On the Retrieval of Accumulation Rates on the Ice Sheets Using SAR

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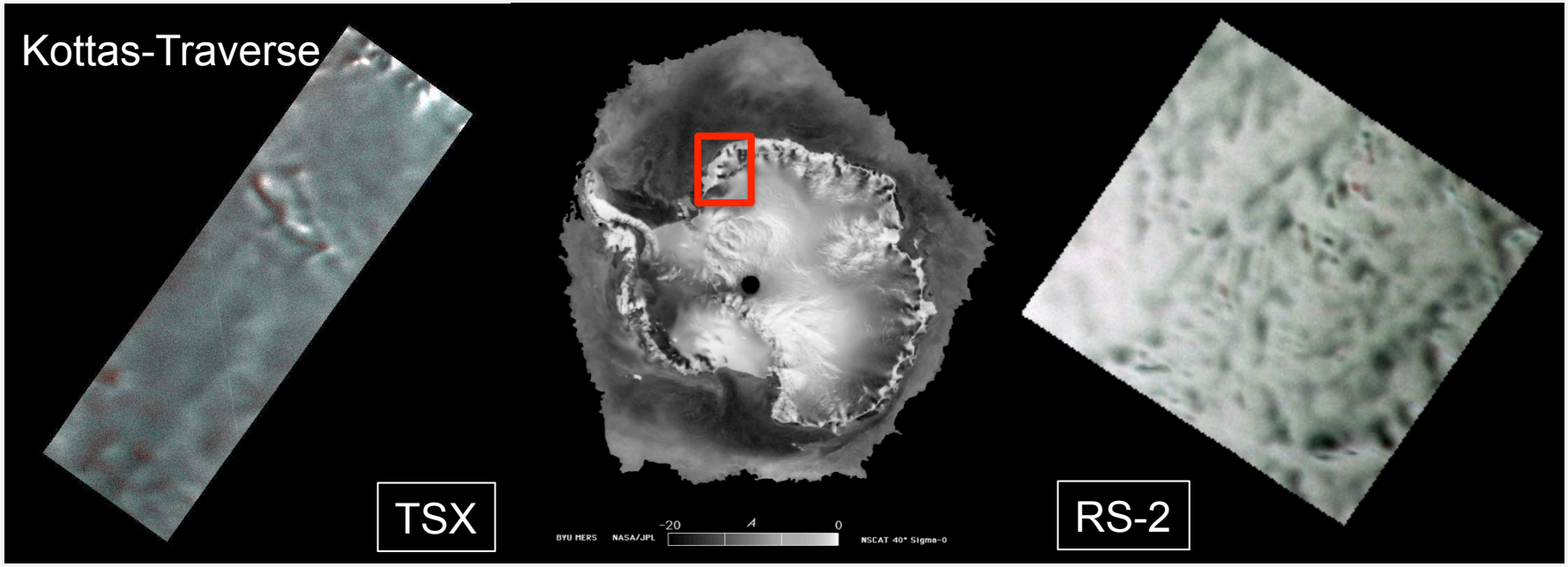


Accumulation Rate Retrieval – Why?

Accumulation rates on ice sheets:

- do the ice sheets loose mass? ➔ sea level rise
- snow accumulation is the *gain* in the mass balance of an ice sheet

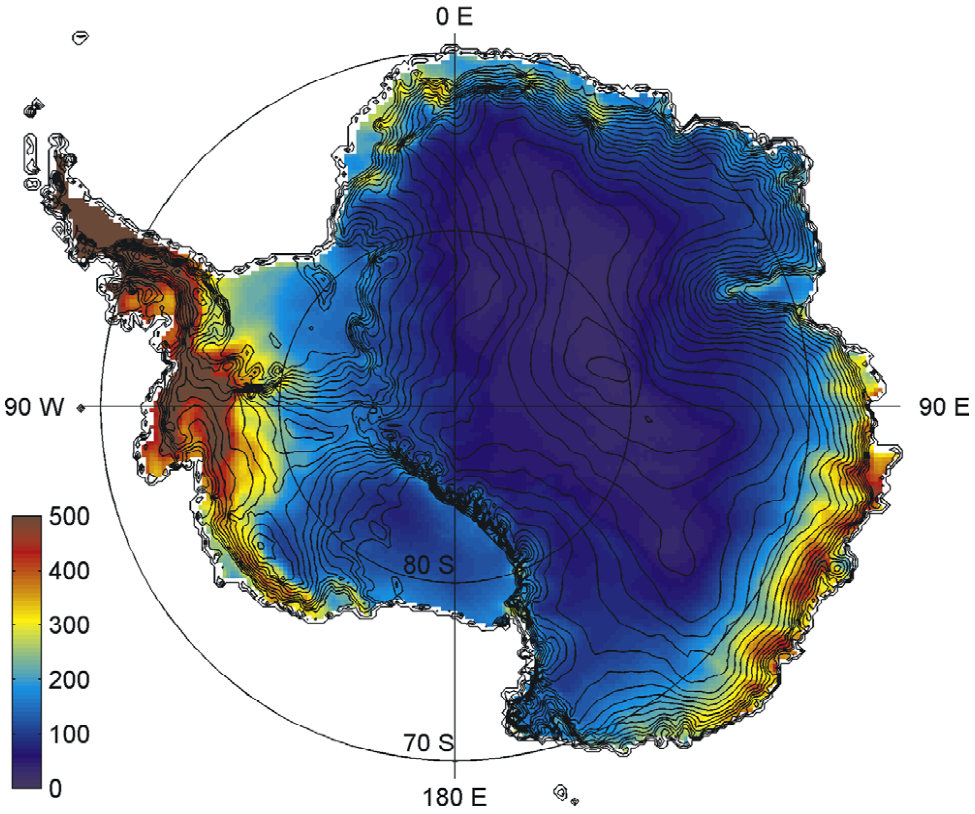


Figure 4. The map of Antarctic snow accumulation rate derived in this study (kg m^{-2} a^{-1}).

Accumulation rates retrieved from AMSR-E 6.9 GHz satellite data combined with ground data (Arthern et al., JGR, 2006)

Why Use Radar?

Low accumulation rates:

large grain sizes, thin annual layers

Large accumulation rates:

small grains, thicker layers

Radar (C to Ku-band) :

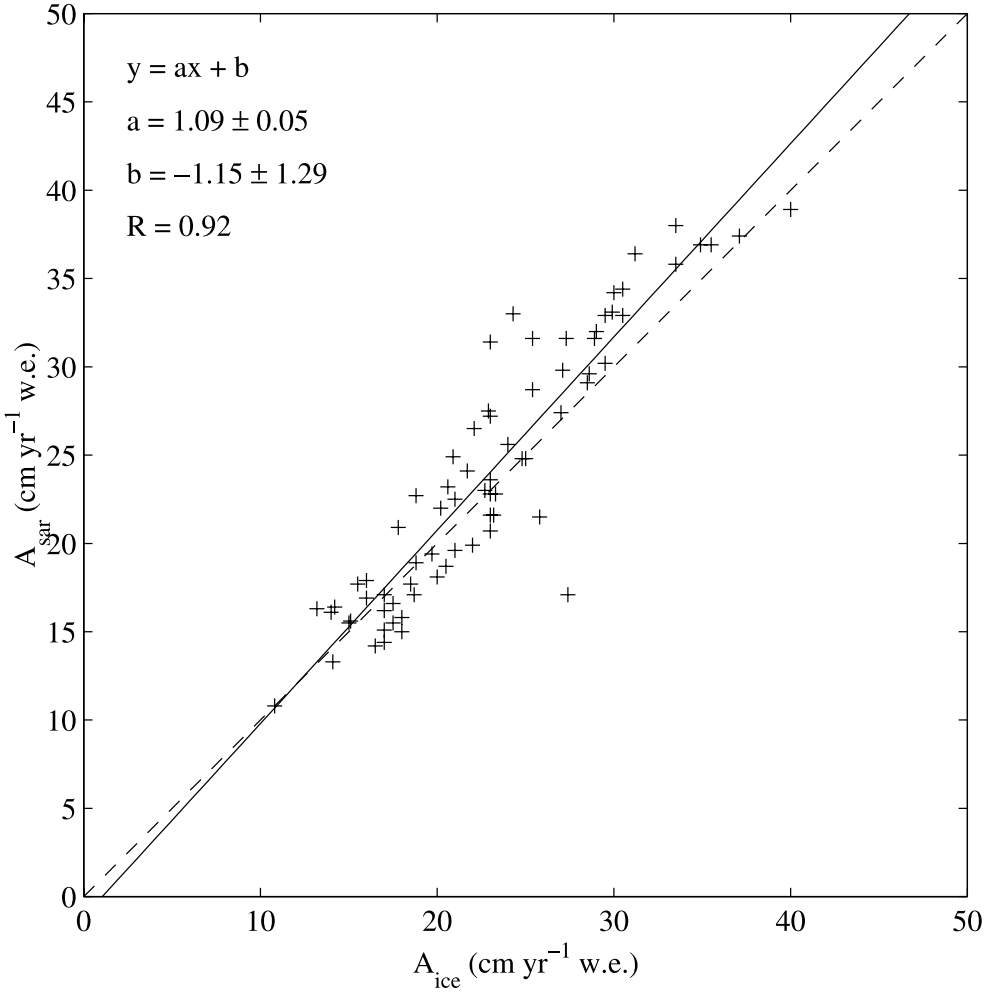
- very sensitive to grain size
- measured intensity depends on snow layering
- high spatial resolution (SAR)

Example from Greenland

Munk et al., JGR, 2003

- based on combination of snow metamorphosis and radar scattering model
- data: ERS-1 SAR
- valid for dry-snow zone

Example from Greenland



Retrieved from SAR data ➔

In-situ data ➔

Munk et al., JGR, 2003

Problems With Radar...

- Large penetration depths
  dependent on accumulation rate and temperature regime
    C-band 20-80 m
    Ku-band 5-20 m
  (corresponding to covering 10s and up to 100s of years)

- Is the backscattering coefficient sufficiently sensitive to accumulation rate?

