

Characterisation of oriented volumes in glacier ice and extinction inversion with Pol-InSAR

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Pol-InSAR for ice characterisation/extinction estimation

Motivation:

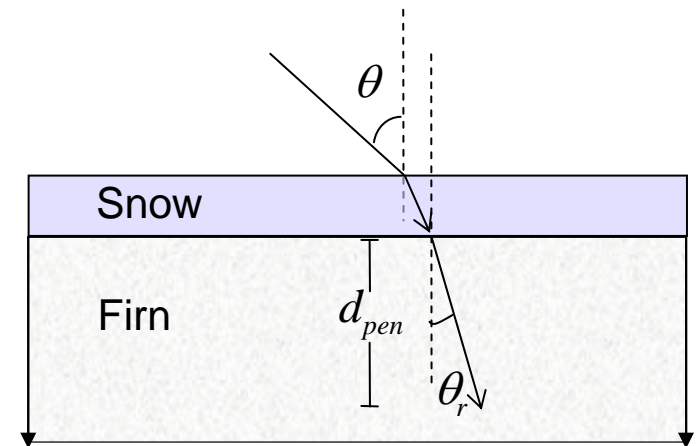
- Monitor the cryosphere, greater understanding of the properties of glaciers/ice sheets including their **densities and internal structure (related to rate of extinction)**

Extinction:

- Extinction (κ_e) accounts for the combined effect of absorption and scattering in the medium
- may be expressed in terms of the penetration depth (d_{pen}) at which the 1-way backscattered power falls to e^{-1} (~ 37%)

$$\kappa_e = \kappa_a + \kappa_s = \frac{-\cos \theta_r}{d_{pen}}$$

- Conventionally expressed as a 2-way coefficient in units of dB/m



Goal:

- use **Pol-InSAR observables** (combining polarimetric decomposition and interferometric coherences) to estimate glacier ice extinctions for oriented volumes

Data description

- **ICESAR data campaign**
(joint project between DLR, ESA, AWI)
- conducted in Mar/Apr 2007 over Austfonna ice cap (Summit) and Etonbreen drainage basin, Svalbard, Norway (~ 80°N, 24°E)
- Multibaseline fully-polarimetric L-band (1.3 GHz) and P-band (0.35 GHz) data



Corner reflector at Summit



DLR's E-SAR (left), AWI's airborne platform

Experimental Data, Summit, Pauli images

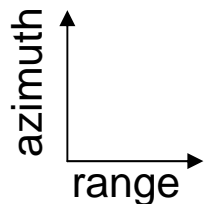


surface
(HH+VV)

double bounce
(HH-VV)

volume
(2HV)

Rng. Swath
~3.5 km,
Az. Swath
~10 km





Modelling Oriented Volumes & Ice Extinctions

Oriented Volumes

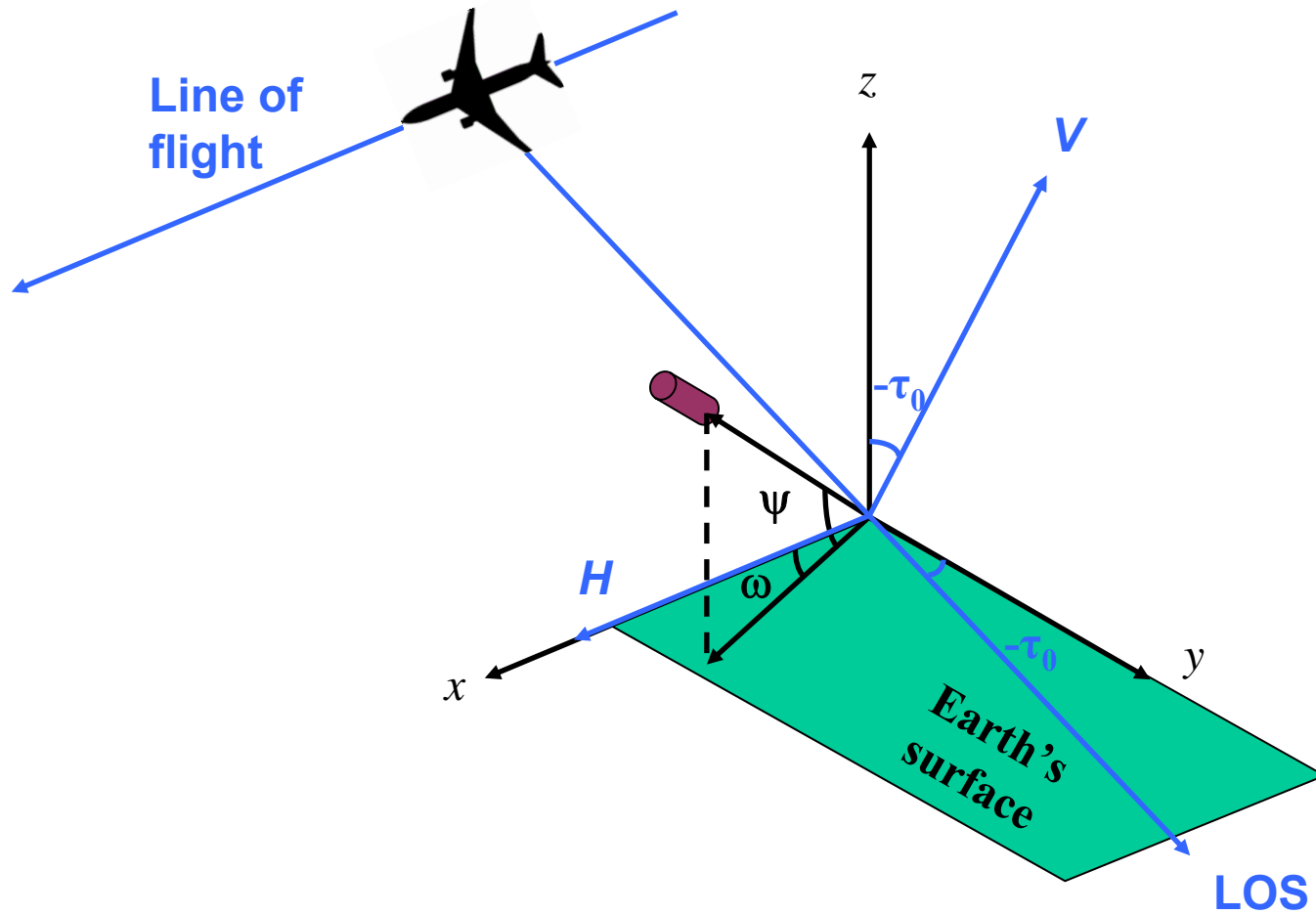
Background:

