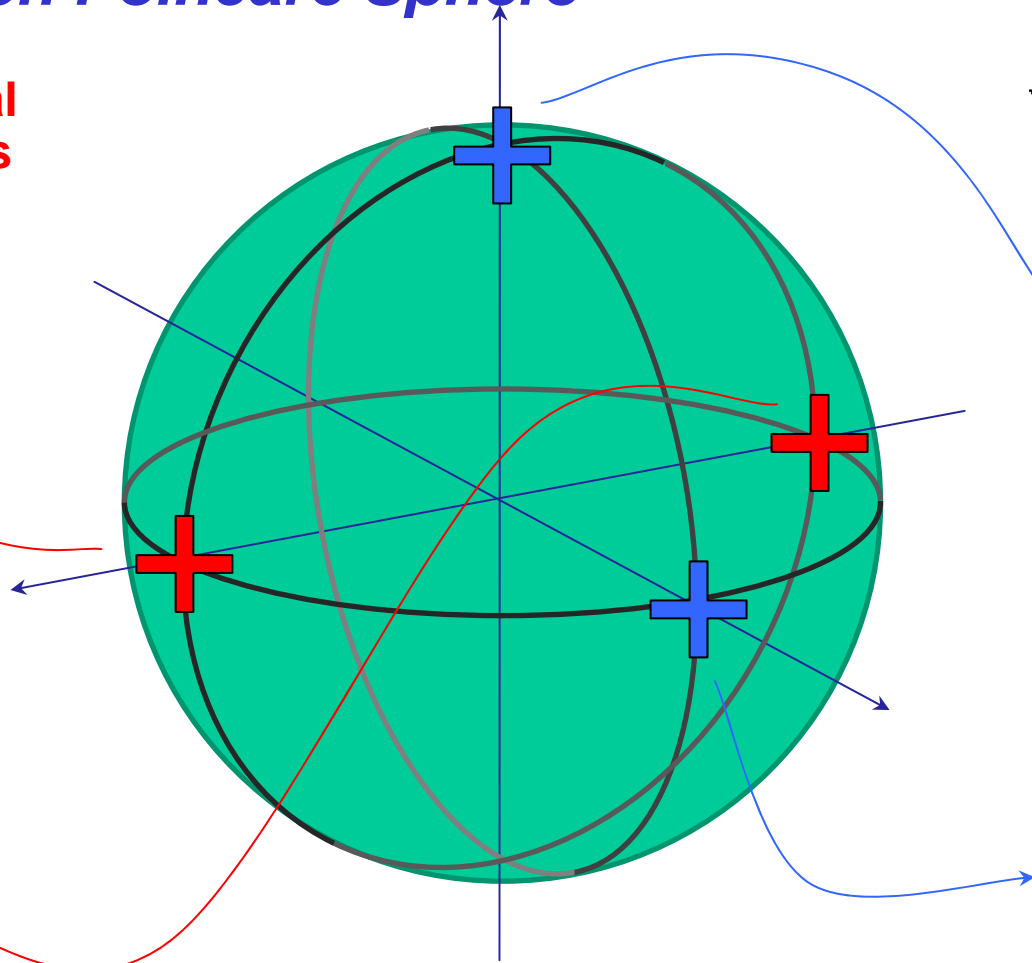
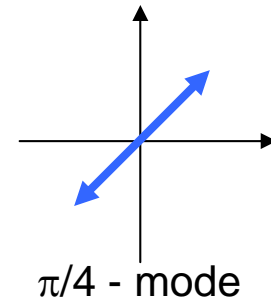
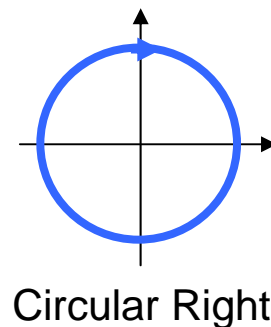
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Compact Polarimetry -on Poincaré Sphere