- Different snow regimes – different sensitivities
  (implications for snow metamorphosis model)

Sensitivity of σ^0 to accumulation rate

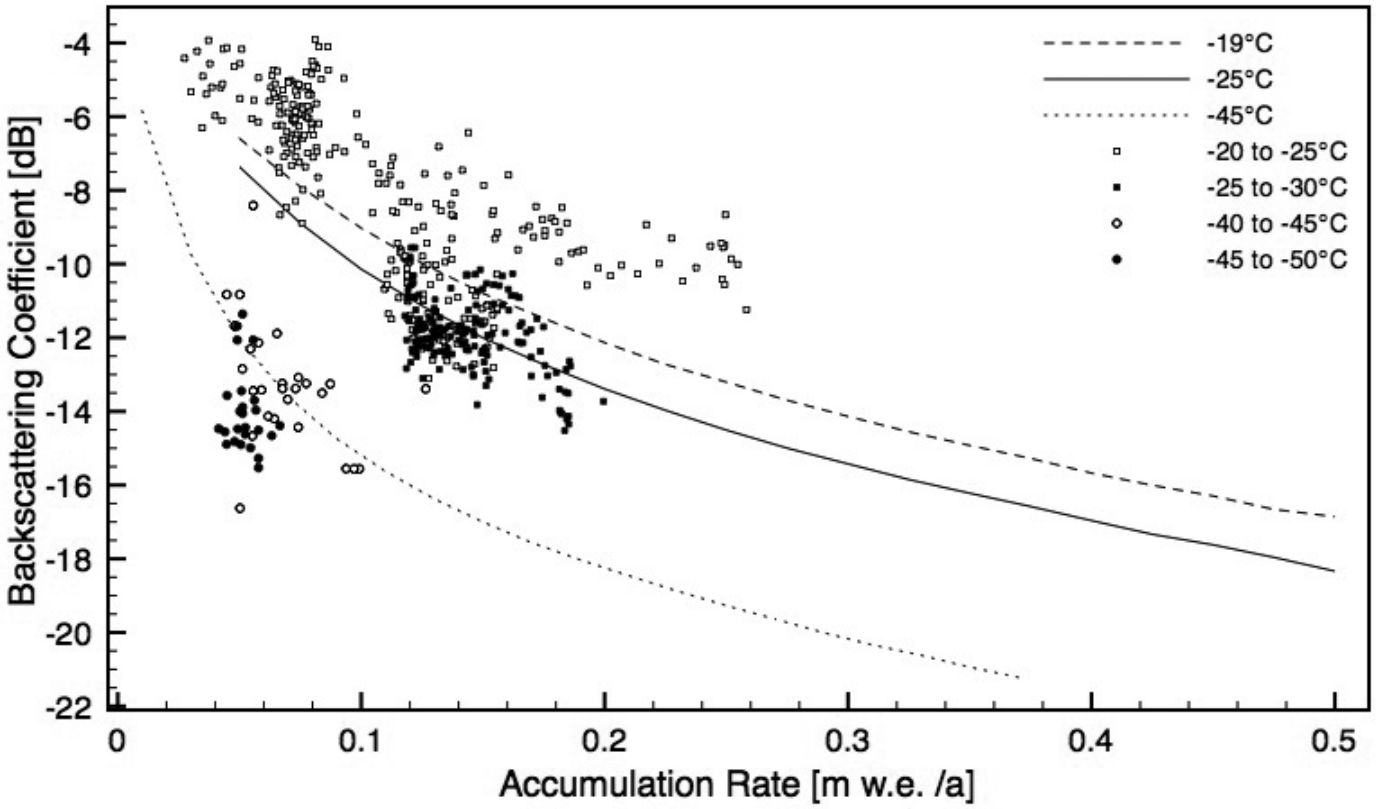


Figure 9. C-band backscattering coefficients measured at different temperature intervals as a function of accumulation rate from the Kottas Traverse (Dec 27, 2008) and from the Amundsenisen Plateau (Feb 2009). Results of simulations for different temperatures are also shown.

Dierking et al., JGR, 2012

Snow Regimes From Scatterometry

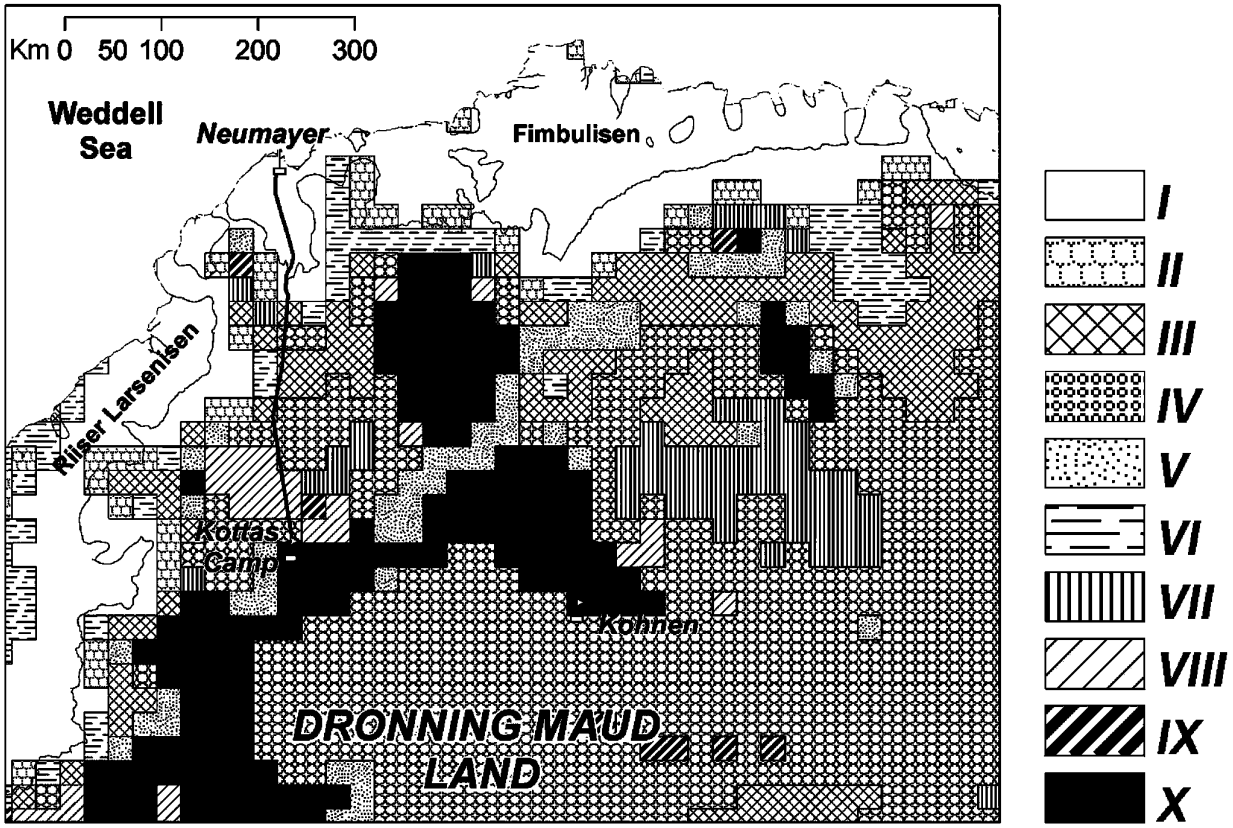
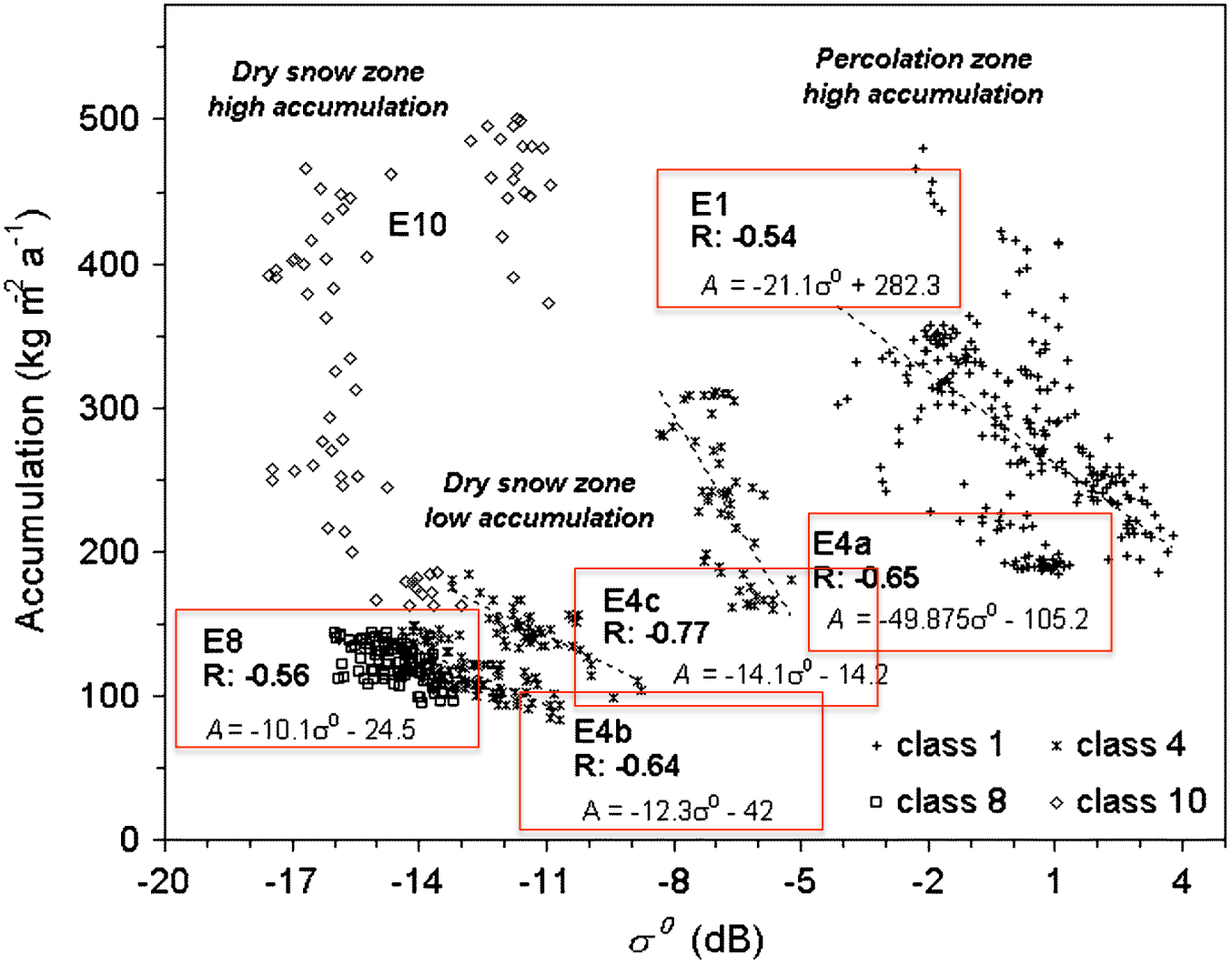


Fig. 10. Escat MLH classification result for DML study region.