- *Comparatively little research has been done to date on characterisation of orientation of **distributed volumetric targets** using polarimetry*
- *Typically, oriented volumes modelled only for particles lying on the plane perpendicular to the radar LOS (line-of-sight)*

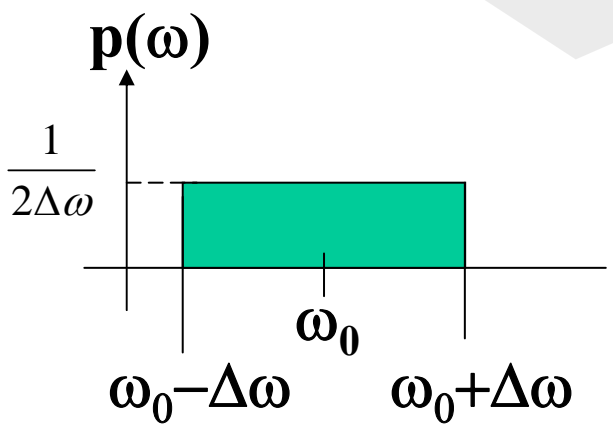
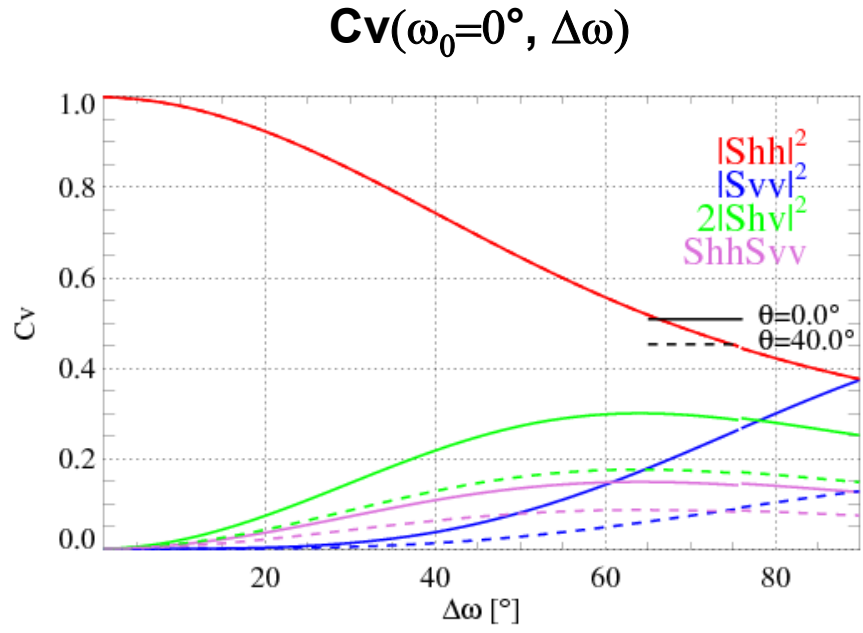
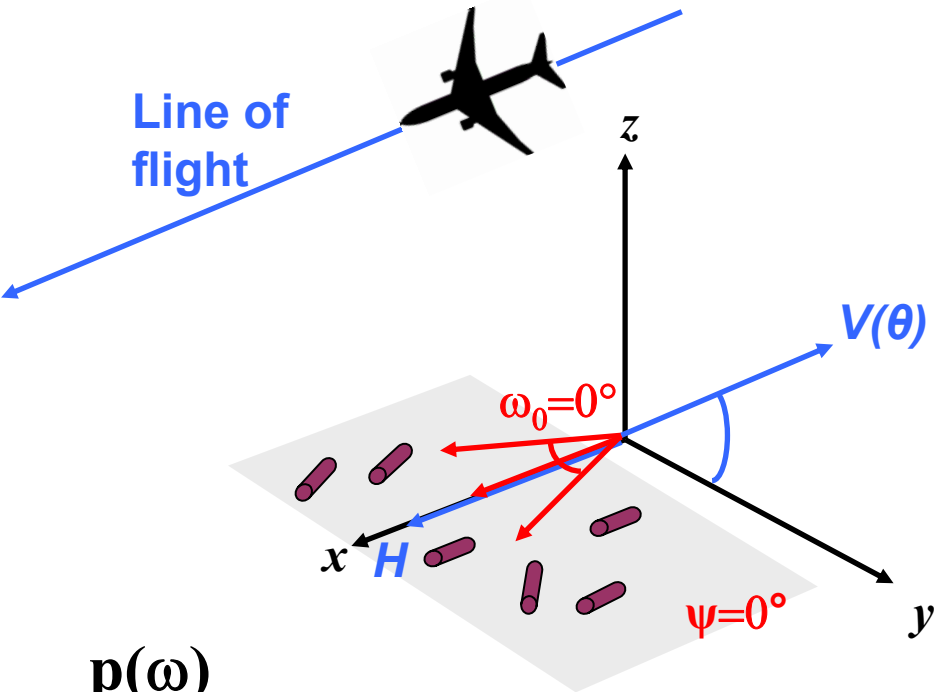
Advantages/Limitations:

