Investigation of Penetration Bias of Surface Elevation Models from SAR Interferometry in Dependence of Subsurface Structure, Frequency and Polarization

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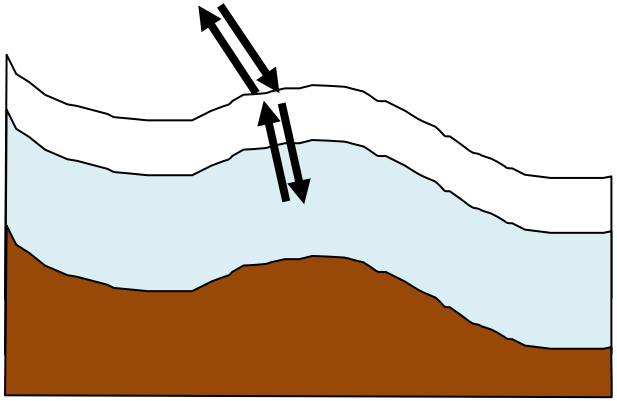
[1]DLR, Microwaves and Radar Institute, Germany
[2]ETH Zurich, Institute of Environmental Engineering, Switzerland

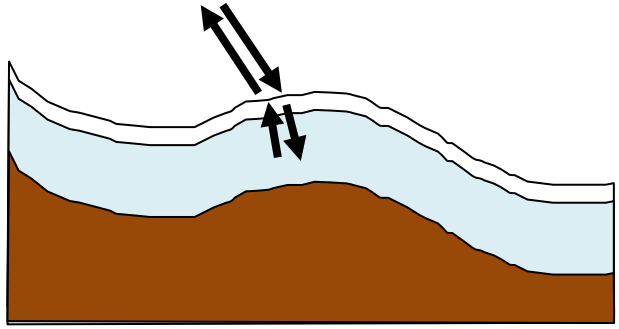
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

DLR



InSAR Surface Elevation over Ice Sheets





Microwave penetration



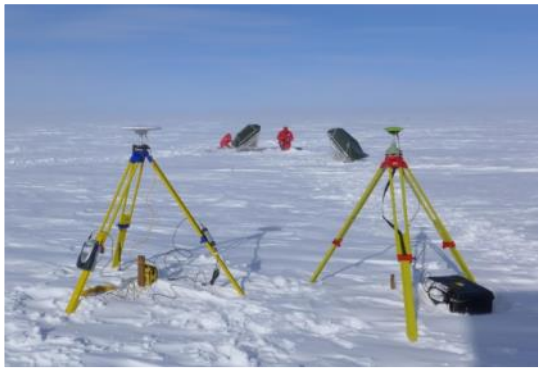
Error in ice sheet mass balance

No simple value for phase center depth
Depends on:

- Frequency
- Polarization
- Vertical subsurface structure (density, ice inclusions, temperature, grain size)











Pictures by Silvan Leinss, ETH Zurich

EGIG T05

FoxxGull

Kangerlussuaq Airport

K-Transect

Helheim Glacier

DYE-3

South Dome

ARCTIC15 Campaign

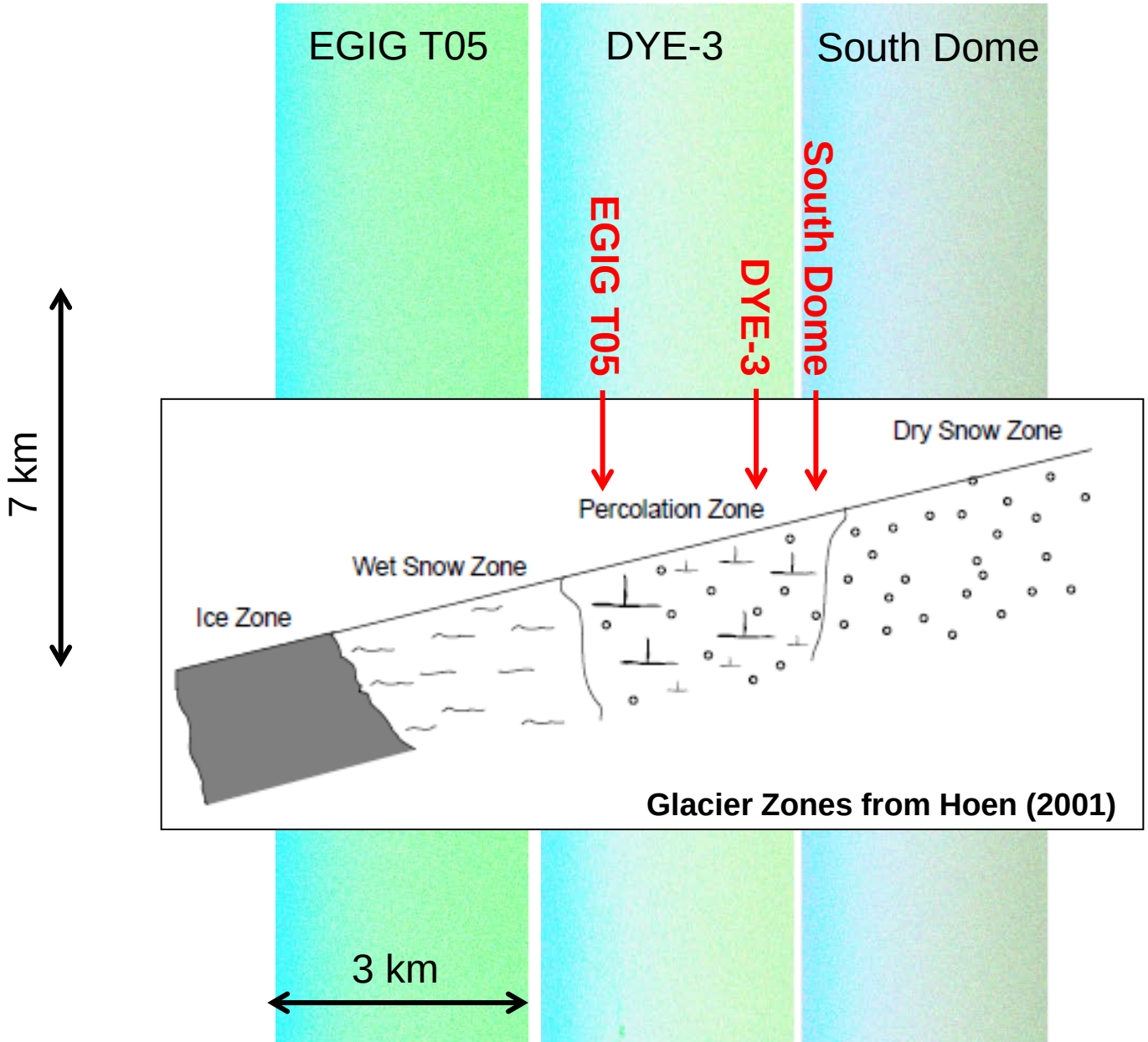
F-SAR airborne sensor (DLR)