Rotschky et al., TGRS, Vol. 44, No. 4, 2006

Accumulation Versus σ^0 For Different Snow Regimes

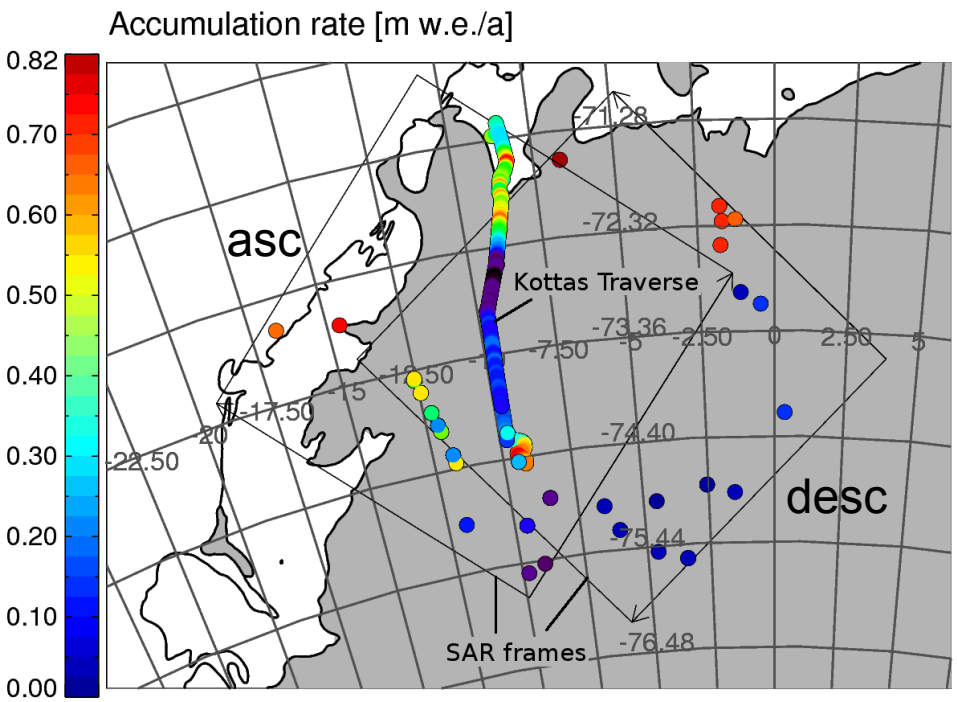


Rotschky et al., TGRS, Vol. 44, No. 4, 2006

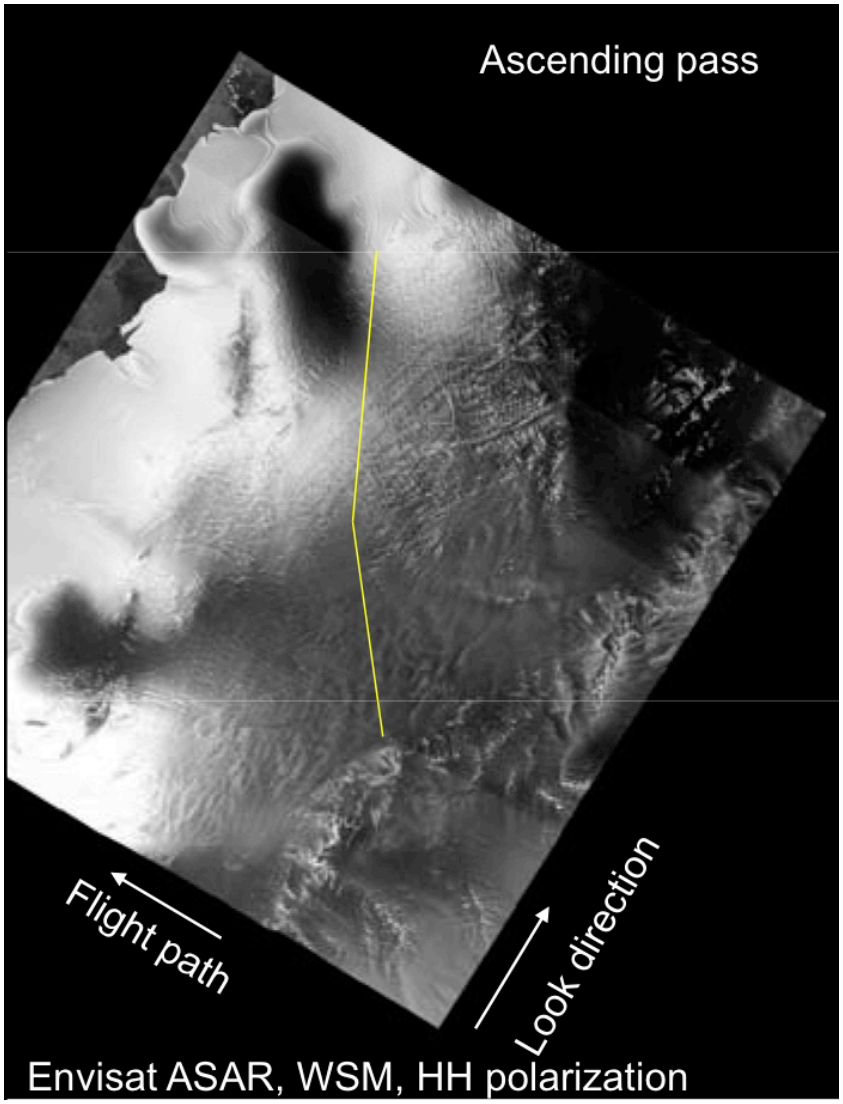
Accumulation Rate Retrieval - Approach

Strategy: Combining

- empirical models for snow parameter profiles (d, r, ρ)
  (Linow et al., J. Glac., 2012)
- radar scattering model



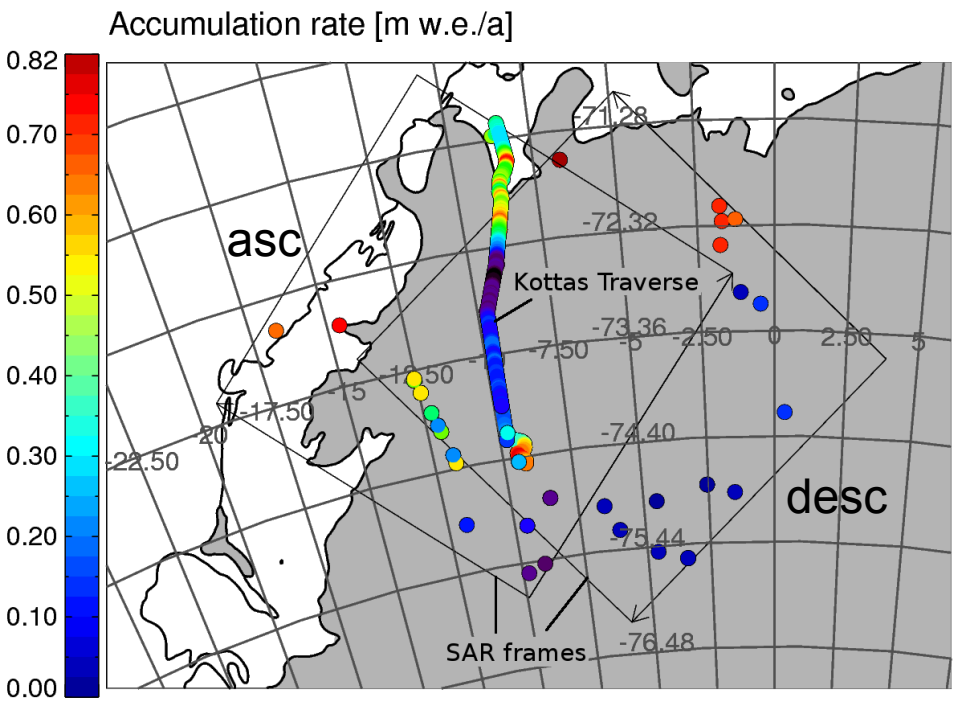
From: Dierking et al., JGR 2012



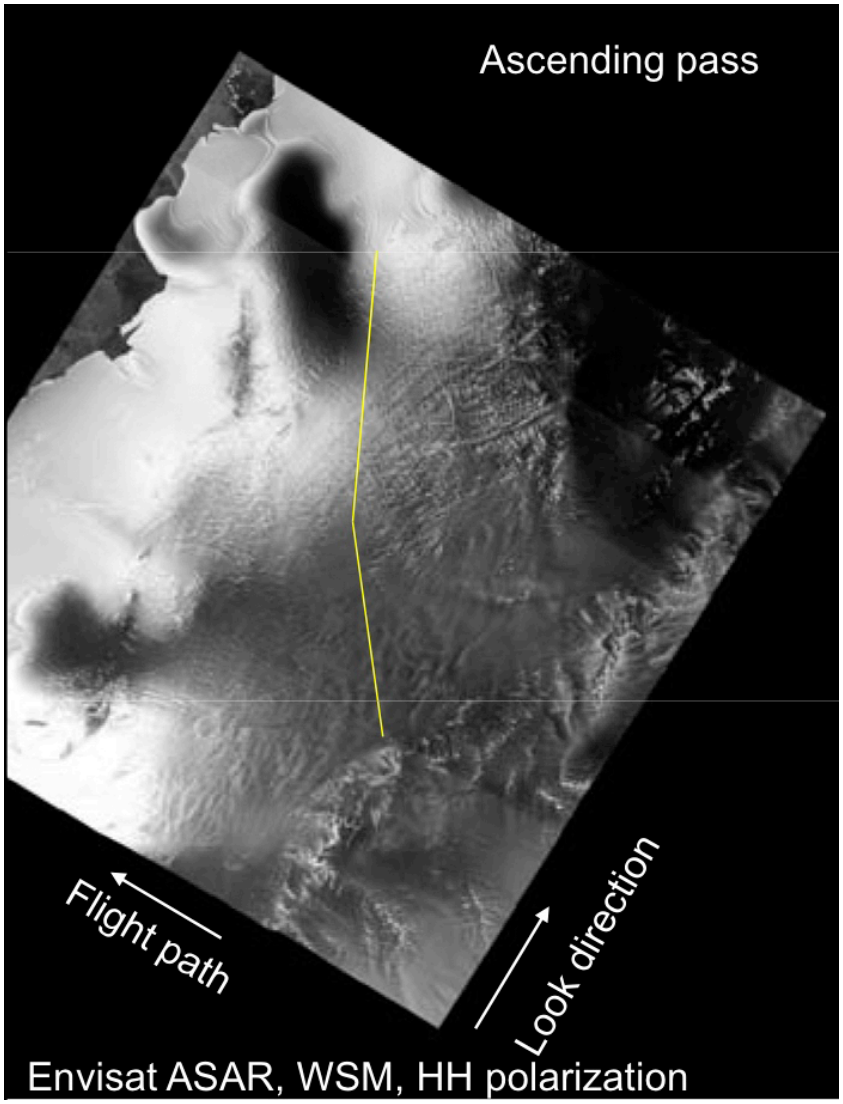
Accumulation Rate Measurements

Kottas Traverse:

- stake measurements
- 675 sites
- 500 m intervals
- down to 1.4-2 m depth



From: Dierking et al., JGR 2012

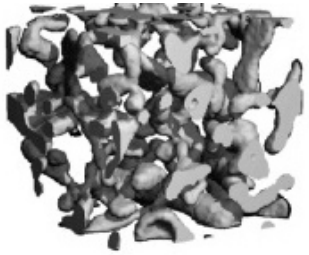


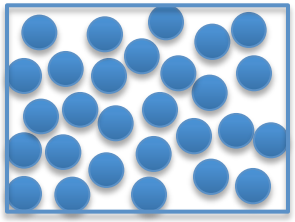
Radar Scattering Model

Radar scattering: volume contribution, regime bridging

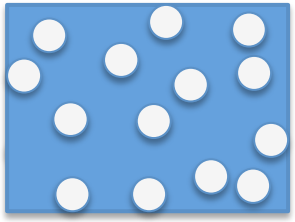
Scattering from firn: dense medium effect

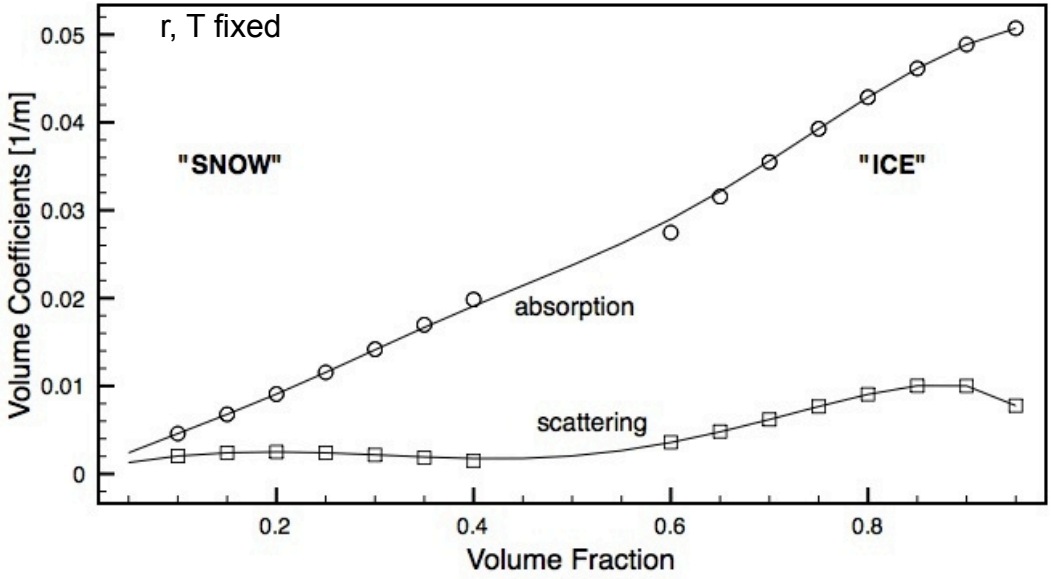
model (Wen et al., TGRS 1990) valid for firn densities < 0.3 g/cm3
(close-to-) surface firn density already 0.3-0.45 g/cm3