- *Computation of the modelled **covariance [C]** matrix relatively straightforward*
- *However, following issues should be considered:*
 - *Modelling is confined to a 2-D plane, whereas scatterers are distributed in 3-D.*
 - *Results referenced to the plane \perp to LOS are difficult to relate to physical orientations of scatterers.*
 - *The reference plane (\perp to LOS) changes with θ_{inc} , further complicating interpretation.*

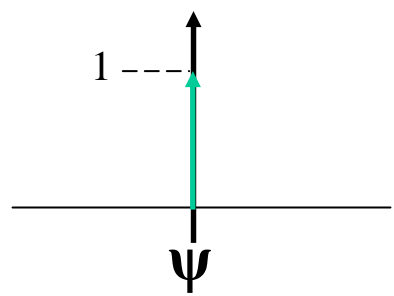
Oriented Volume



Simulations: $\omega_0=0^\circ$, fix $\psi=0^\circ$



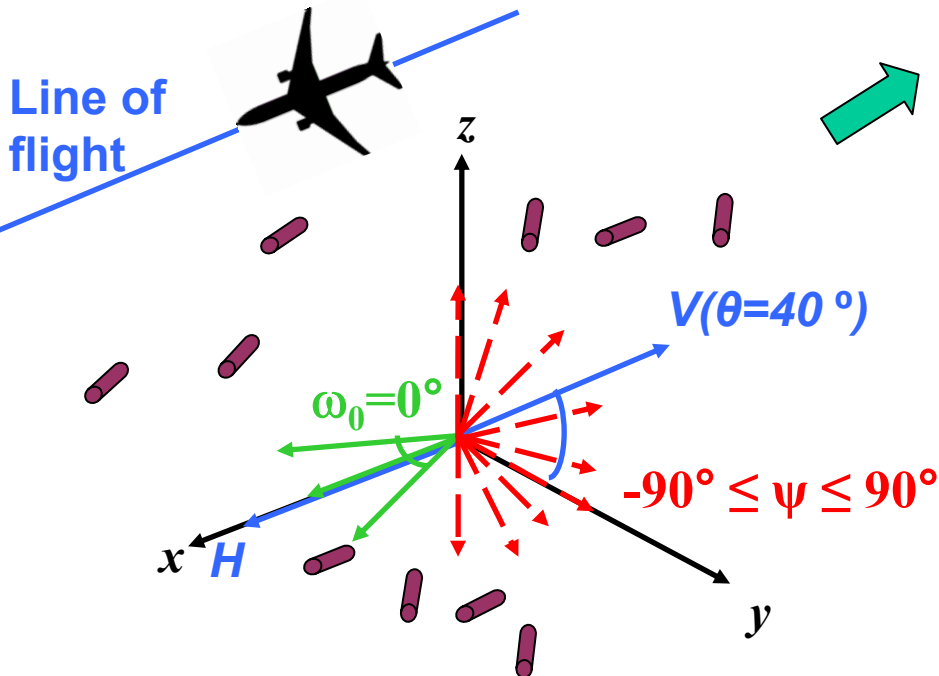
$$p(\psi) = \delta(0)$$



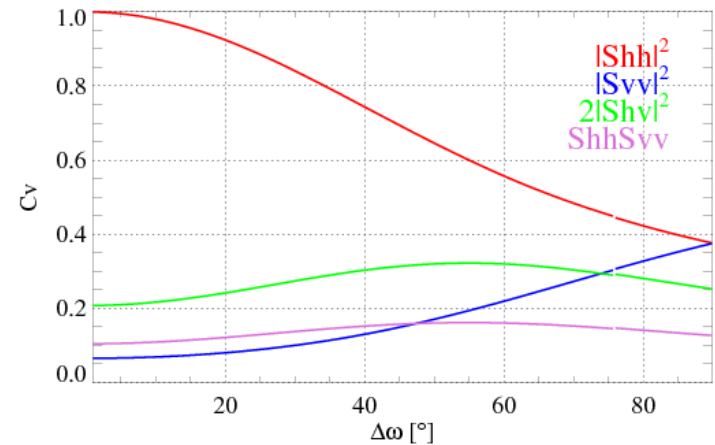
➤ Results at $\theta = 0^\circ$ equivalent to results from 2-D (plane \perp to LOS) model

➤ As θ_{inc} increases, VV and HV differ significantly from values assuming scatterers lie in the plane \perp to LOS

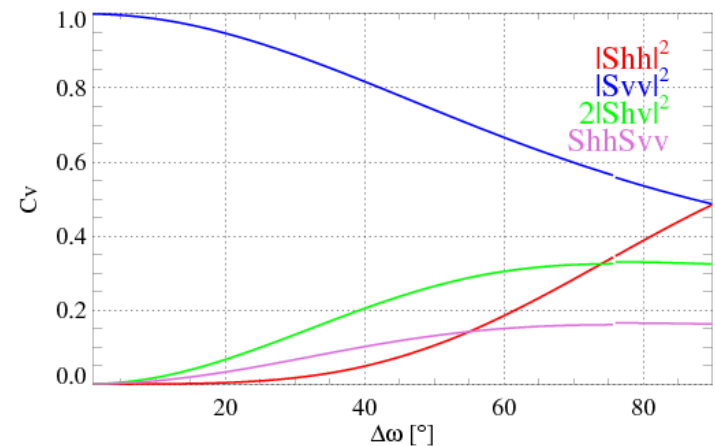
Simulations: $\omega_0 = 0^\circ, -90^\circ \leq \psi \leq 90^\circ$



$Cv(\omega_0=0^\circ, \theta=40^\circ, \Delta\omega)$



$Cv(\omega_0=90^\circ, \theta=40^\circ, \Delta\omega)$



- Can model a wide range of $|HH|^2/|VV|^2$ polarisation ratios, required to reproduce the diversity seen in experimental data