P-, L-, S-, C-, X-band

Fully polarimetric

Tomographic dataset

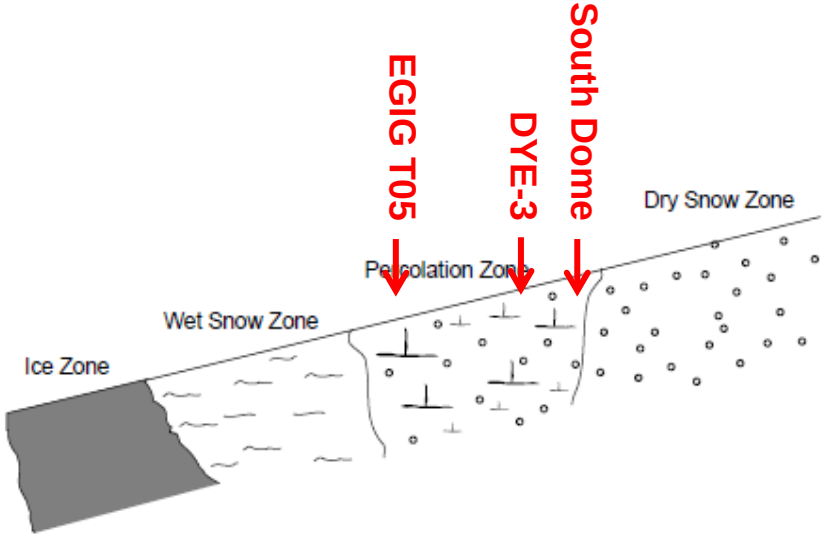
Pauli-Images @ L-band / Percolation Zone HH+VV HH-VV HV



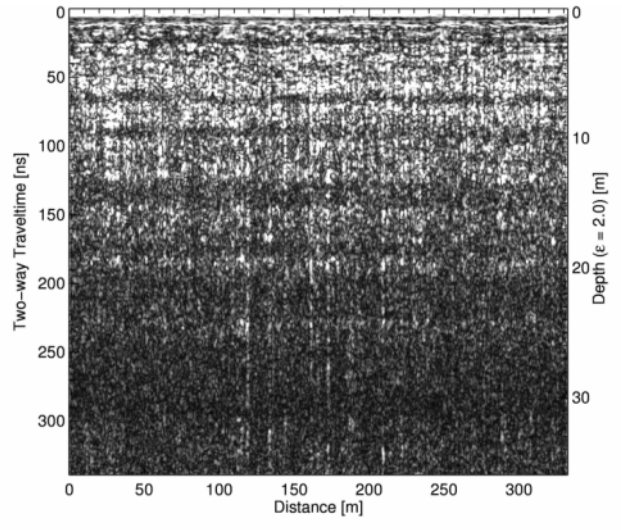


Subsurface Structures

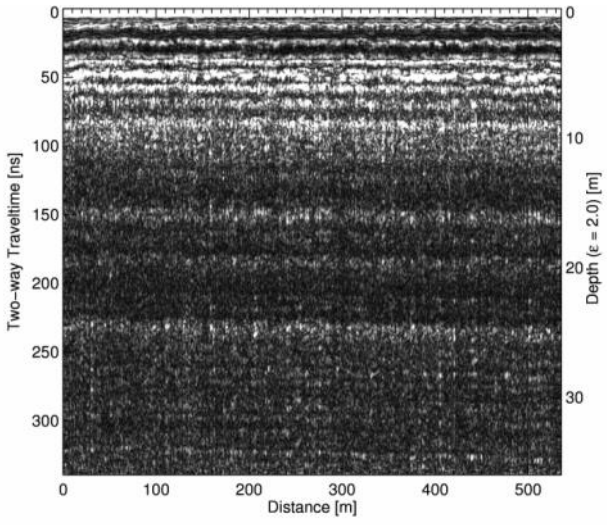
- Ground Penetrating Radar 500 MHz
- Uniform scattering vs. distinct layers