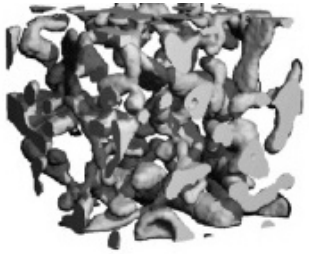
scatter
regime
bridging

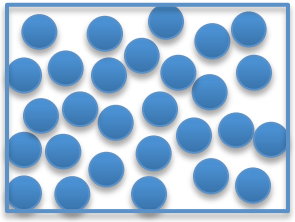




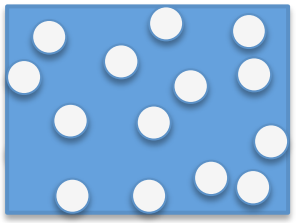
Dierking et al., JGR 2012

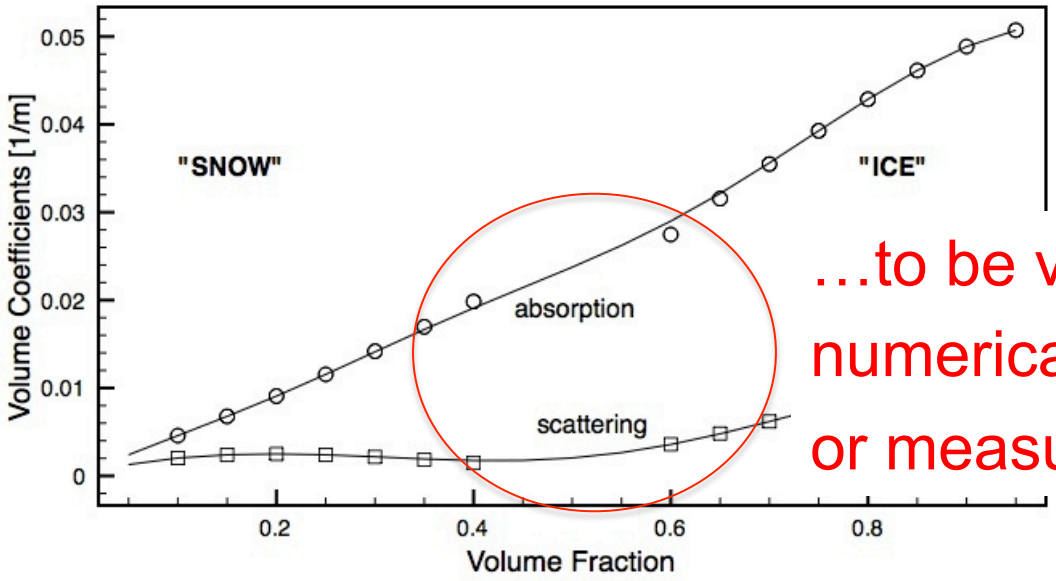
Radar Scattering Model





scatter
regime
bridging



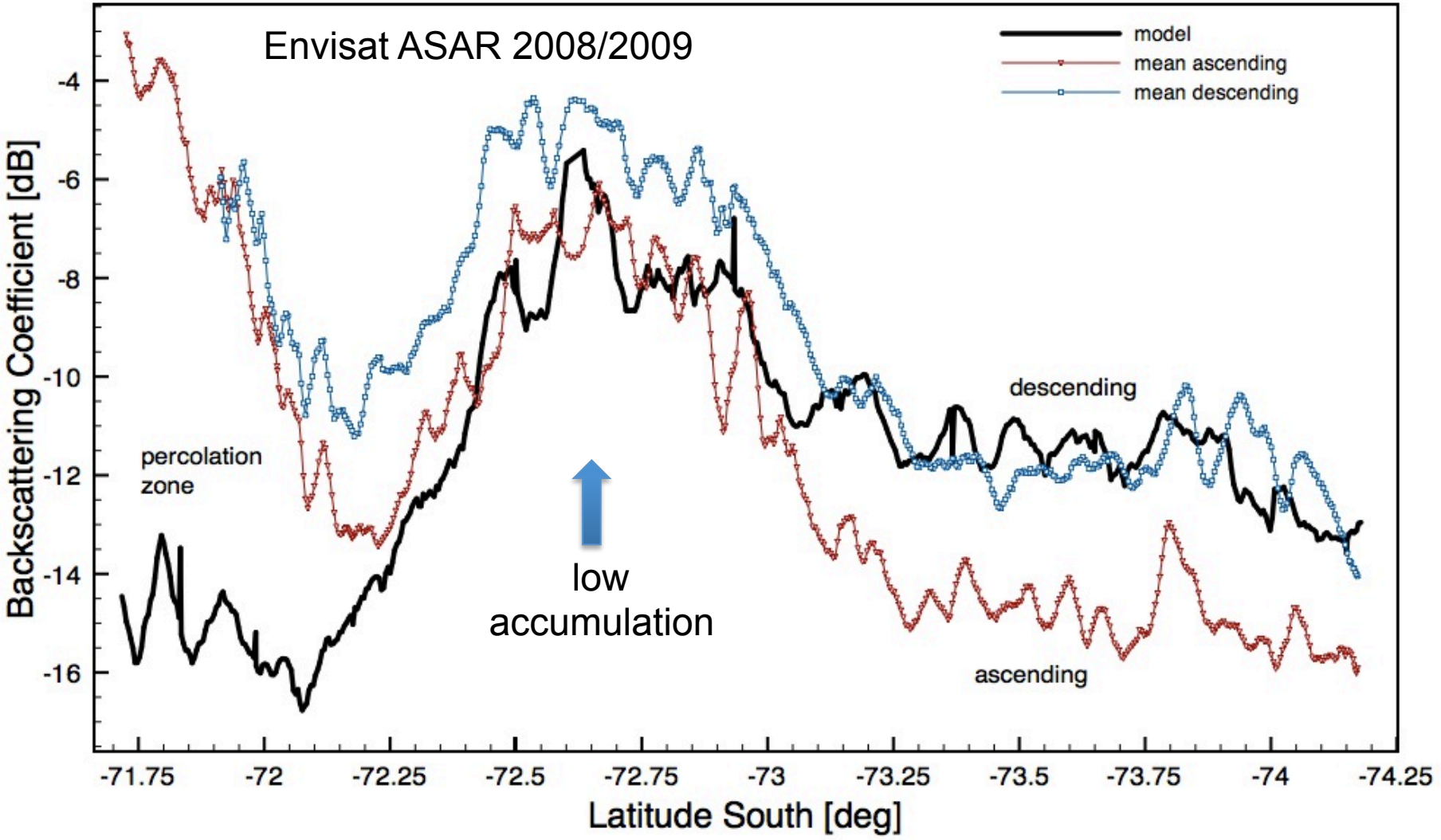


…to be validated by numerical simulations or measurements…

Qualitative agreement with scatterometer measurements by Kendra et al (1998) over artificial snow of density 0.5 g/cm^3.

Model Results Versus Satellite SAR Data

Comparison Modelled Vs. Measured Sigma_Nought



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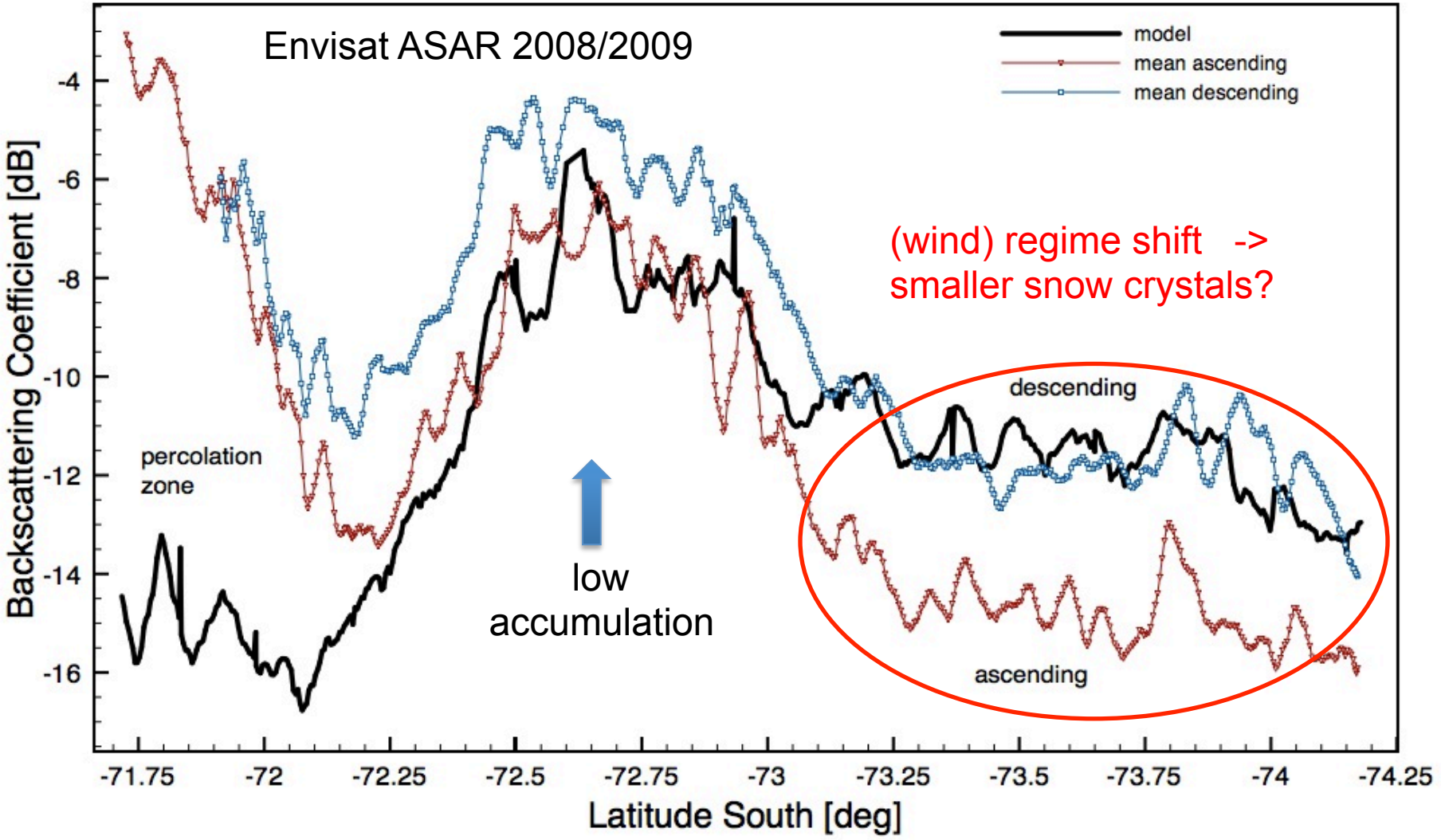
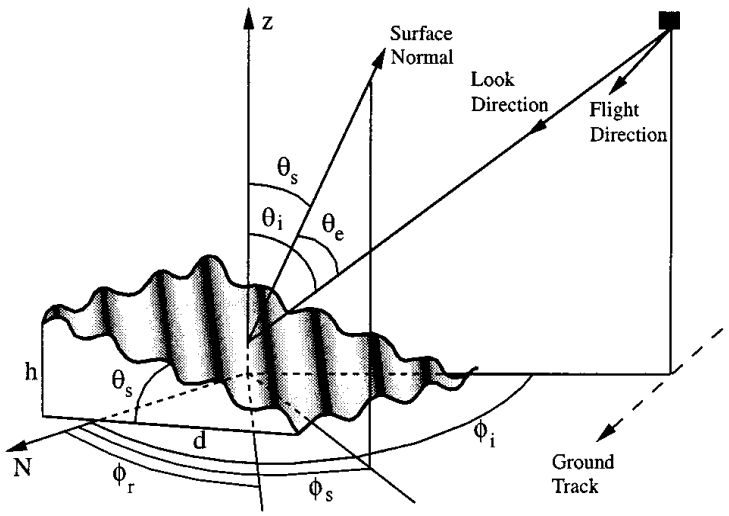
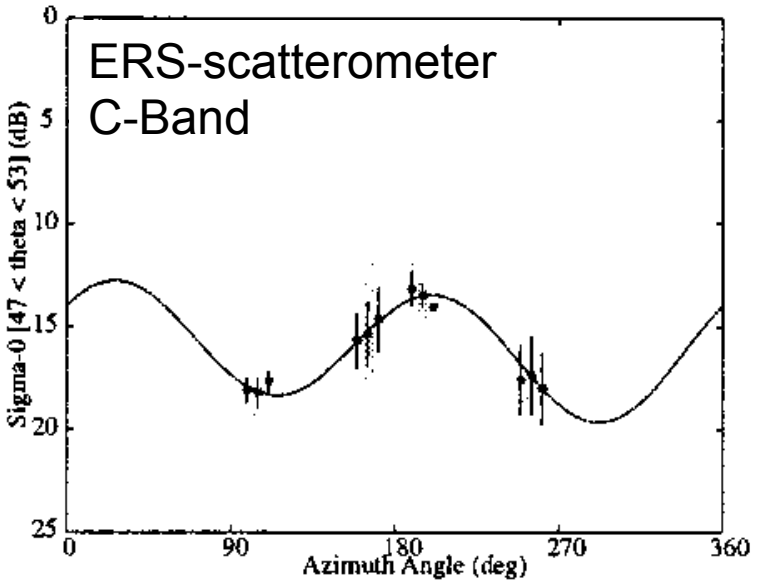