- At $\Delta\omega = 90^\circ$ (random volume), $HH=VV$

Polarimetric Decomposition

Surface and Oriented Volume

- Assume **surface** described by **Small Perturbation Model (SPM)**
- Model oriented volume $[C_v]$ ($\tau_0, \omega_0, \Delta\omega$)
- Adjust volume component for snow-ice transmissivities (Y_S, Y_P)
- Fix ω_0 based on observed HH/VV
- Invert observed $[C]$ for $f_s, f_v, \Delta\omega$

Ground-to-volume scattering ratio

- Define vector m :

$$m_{HH} = \frac{P_{S\ HH}}{P_{V\ HH}} \quad m_{VV} = \frac{P_{S\ VV}}{P_{V\ VV}} \quad m_{HV} = 0$$

$$[C_{total}] = [C_s] + [C_v]$$

$$= f_s \begin{bmatrix} 1 & 0 & \beta \\ 0 & 0 & 0 \\ \beta^* & 0 & |\beta|^2 \end{bmatrix} + f_v \begin{bmatrix} Y_S^2 C_{v11} & 0 & Y_S Y_P C_{v13} \\ 0 & Y_S Y_P C_{v22} & 0 \\ Y_S Y_P C_{v13} & 0 & Y_P^2 C_{v33} \end{bmatrix}$$

$$C_{v11} = 12\Delta\omega + 8\cos(2\omega_0)\sin(2\Delta\omega) + \cos(4\omega_0)\sin(4\Delta\omega)$$

$$C_{v13} = 4\Delta\omega + 2\cos^2(\tau_0)\cos(2\omega_0)\sin(2\Delta\omega) - \cos(4\omega_0)\sin(4\Delta\omega)\sin^2(\tau_0)$$

$$C_{v22} = 2C_{v13}$$

$$C_{v33} = 12\Delta\omega + 2(5 + \cos(2\tau_0))\cos(2\omega_0)\sin(2\Delta\omega)\sin^2(\tau_0) + \cos(4\omega_0)\sin(4\Delta\omega)\sin^4(\tau_0)$$