➤ Conventional Polarizations

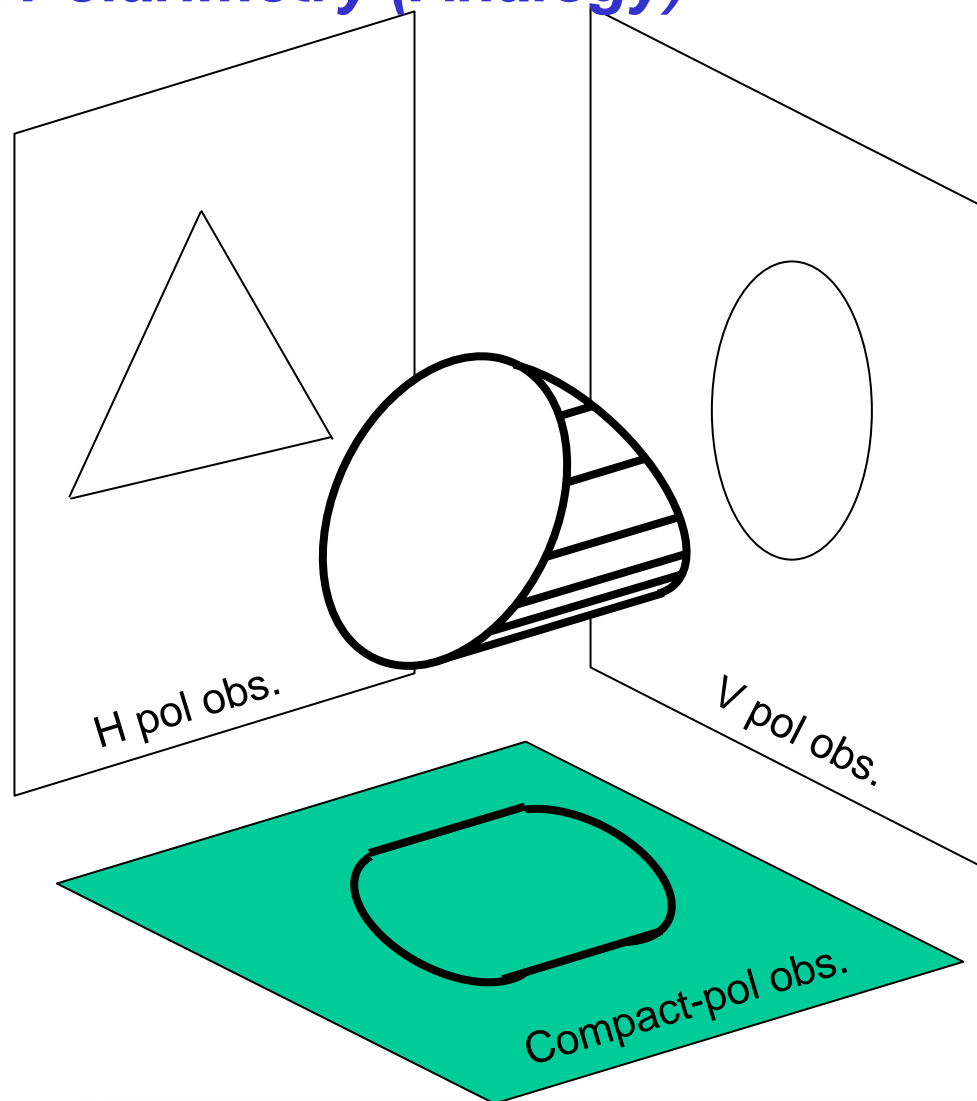


➤ Compact Polarimetry





Compact Polarimetry (Analogy)



Projection Matrix

-Quad-pol to Comp-pol

➤ Definition of scattering vector:
$$\vec{k} = \frac{1}{\sqrt{2}} \begin{pmatrix} S_{hh} + S_{vv} \\ S_{hh} - S_{vv} \\ 2S_{hv} \end{pmatrix}$$

➤ Scattering vector of Compact Polarimetry:

$$\begin{aligned} \vec{j} &= \frac{1}{\sqrt{2}} \begin{pmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{pmatrix} \begin{pmatrix} 1 \\ e^{i\delta} \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} S_{hh} + e^{i\delta} S_{hv} \\ S_{vh} + e^{i\delta} S_{vv} \end{pmatrix} \\ &= \frac{1}{2} \begin{pmatrix} 1 & 1 & e^{i\delta} \\ e^{i\delta} & -e^{i\delta} & 1 \end{pmatrix} \vec{k} \equiv \mathbf{A}^{*T} \vec{k} \end{aligned}$$

➤ Covariance matrix of Compact Polarimetry:

$$\begin{aligned} \mathbf{J} &= \langle \vec{j} \cdot \vec{j}^{*T} \rangle = \left\langle \left(\mathbf{A}^{*T} \vec{k} \right) \cdot \left(\mathbf{A}^{*T} \vec{k} \right)^{*T} \right\rangle \\ &= \mathbf{A}^{*T} \langle \vec{k} \cdot \vec{k}^{*T} \rangle \mathbf{A} = \mathbf{A}^{*T} \mathbf{T} \mathbf{A} \end{aligned}$$



Various projection matrices

➤ Linear Transmissions ($\delta = 0, \pi$)

$$\mathbf{A}_{\pi/4}^{*T} = \frac{1}{2} \begin{pmatrix} 1 & 1 & 1 \\ 1 & -1 & 1 \end{pmatrix} :L1 \quad \mathbf{A}_{-\pi/4}^{*T} = \frac{1}{2} \begin{pmatrix} 1 & 1 & -1 \\ -1 & 1 & 1 \end{pmatrix} :L2$$