Azimuthal Modulation of σ^0 in Antarctica



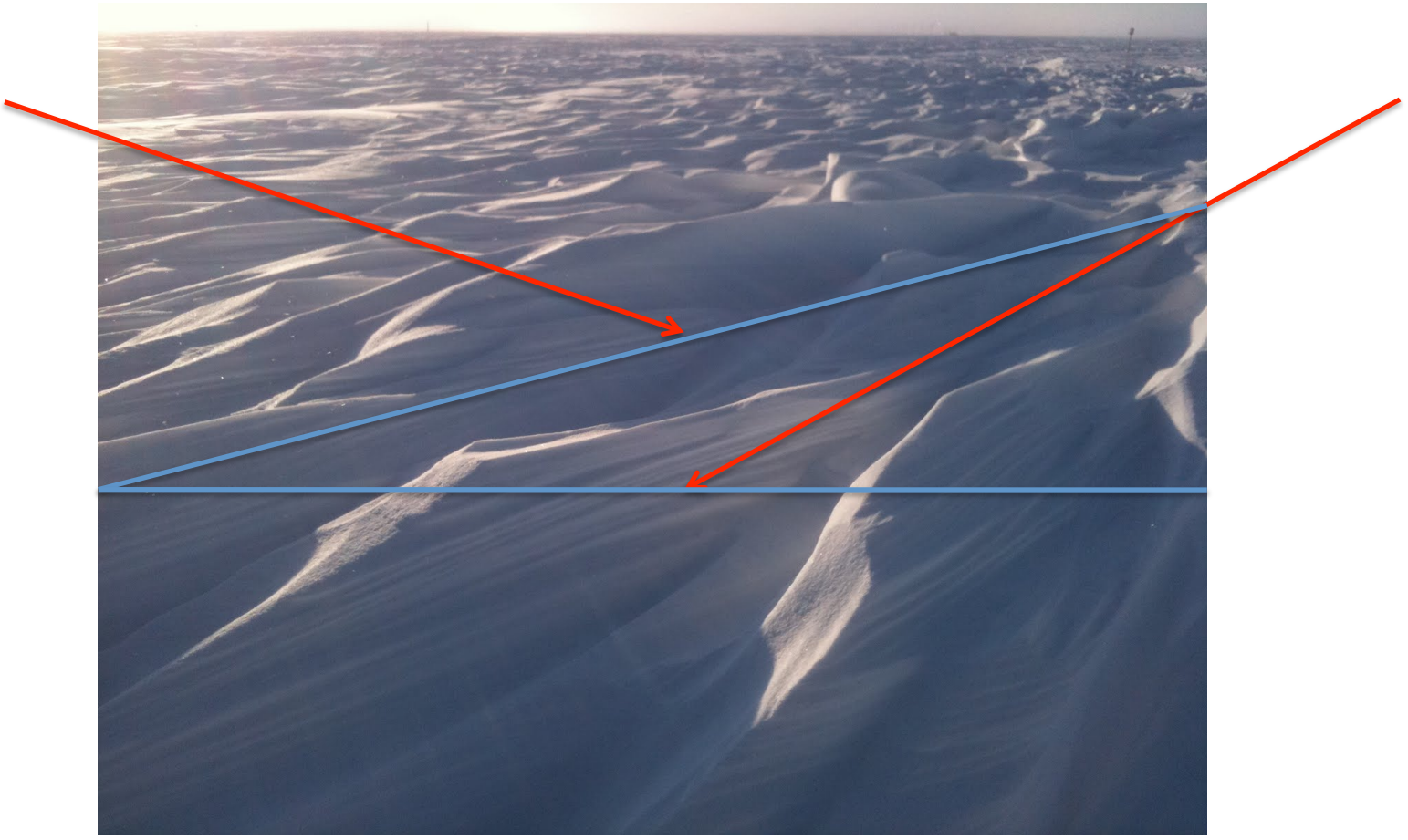


- measured σ^0 depends on sensor look direction
- strong link with wind-generated surface undulations
- depends on incidence angle

Long and Drinkwater, TGRS, 2000

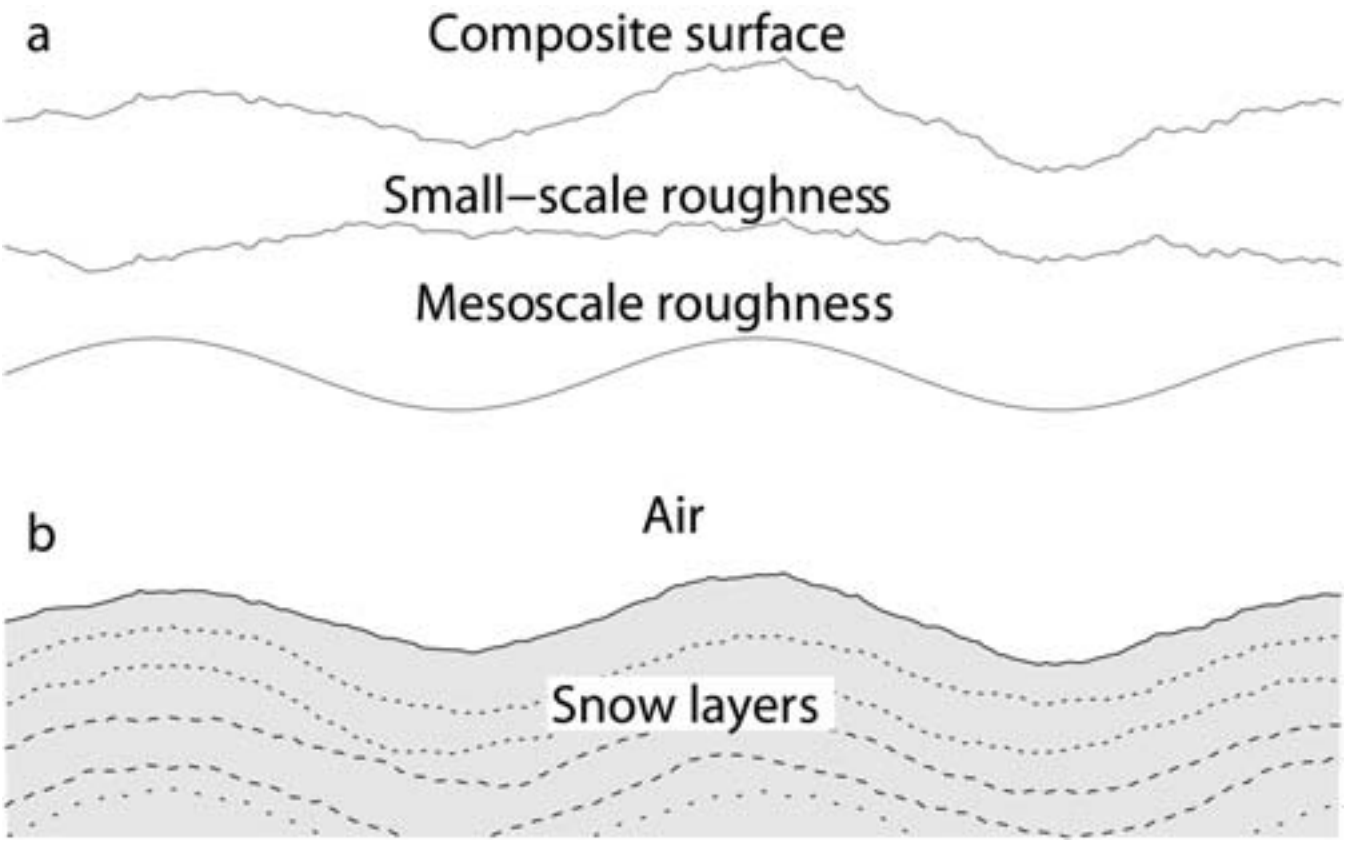
Reason For Azimuthal Dependence?

Surface undulations: sastrugi



- high intensity if radar look direction perpendicular to crests
- low intensity if radar look direction parallel to crests

How to Model Surface/Interface Scattering?



From Ashcraft & Long, J. Glac., Vol. 52, No. 177, 2006

How to Model Surface/Interface Scattering?

Small scale surface roughness:
"Surface roughness parameters represent an equivalent single layer roughness estimate for a multi-layer surface"

Depth hoar layers forming interfaces in the snow?

Until now no convincing model exists for explaining the azimuthal variation of radar intensity…

New Data For Kottas Traverse

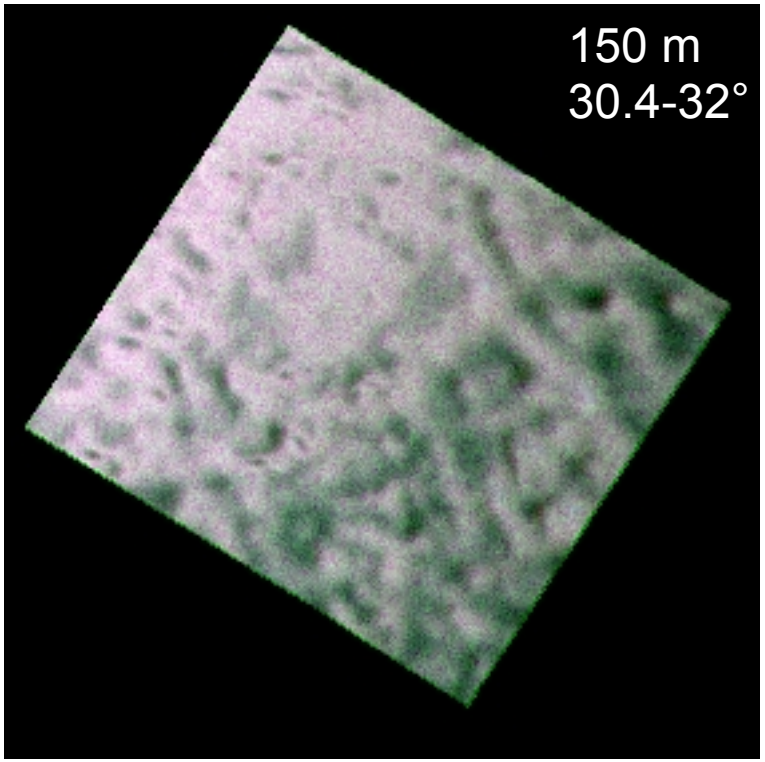
Multi-frequency, multi-polarization data: additional information for model development and accumulation rate retrieval ?