Coherence modelling

➤ Fundamental InSAR observable **coherence**: γ

➤ Assuming scattering medium is ¹:

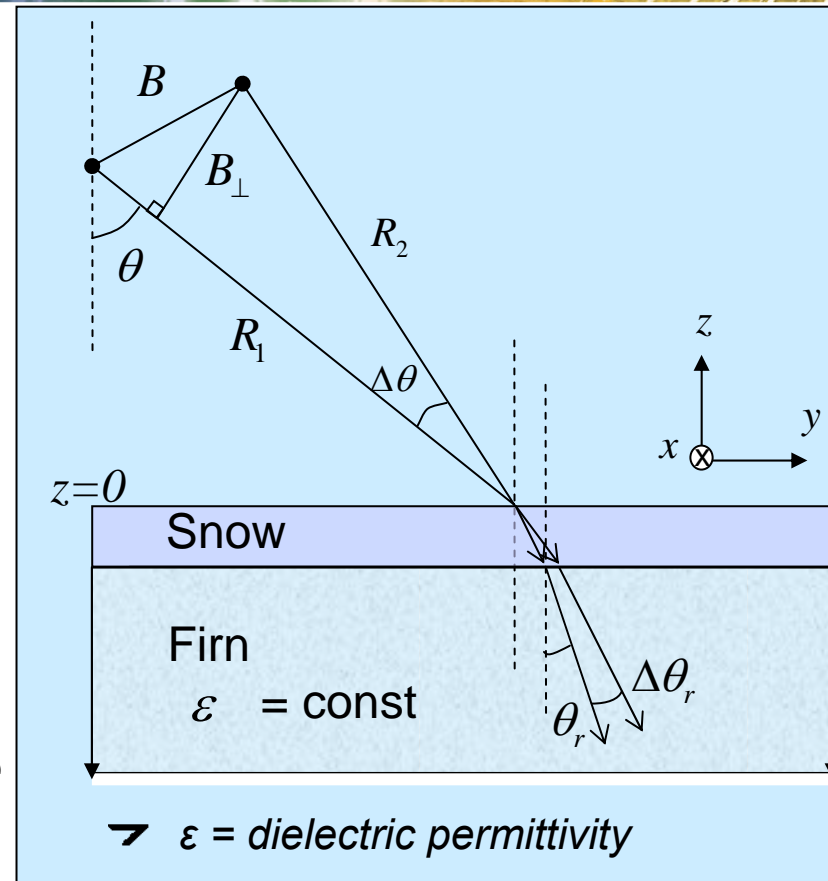
➤ **infinite**, homogeneously lossy (**constant extinction** κ_e [1/m])

➤ consists of uniformly distributed and uncorrelated scattering centres

$$\gamma_{vol} = \frac{1}{1 + \frac{j \cos \theta_r k_{zvol}}{2 \kappa_e}} \quad k_{zvol} = \frac{4\pi\sqrt{\varepsilon}}{\lambda} \frac{\Delta\theta_r}{\sin \theta_r}$$

➤ k_{zvol} = vert. wave number in the volume

➤ Combine with a ground contribution from snow-firn interface (m = ground-to-volume scattering ratio):