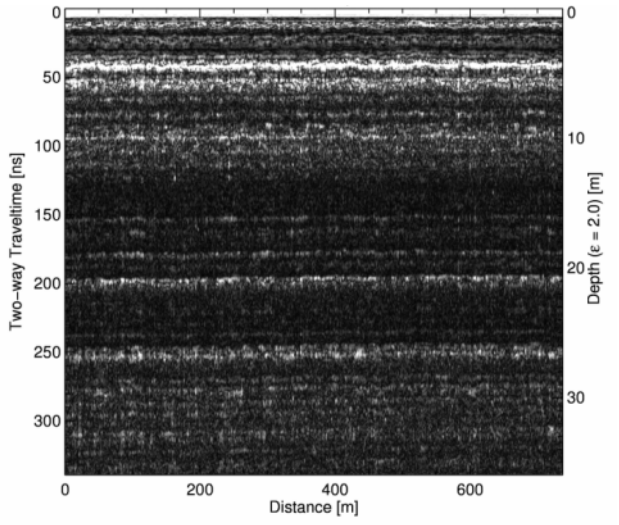
EGIG T05



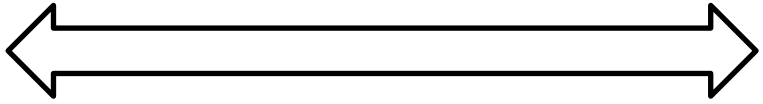
DYE-3



South Dome

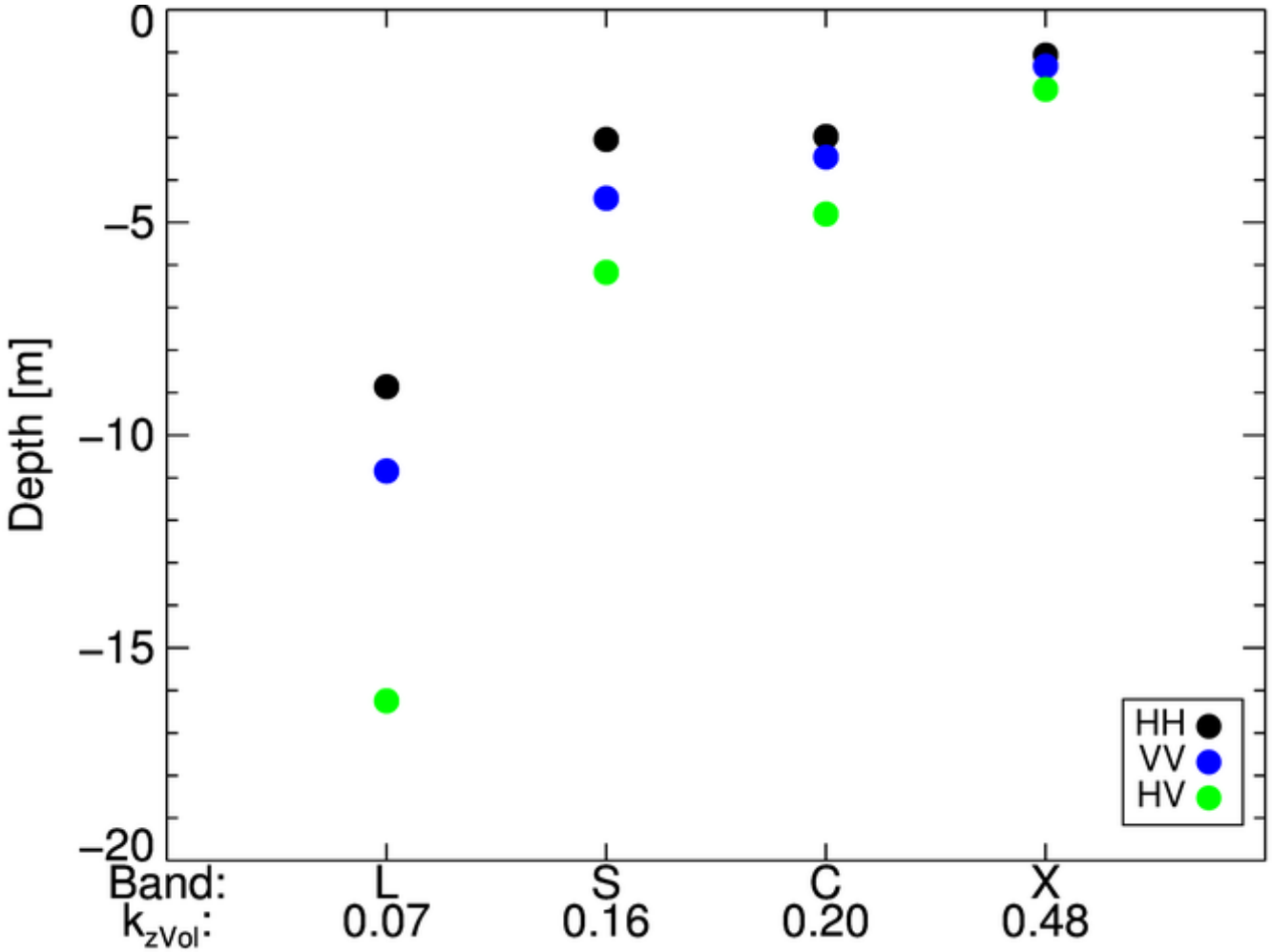


More Melting
More Ice Inclusions



Less Melting
Less Ice Inclusions

Phase Centers Depths at Corner Reflectors



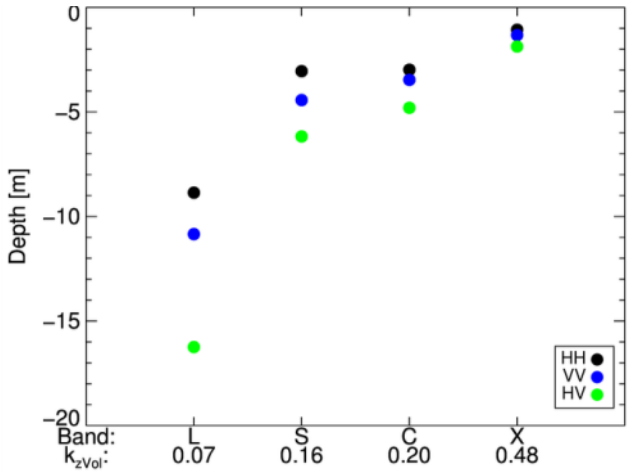
EGIG T05



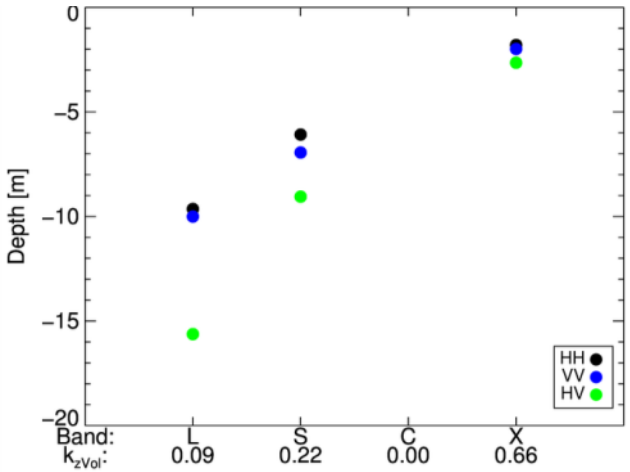
Phase Centers Depths at Corner Reflectors

- Expected behavior with frequency and polarization
- HH > VV > HV

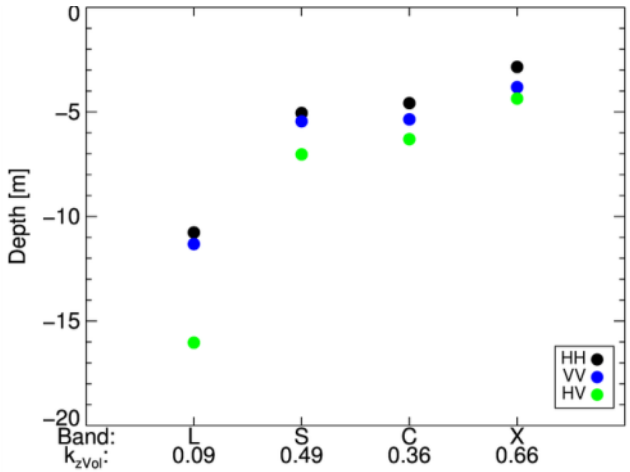
EGIG T05



DYE-3



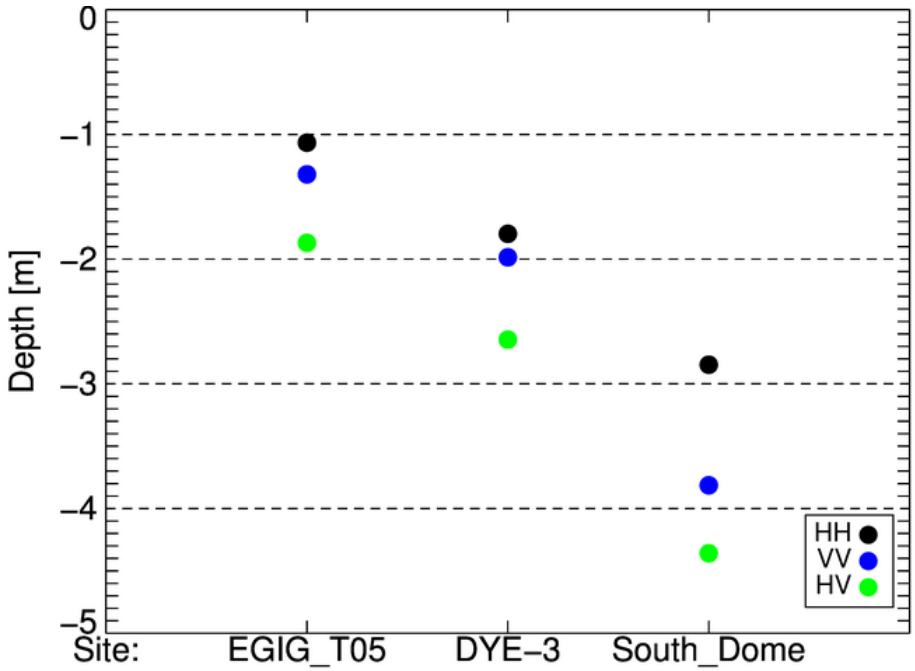
South Dome





Differences Between Test Sites

Case of X-band
(e.g. TanDEM-X)