- 6 RS-2 scenes from SOAR-EU, quad-pol.
  - January 2012
  - 5 ascending, 1 descending
  - incidence angle 30.4-32°, pixel 25 m
- 18 TSX scenes from MTH0123, SM HH+VV
  - February – April 2013
  - 10 ascending, 8 descending
  - incidence angles 27.5-33.4, pixel 10 m

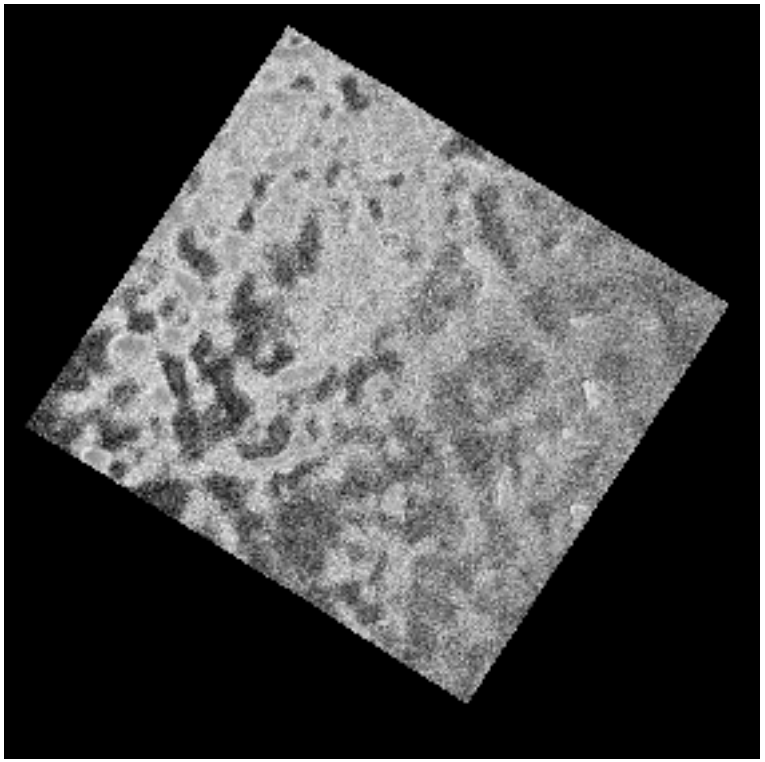
Spatial Distribution Intensity & Phase

Radarsat-2

42,5 km



Backscattering Coefficient [dB]
R – cross-pol., G-HH, B-VV



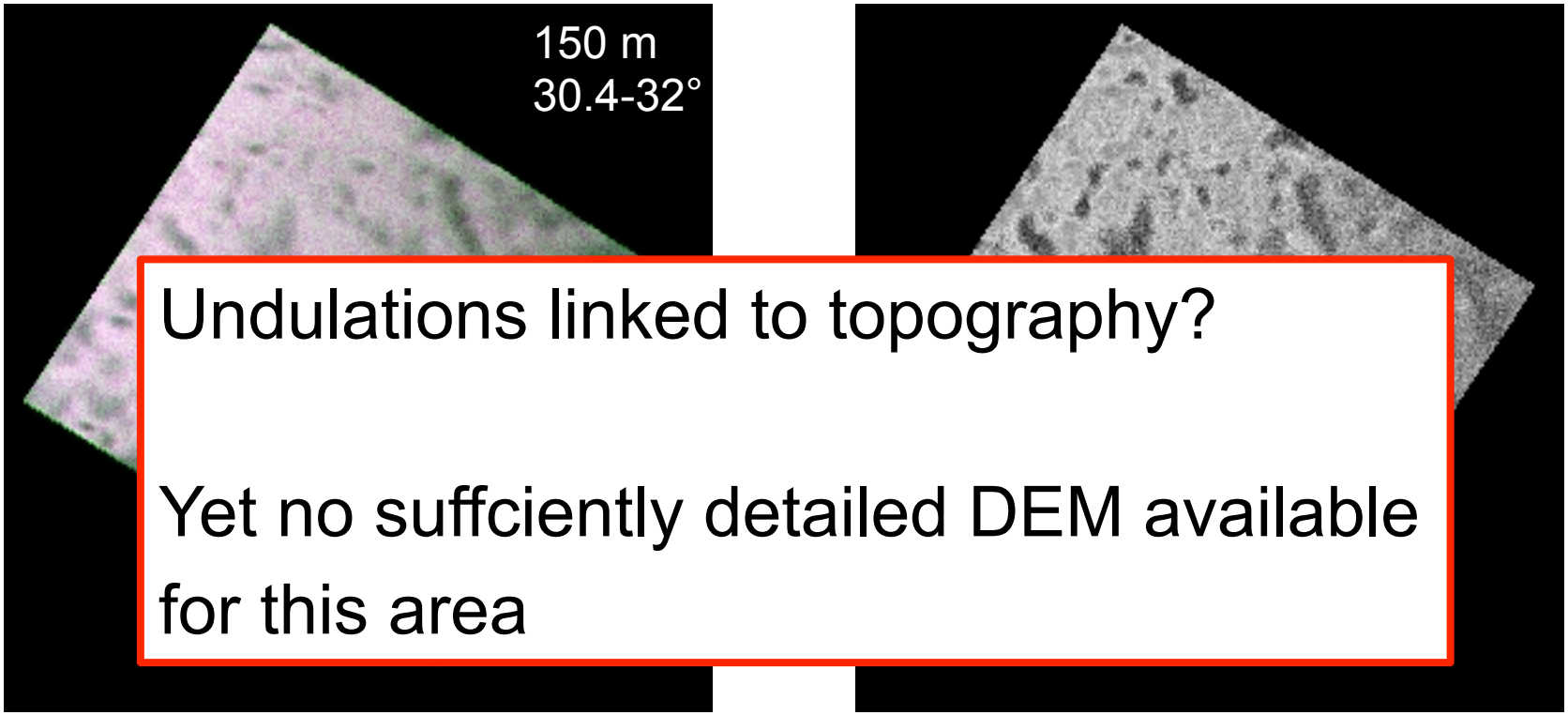
Phase Difference HH-VV [rad]

Kottas-Traverse, FQP 2012/01/24 72.76°S 9.53°W – 73.0°S 9.60°W

Spatial Distribution Intensity & Phase

Radarsat-2

42,5 km



Undulations linked to topography?

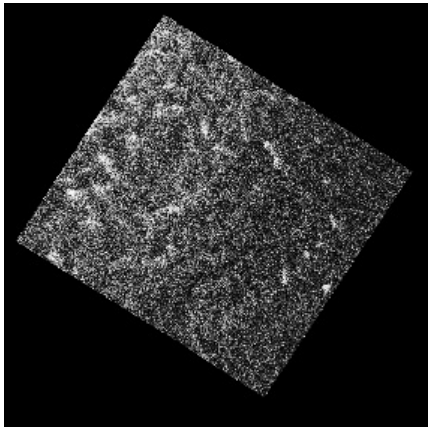
Yet no suffciently detailed DEM available for this area

Backscattering Coefficient [dB]
R – cross-pol., G-HH, B-VV

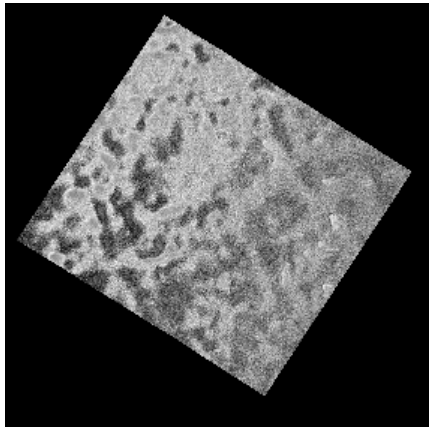
Phase Difference HH-VV [rad]

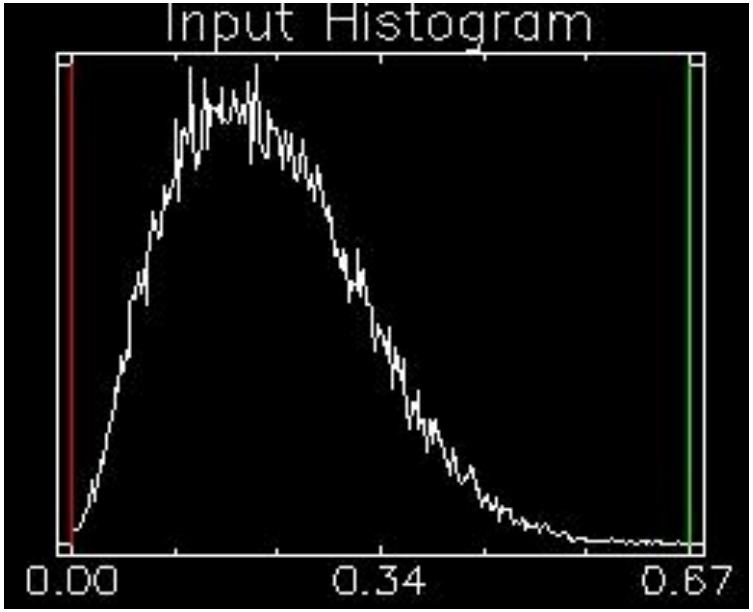
Kottas-Traverse, FQP 2012/01/24 72.76°S 9.53°W – 73.0°S 9.60°W