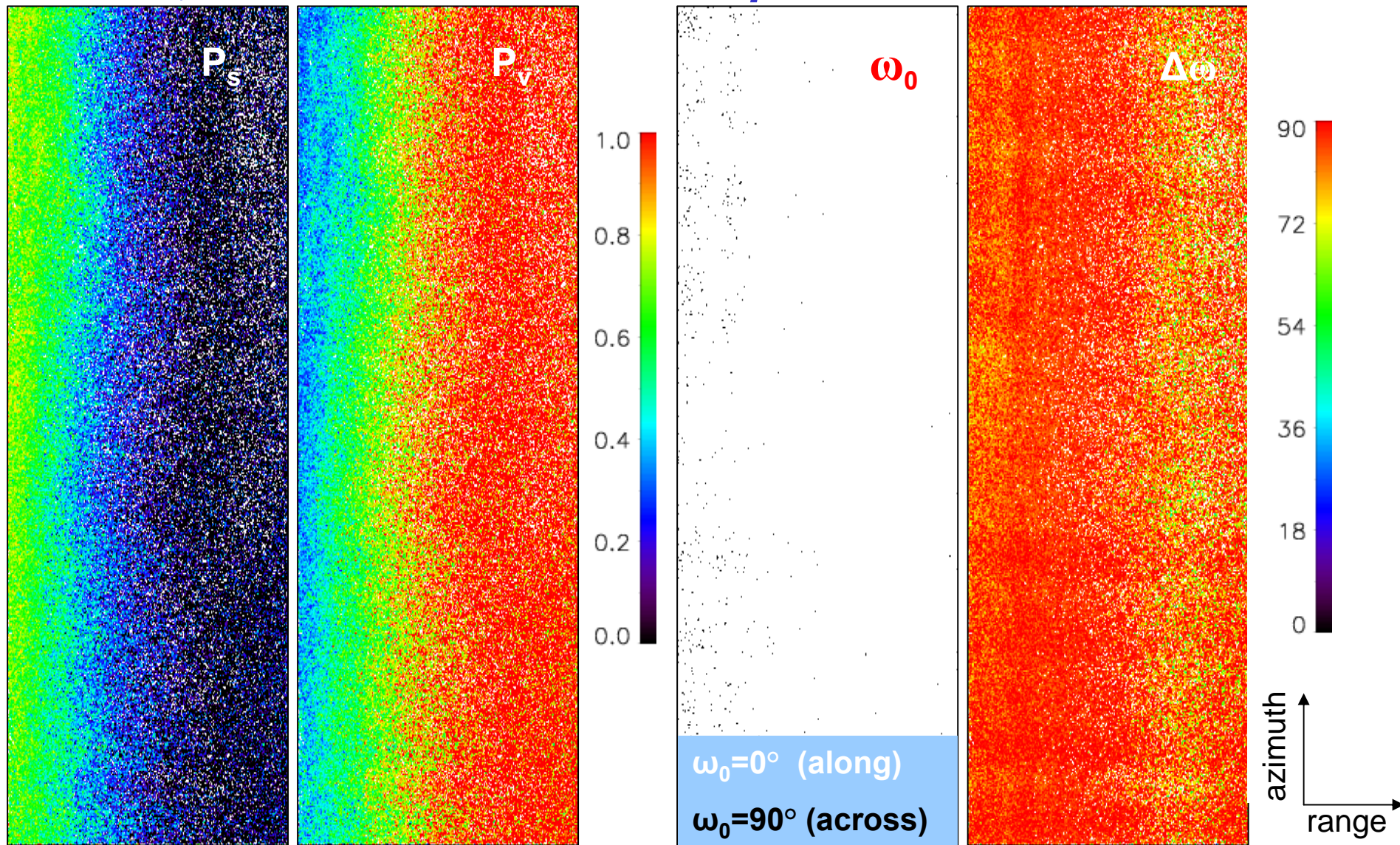
$$|\gamma| = \left| \frac{\gamma_{vol}(\kappa_e) + m}{1 + m} \right|$$