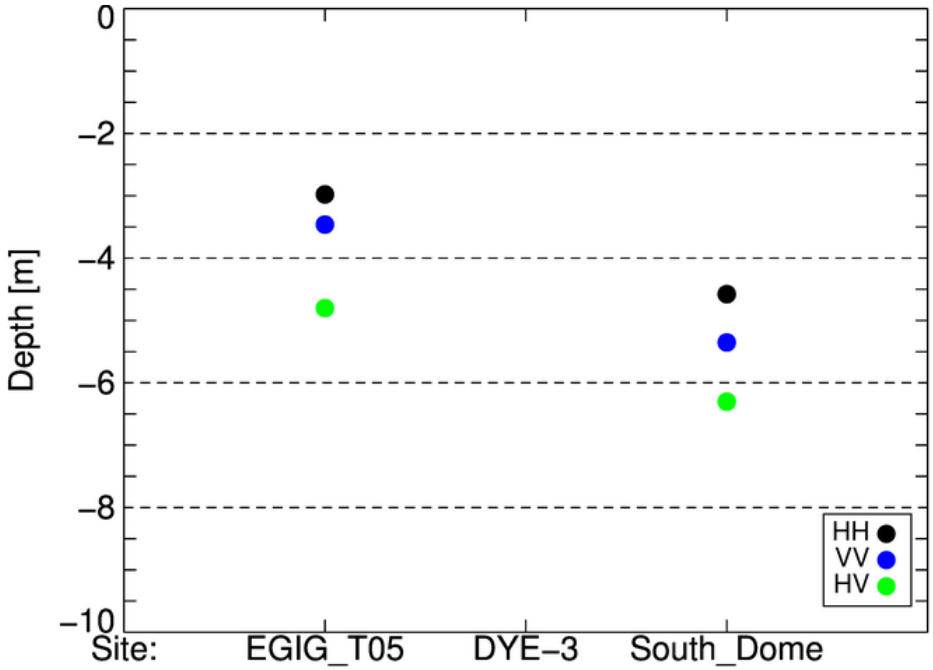


Difference [m]	HH	VV	HV
South Dome – DYE-3	1.0	1.8	1.7
South Dome – EGIG	1.8	2.5	2.5



Differences Between Test Sites

Case of C-band
(e.g Sentinel-1)

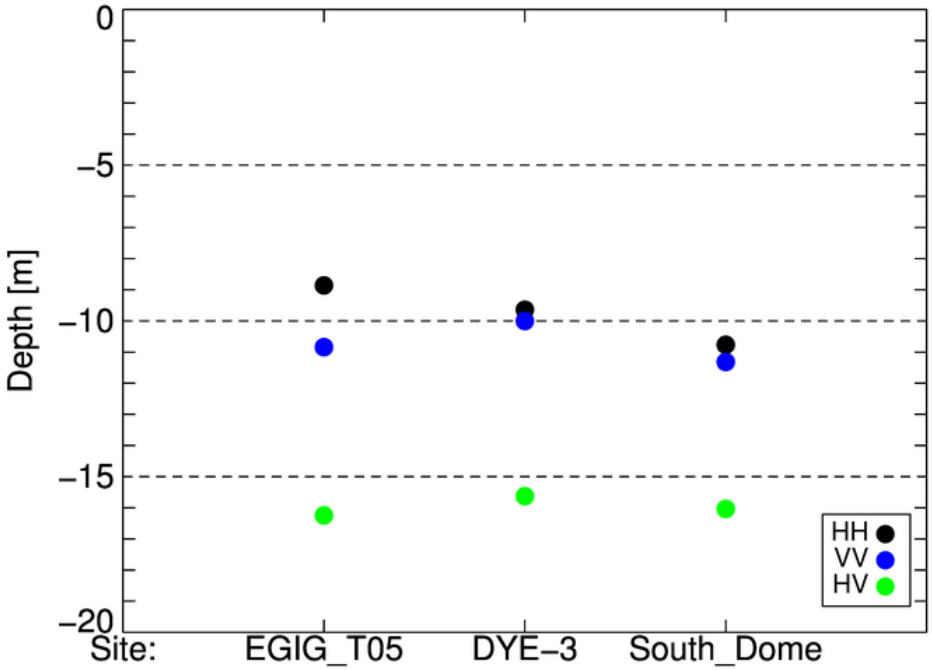


Difference [m]	HH	VV	HV
South Dome – EGIG	1.6	1.9	1.5



Differences Between Test Sites

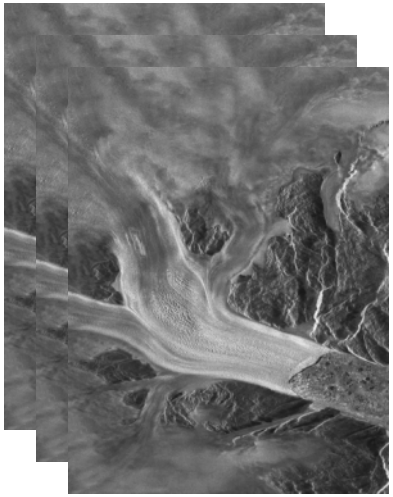
Case of L-band
(e.g. ALOS / Tandem-L)



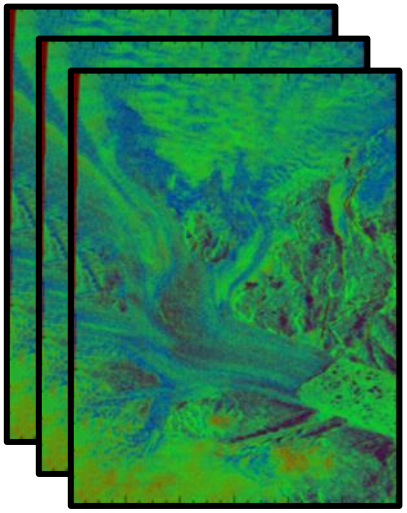
Difference [m]	HH	VV	HV
South Dome – DYE-3	1.1	1.3	0.4
South Dome – EGIG	1.9	0.5	-0.2



Possible Solution: Data Driven Estimation



Phase Center Depth Estimation



- Single-Pol InSAR → 1 complex coherence [e.g HH]
- Quad-Pol InSAR → 3 complex coherences [HH, VV, HV]