➤ Circular Transmissions ($\delta = \pi/2, -\pi/2$)

$$\mathbf{A}_{\pi/2}^{*T} = \frac{1}{2} \begin{pmatrix} 1 & 1 & i \\ i & -i & 1 \end{pmatrix} :CR \quad \mathbf{A}_{-\pi/2}^{*T} = \frac{1}{2} \begin{pmatrix} 1 & 1 & -i \\ -i & i & 1 \end{pmatrix} :CL$$

➤ Dual polarizations

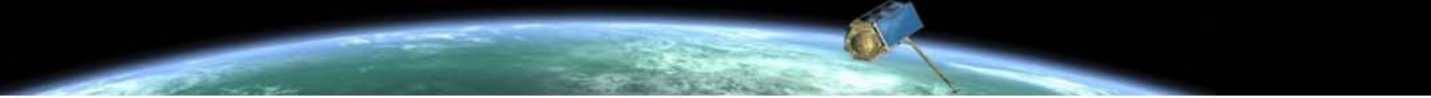
$$\mathbf{A}_H^{*T} = \frac{\sqrt{2}}{2} \begin{pmatrix} 1 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} :DV \quad \mathbf{A}_V^{*T} = \frac{\sqrt{2}}{2} \begin{pmatrix} 0 & 0 & 1 \\ 1 & -1 & 0 \end{pmatrix} :DV \quad \mathbf{A}_{HV}^{*T} = \frac{\sqrt{2}}{2} \begin{pmatrix} 1 & 1 & 0 \\ 1 & -1 & 0 \end{pmatrix} :HV$$



Coherence region (Field of Values)

➤ Complex γ in PolInSAR (How γ varies as w changes?)

$$\gamma = \frac{\vec{w}^{*T} \mathbf{\Omega} \vec{w}}{\vec{w}^{*T} \mathbf{T} \vec{w}}, \text{ where } \mathbf{T} = \frac{1}{2} \sum_i^2 \langle \vec{k}_i \cdot \vec{k}_i^{*T} \rangle \text{ and } \mathbf{\Omega} = \langle \vec{k}_1 \cdot \vec{k}_2^{*T} \rangle$$



Interferometric Coherence:

$$\tilde{\gamma}(\vec{w}_1, \vec{w}_2) = \frac{\langle \vec{w}_1[\Omega] \vec{w}_2^+ \rangle}{\sqrt{\langle \vec{w}_1[T_{11}] \vec{w}_1^+ \rangle \langle \vec{w}_2[T_{22}] \vec{w}_2^+ \rangle}}$$

Optimisation Problem:

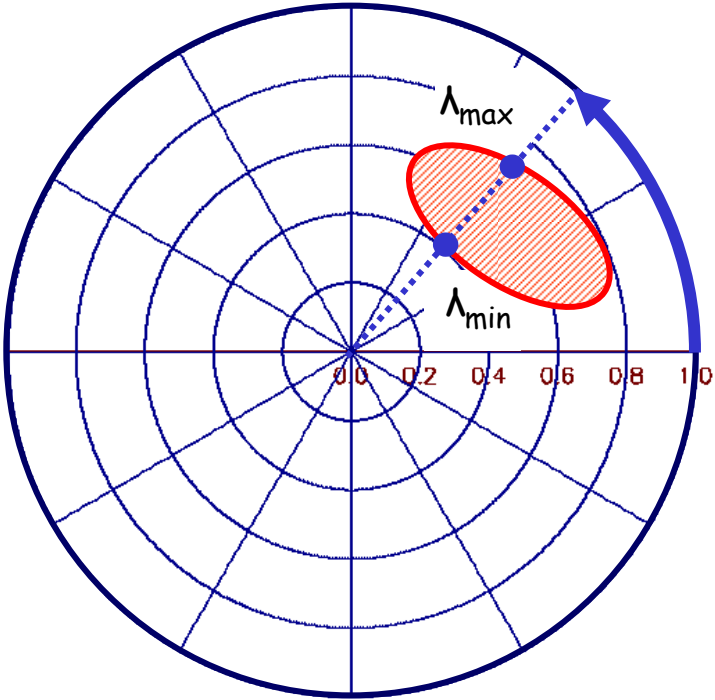


$$\vec{w}_1 = \vec{w}_2$$

$$[T]^{-1}[\Omega_\varphi] \vec{w} = \lambda \vec{w}$$

$$[T] = \frac{1}{2}([T_{11}] + [T_{22}]), \quad \lambda = -(\lambda_1 + \lambda_2^*)$$

$$[\Omega_\varphi] = \frac{1}{2}(\exp(i\varphi)[\Omega] + \exp(-i\varphi)[\Omega]^+)$$



Coherence Region: $\forall \varphi \rightarrow \lambda_{\max}, \lambda_{\min}$ that have to be connected to provide the boundary of the cr.

Shape and size are characterised by the acquisition and scattering parameters