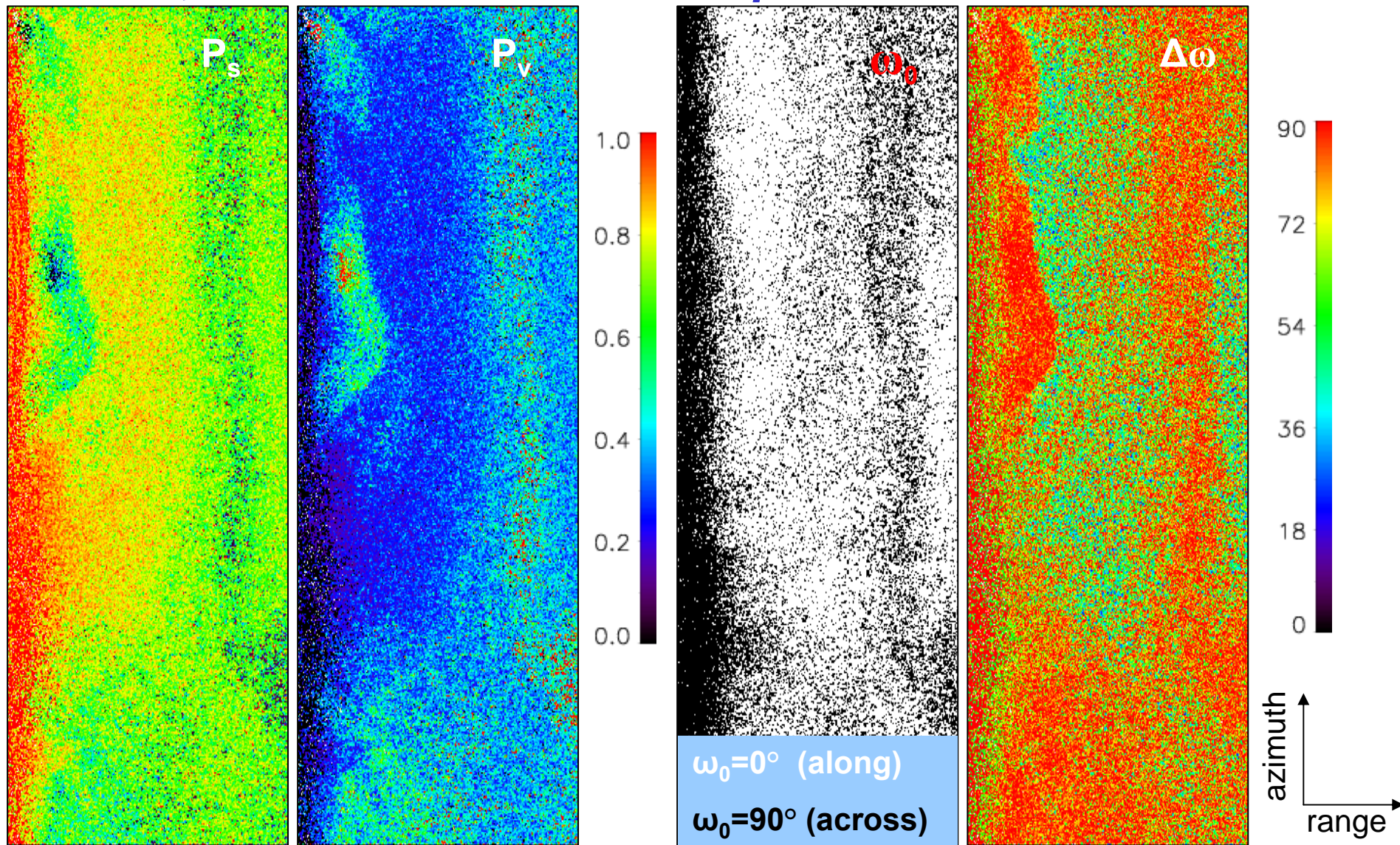
Results with Experimental Data



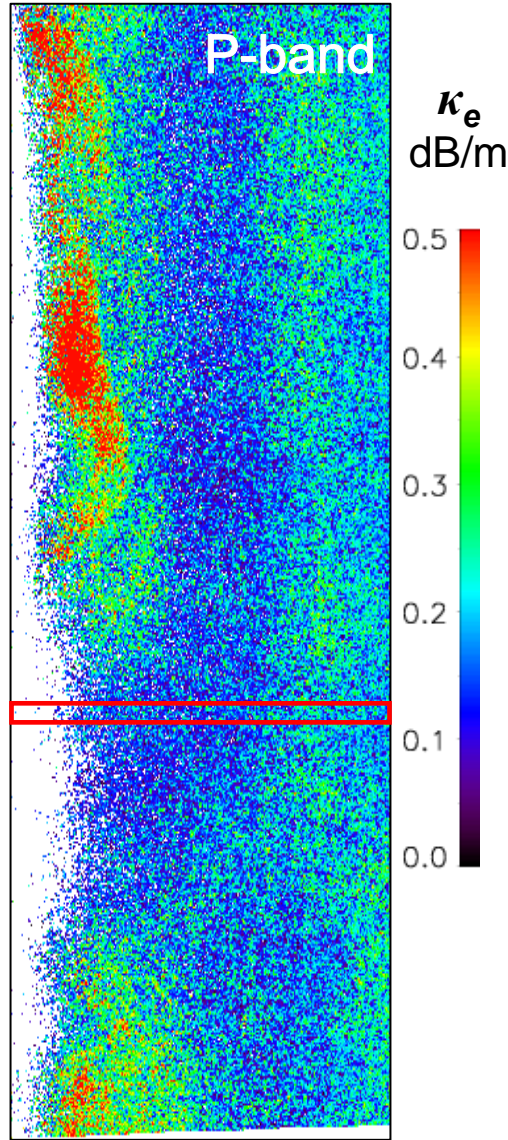
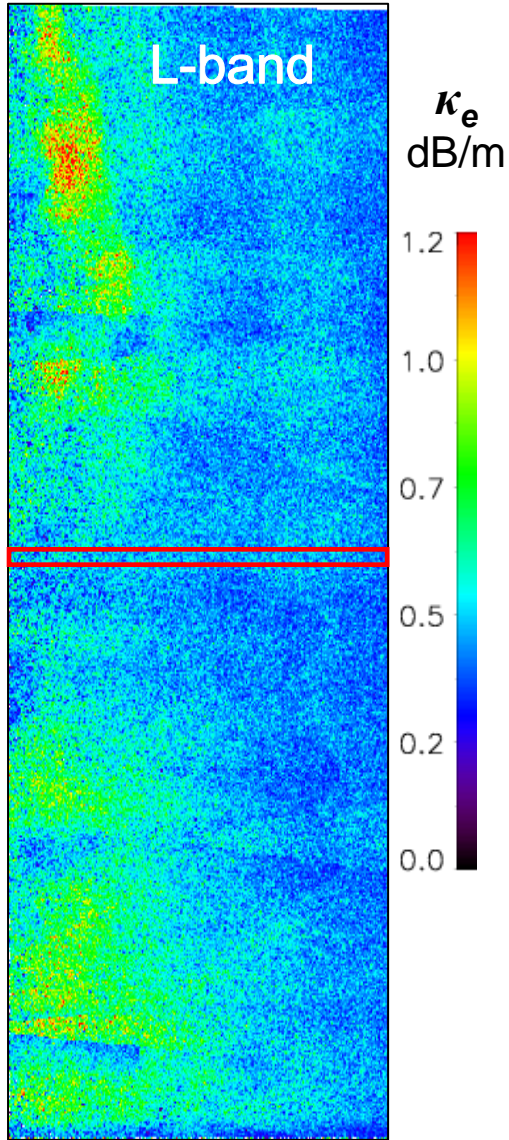
L-band, Oriented Volume Decomposition