→ Theoretical limit for inversion of models

→ Simplified models necessary



Modelling Phase Centers

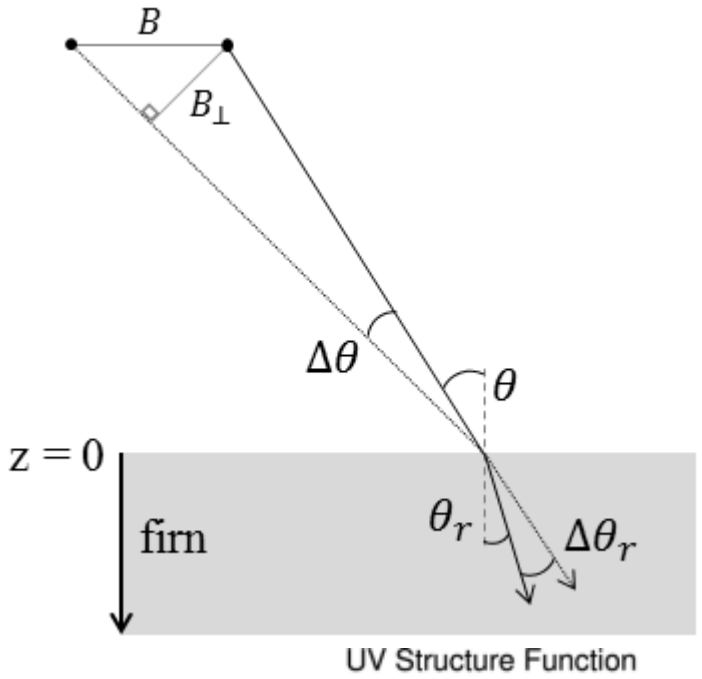
- Volume Coherence

$$\gamma_{Vol} = e^{ik_z z_0} \frac{\int_{-\infty}^{0} \sigma_v(z) e^{ik_{zVol} z} dz}{\int_{-\infty}^{0} \sigma_v(z) dz}$$

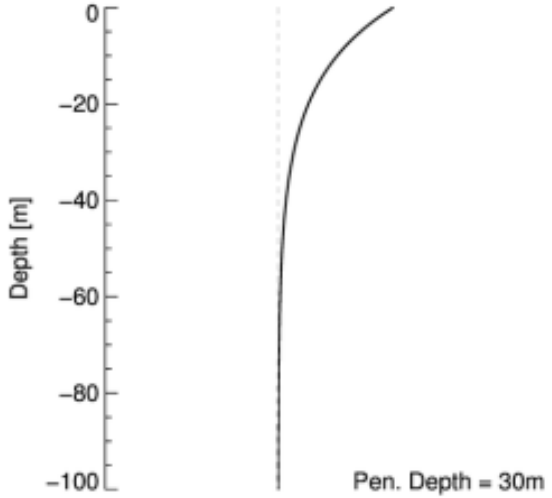
- Uniform Volume [Hoen & Zebker, 2000]

$$\sigma_v(z) = \sigma_v^0 \mathrm{e}^{\frac{2z\kappa_e}{cos\theta_r}}$$

$$\angle\gamma_{vol} = \tan^{-1}\left(\sqrt{\frac{1}{|\gamma_{vol}|^2} - 1}\right)$$



UV Structure Function





Modelling Phase Centers

Possible with Single-Pol InSAR

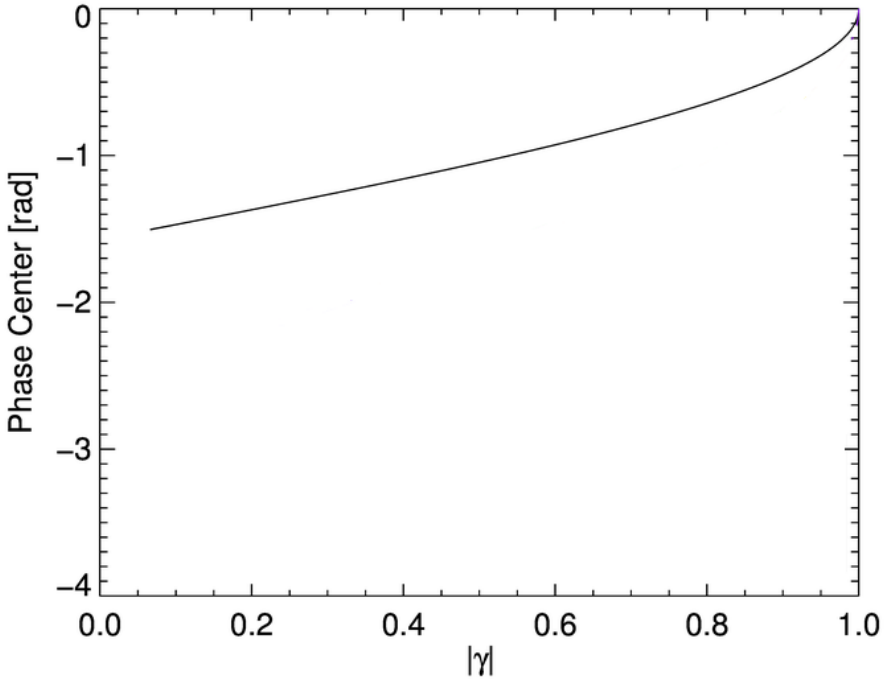
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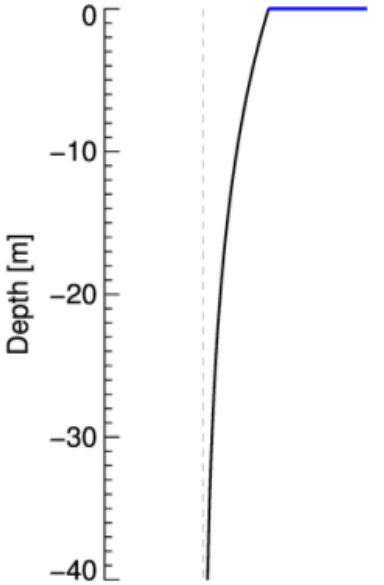
Modelling Phase Centers