Histograms Correlation & Phase

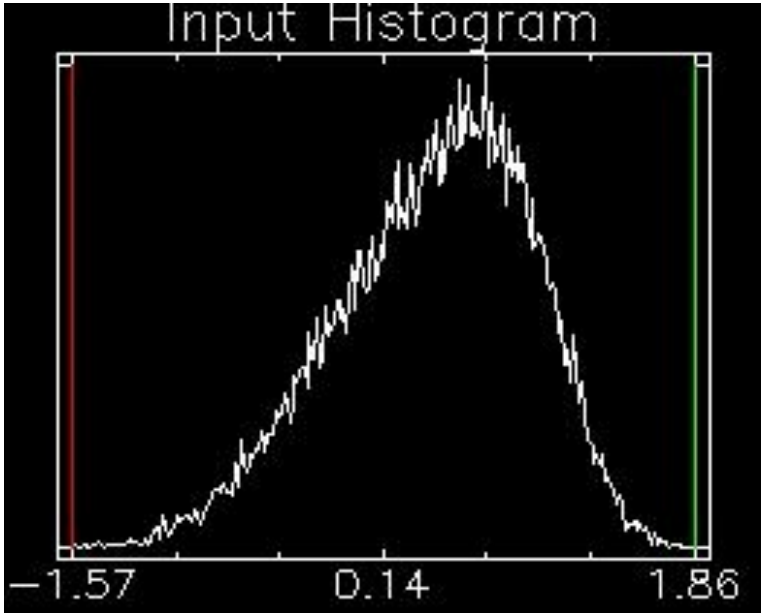


Radarsat-2





Correlation Coefficient

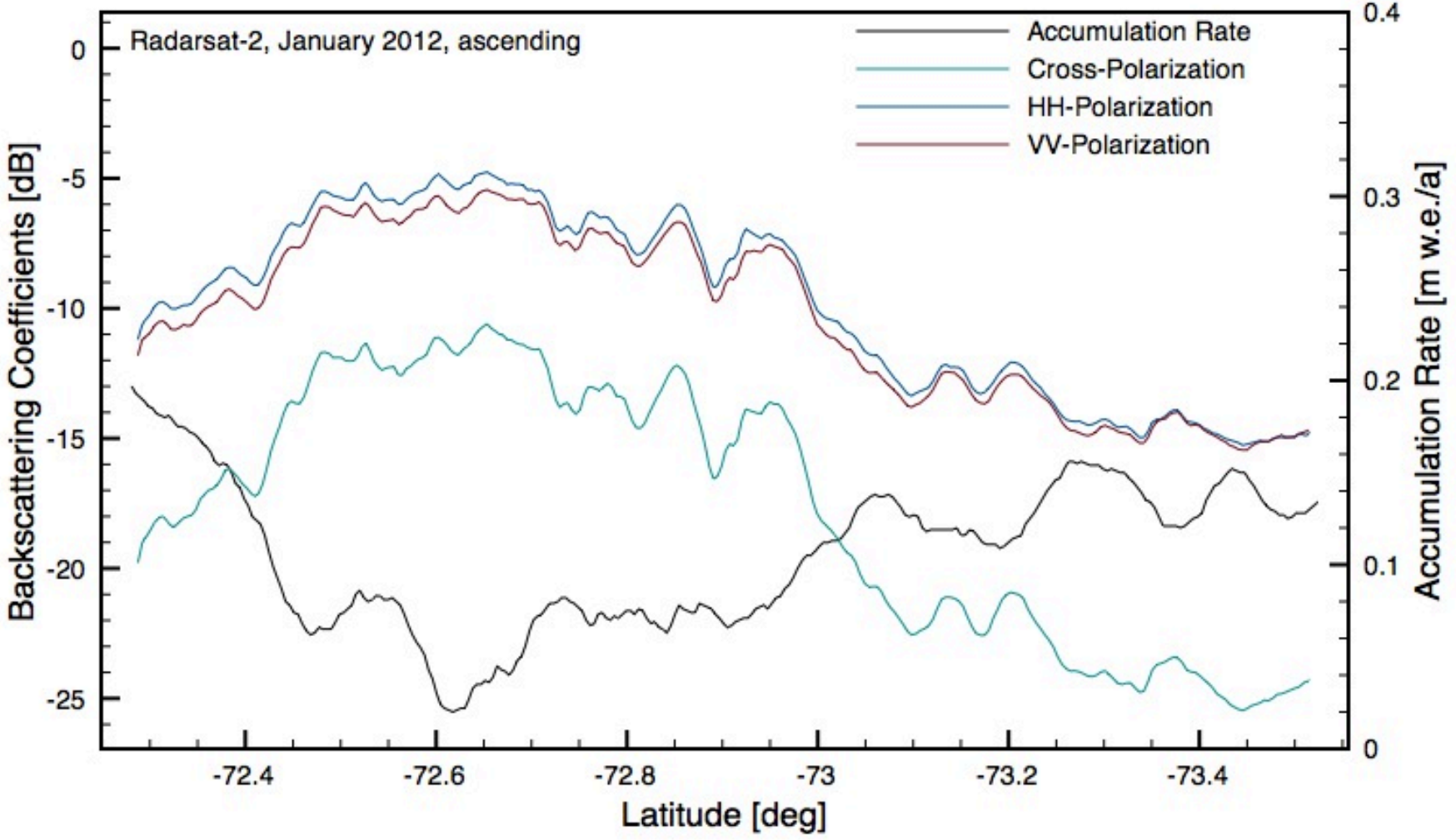


Phase Difference HH-VV [rad]

Kottas-Traverse, FQP 2012/01/24 72.76°S 9.53°W – 73.0°S 9.60°W

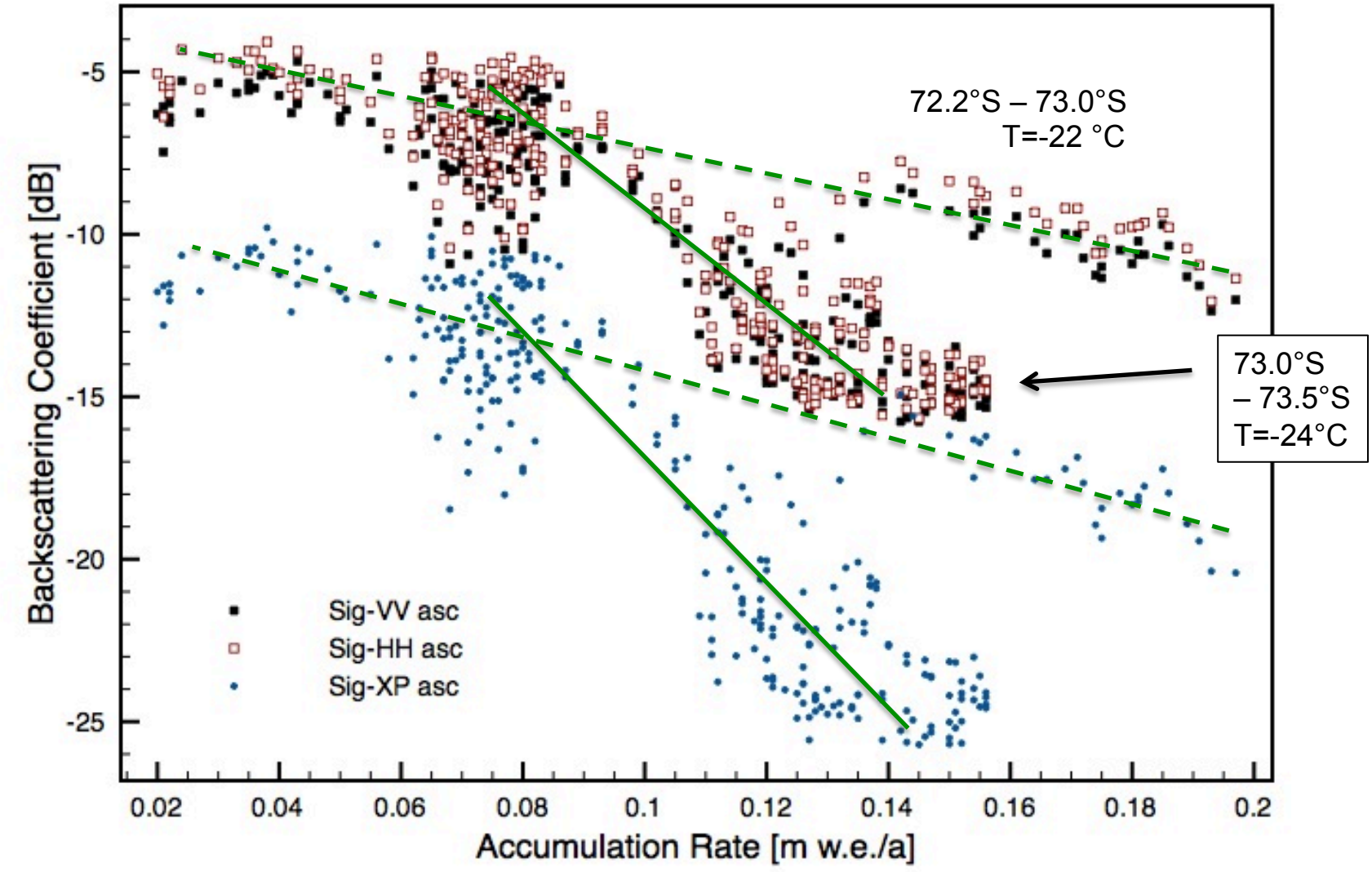
C-Band Radar Intensity Over Kottas-Traverse

Radarsat-2 FQP data



Radar Intensity Versus Accumulation Rate

Radarsat-2



Radar Intensity Versus Accumulation Rate

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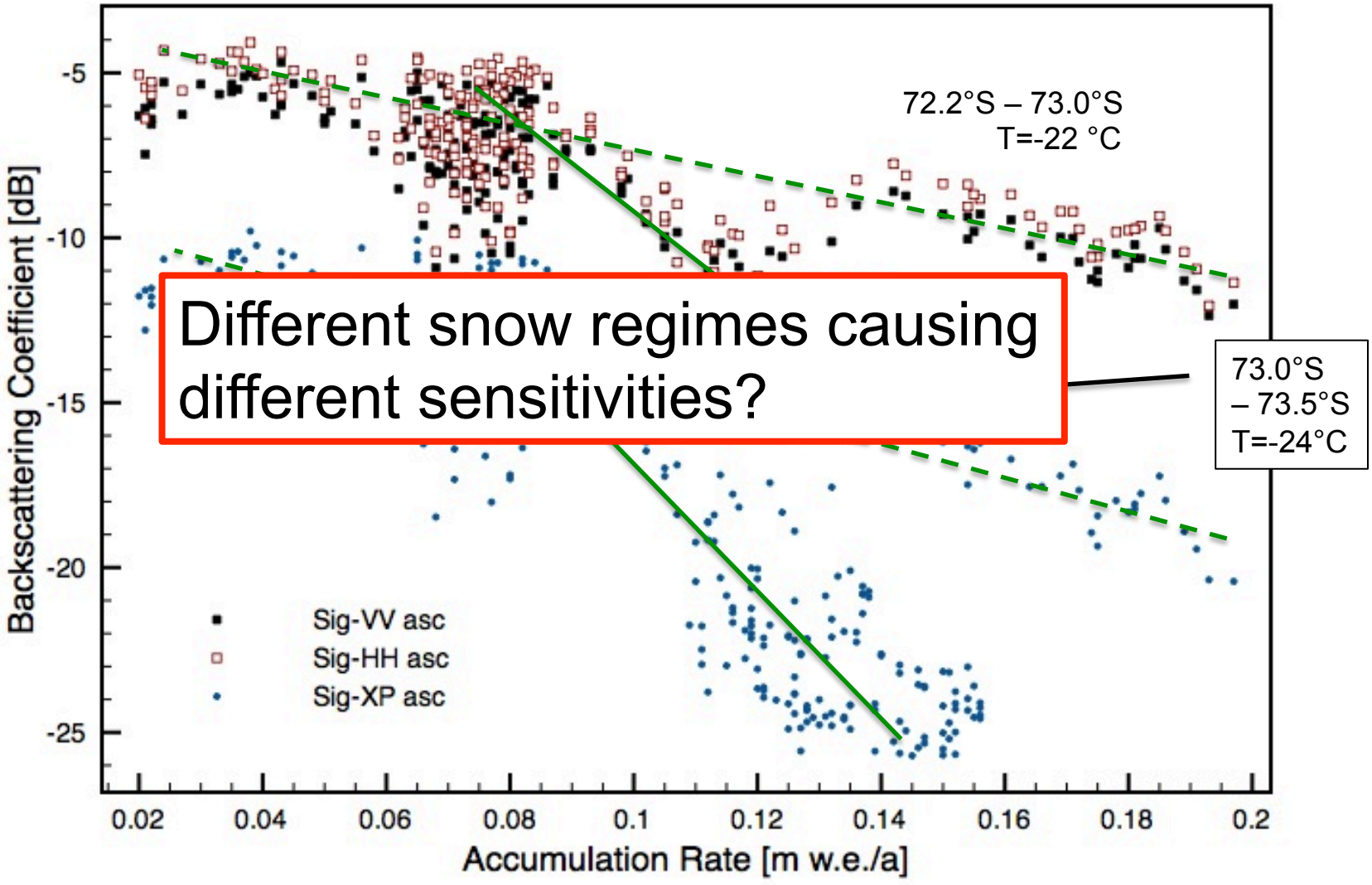
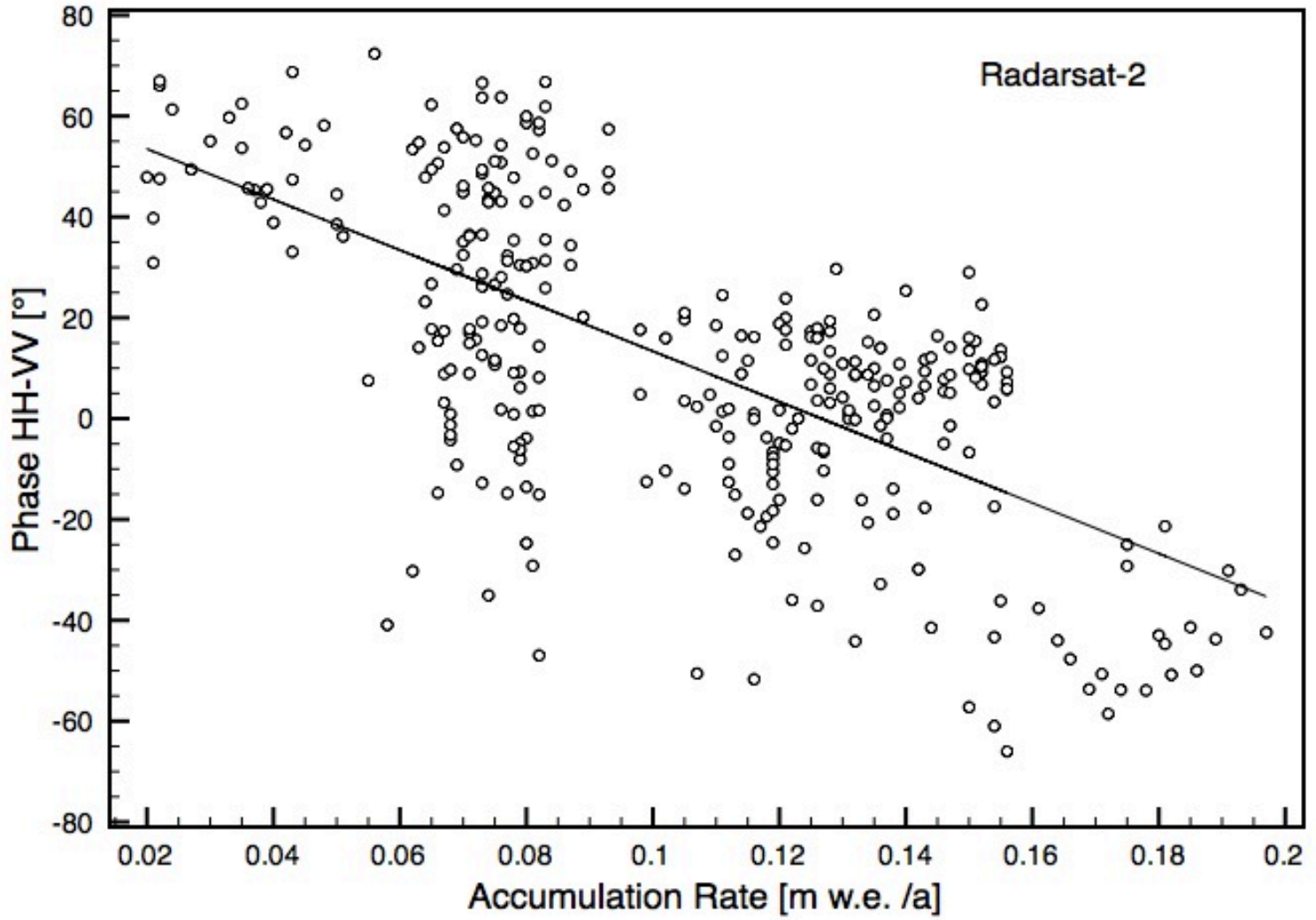