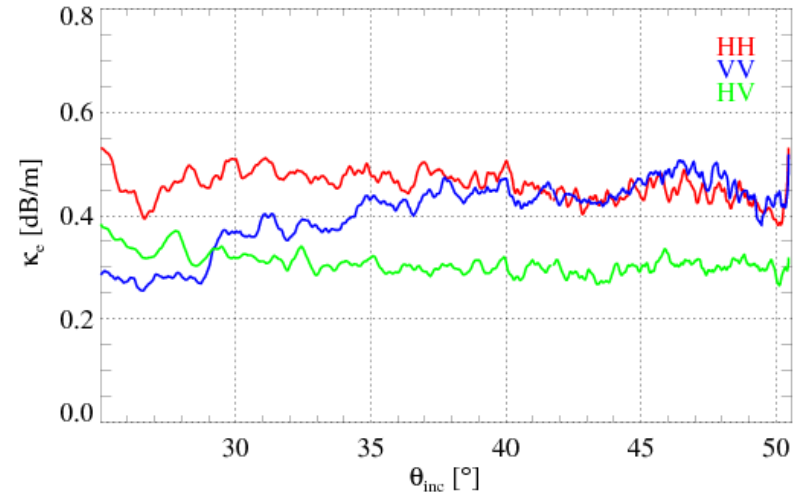
P-band, Oriented Volume Decomposition



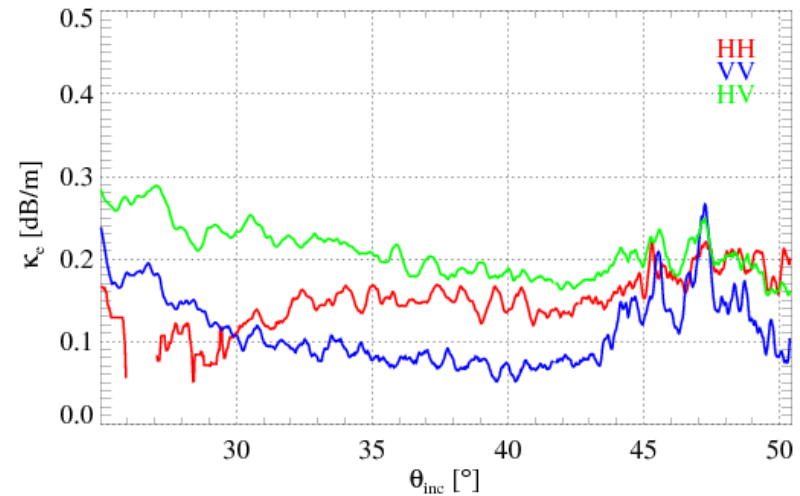
$\kappa_{e\ HH}$, Multibaseline ($mask\ 0.01 < k_z < 0.1$)



L-band Subset



P-band Subset





Summary

Extinction model

- **Separated ground and volume contributions** using novel polarimetric decomposition for oriented volumes
 - Model has the advantage of a direct relation to the physical orientations of scatterers in an Earth-based reference system
 - Allows for a 3-D distribution of volume particles
- **Estimated extinctions** using a Pol-InSAR coherence model, combining baselines for a more robust solution
- **2-D images of extinctions at L- and P-band**, useful in identifying regions of internal ice structure, not visible with optical systems nor 1-D GPR profiles

Recommendations

- **Cross-track passes** \perp to the glacier centre line should be flown for additional insight into possible orientation effects of the ice scattering bodies
- **GPR data** collected nearly simultaneously to the SAR data and at the same centre frequencies recommended for a meaningful comparison with inverted extinctions
- **Time series of P-band** data to track changes in ice structure, which could reveal changes in long-term accumulation, wind, and melt patterns



Thank you