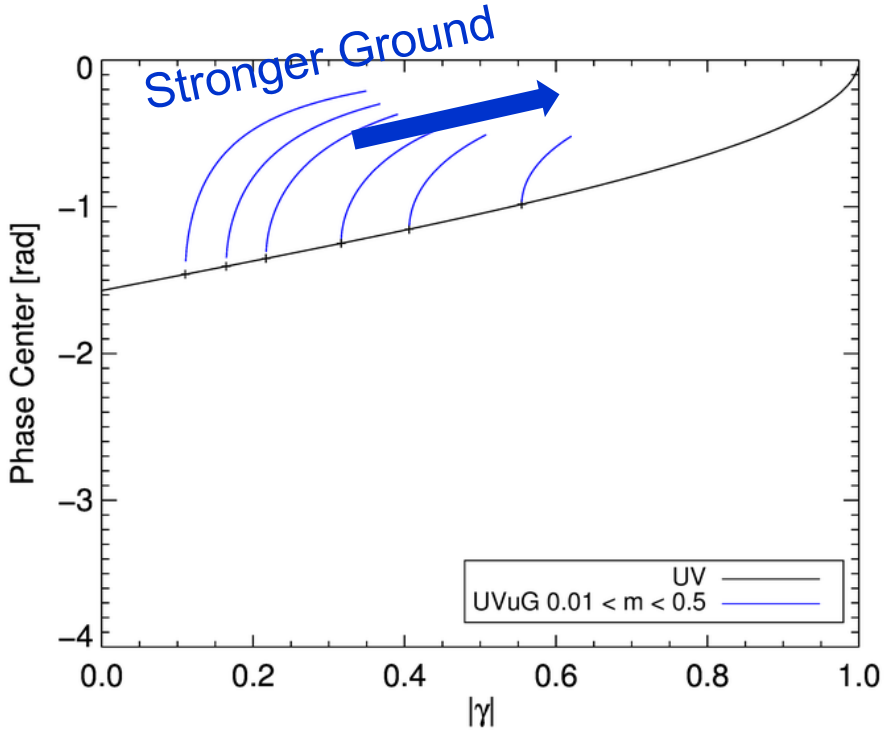
Possible with Quad-Pol InSAR

- Uniform Volume under Ground

$$\gamma = e^{ik_z z_0} \frac{\gamma_{Vol}(k_{zVol}, \kappa_e) + m}{1 + m}$$

with ground-to-volume ratio m

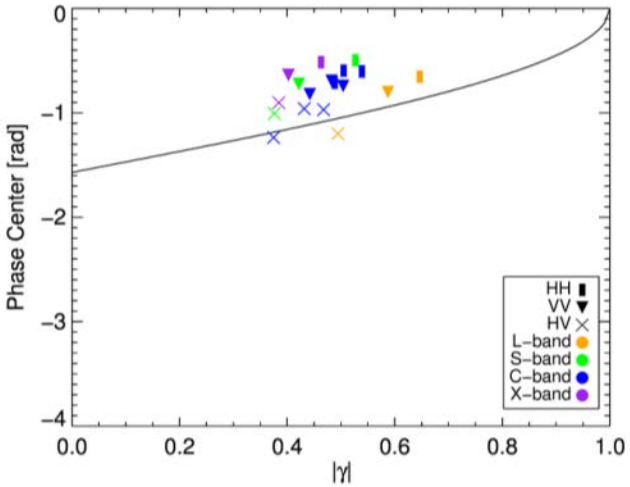




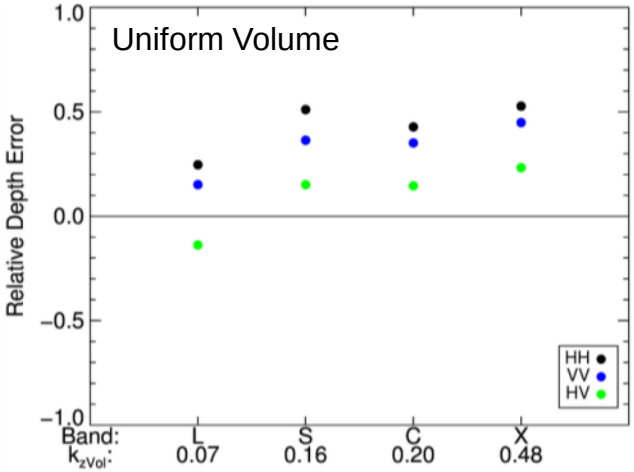


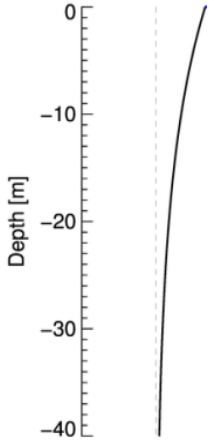
Multi-frequency Phase Center vs $|\gamma|$

Data: EGIG T05

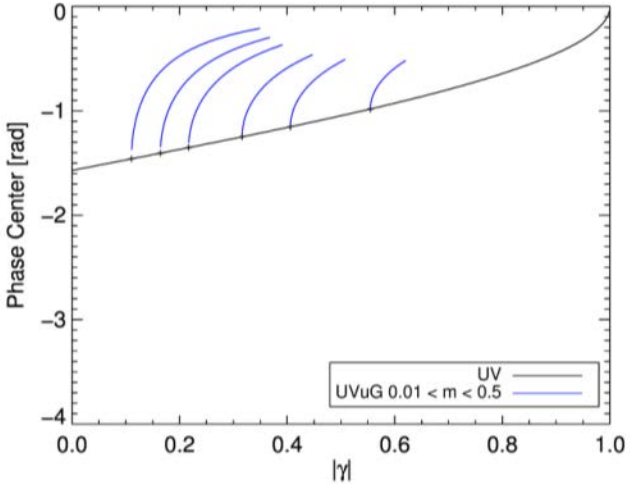


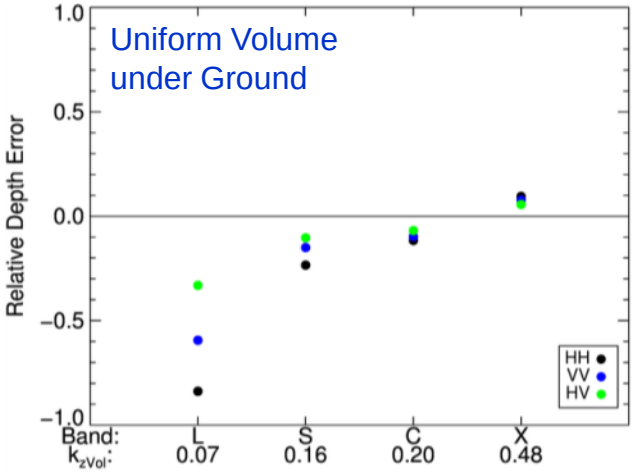
Phase Center Estimation:

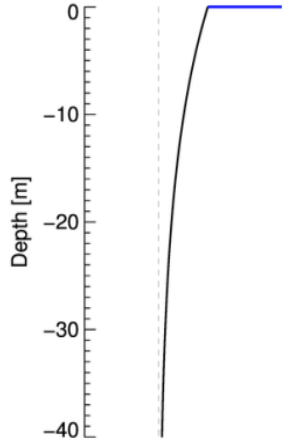




Model: Uniform Volume under Ground

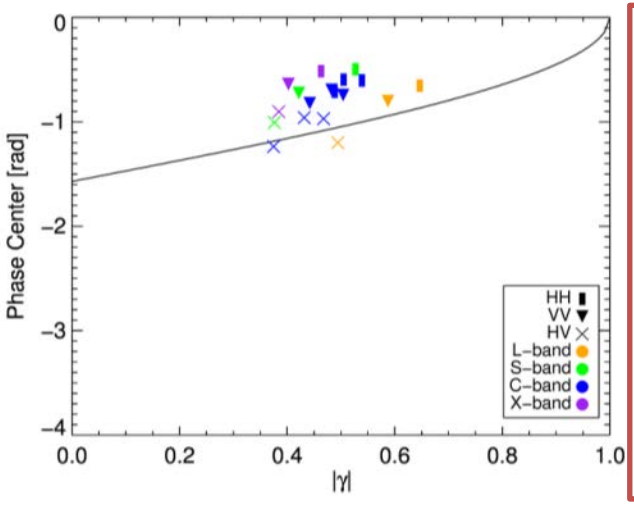




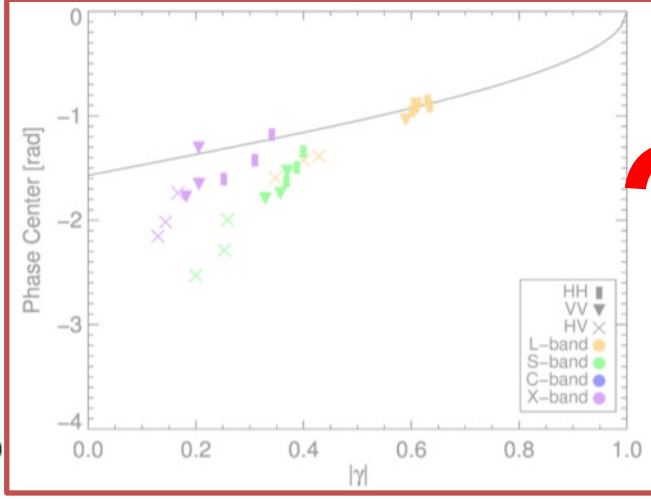


Multi-frequency Phase Center vs $|\gamma|$

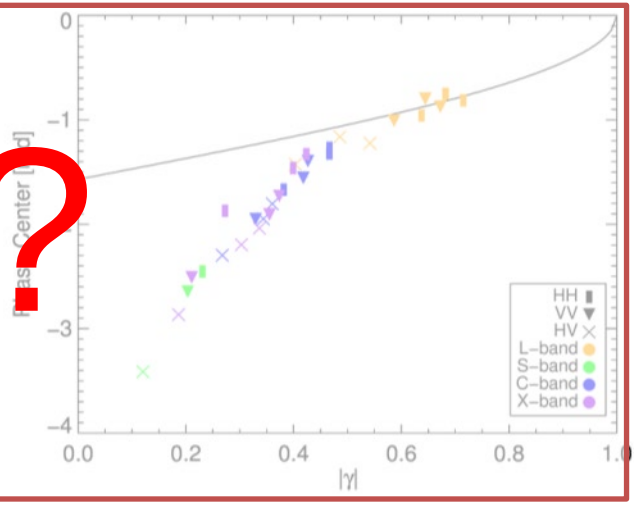
EGIG T05



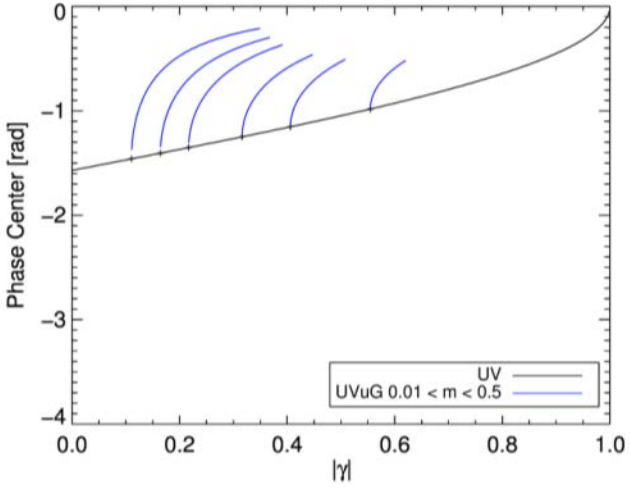
DYE-3



South Dome



Uniform Volume under Ground



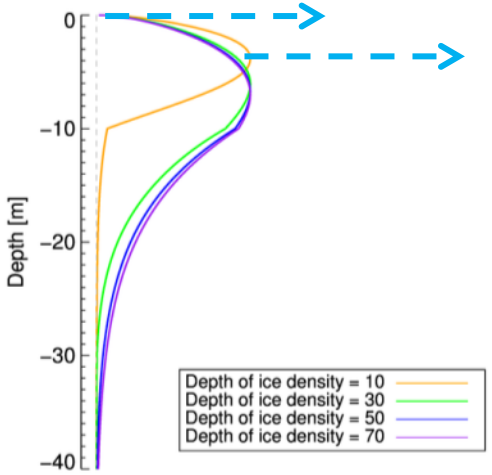


South Dome / DYE-3: Non-Uniform Volume + 2 Layer

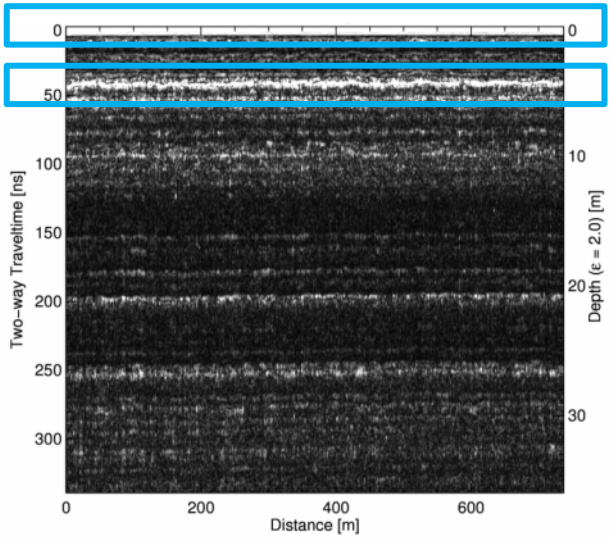
- No constant extinction:
  - Grains grow with depth
  - Increase in density with depth

- Surface + 2nd layer necessary

Non-Uniform Structure

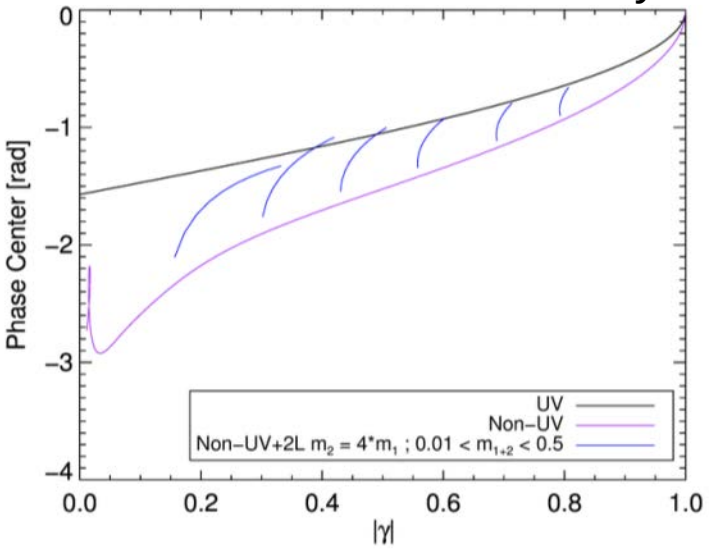


[Mätzler, 1998; Oveisgharan & Zebker, 2007]

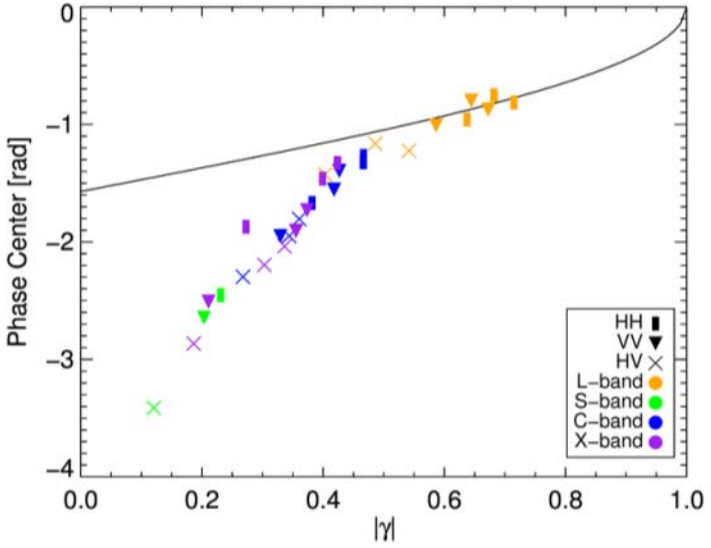


South Dome / DYE-3: Non-Uniform Volume + 2 Layer

Non-Uniform Volume + 2 Layer



South Dome



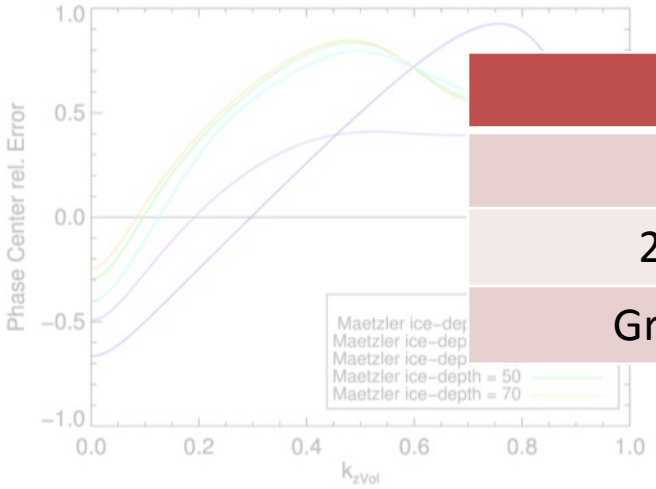
$$\gamma = e^{ik_z z_0} \frac{\gamma_{Vol}(k_{zVol}, \rho(z), R_g(z)) + \sum_{j=1}^{N} m_j e^{ik_{zVol} z_j}}{1 + \sum_{j=1}^{N} m_j}$$

Future Work: Is there a clever way to still estimate phase centers?

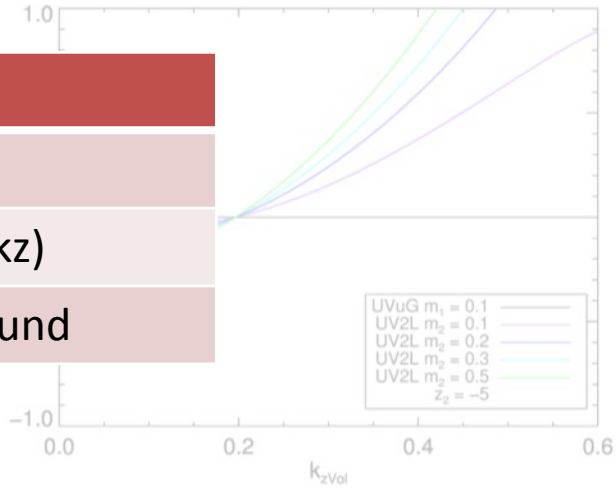


Accuracy of Phase Center Depth Modelling

UV vs Non-Uniform



UVuG vs UV2L



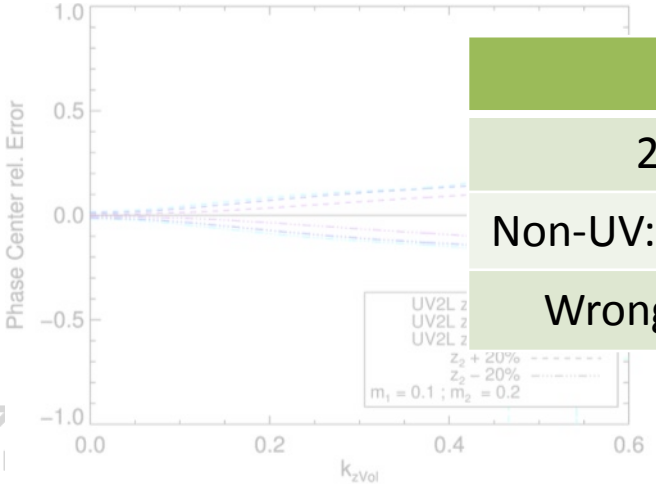
Large Errors

UV vs Non-UV

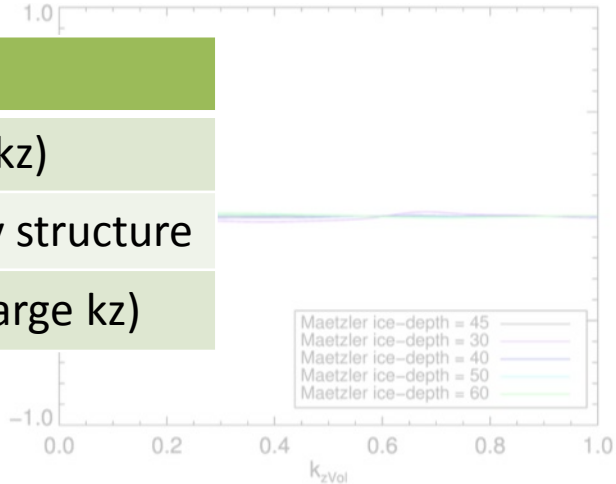
2nd layer (large kz)

Ground vs No-ground

20% error on depth of 2nd layer



Wrong depth of ice density



Small Errors

2nd layer (small kz)

Non-UV: Vertical density structure

Wrong d_{pen} for UV (large kz)

Summary

Understanding phase center depths

- Frequency & polarization behavior as expected
- But:
  - Non-Uniform subsurface structures
  - Scattering from layers in the subsurface

Phase center estimation

EGIG T05
- Standard Pol-InSAR models
- Estimation accuracy up to 10%

South Dome / DYE-3
- Wrong model → large error
- Inaccurate parameters → smaller impact

Extent of model applicability unknown

Model complexity too high for straight-forward estimation



Thank You for Your Attention



ARCTIC15
Team

DLR

ETH zürich

Danish Defence
Acquisition and Logistics Organization