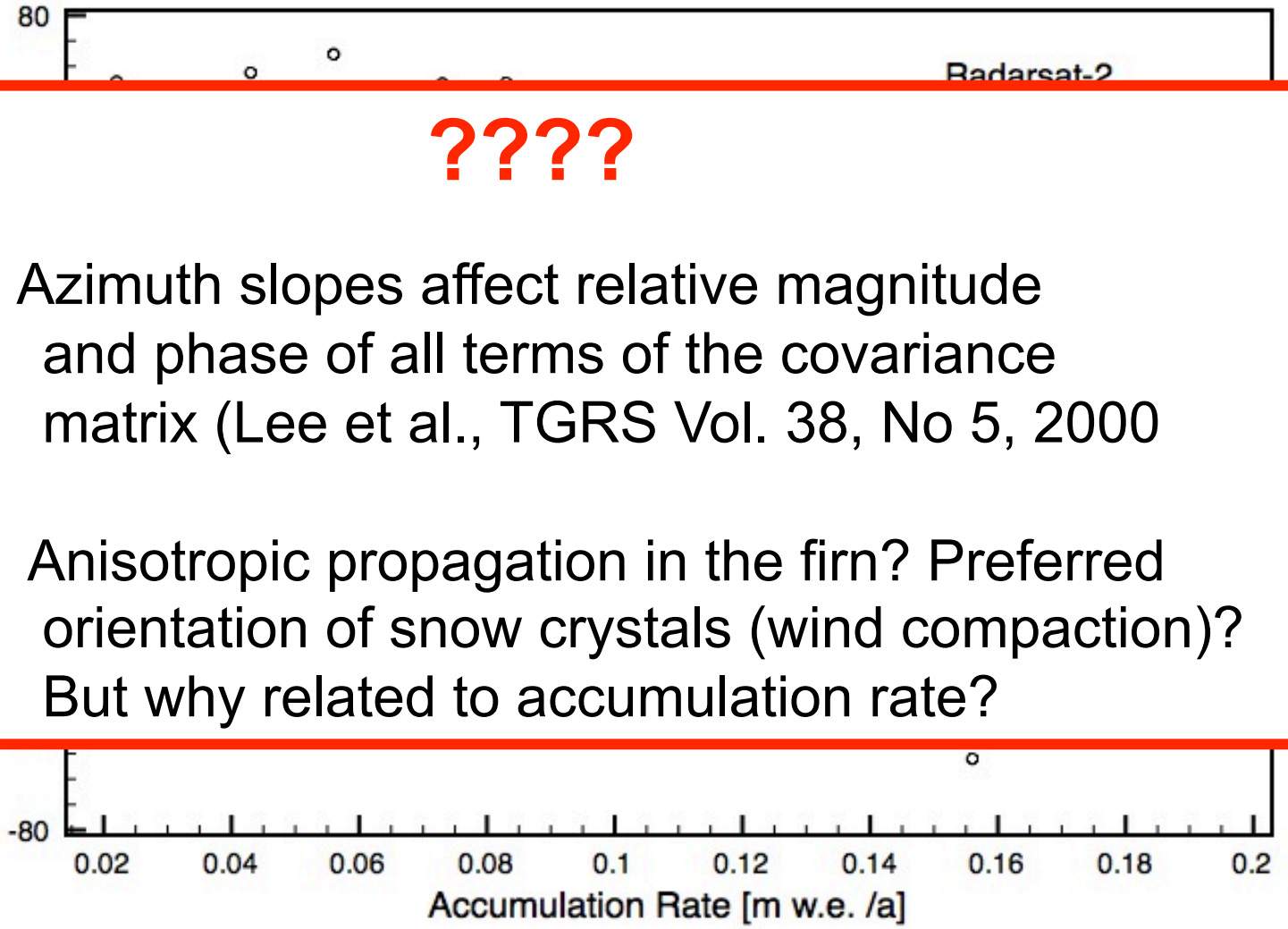
Phase HH-VV vs. Accumulation Rate

Radarsat-2



Phase HH-VV vs. Accumulation Rate

Radarsat-2



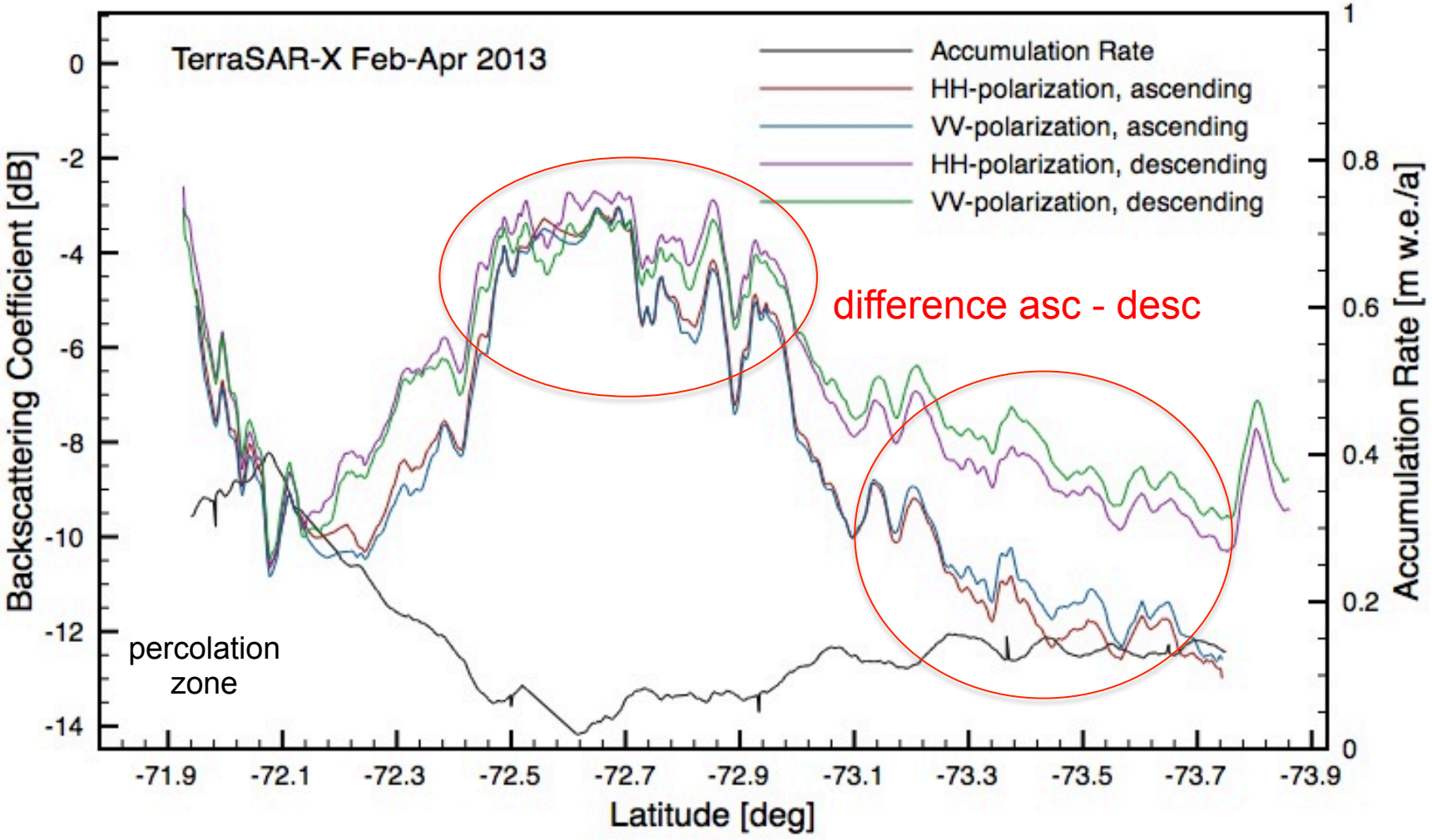
????

- Azimuth slopes affect relative magnitude and phase of all terms of the covariance matrix (Lee et al., TGRS Vol. 38, No 5, 2000

- Anisotropic propagation in the firn? Preferred orientation of snow crystals (wind compaction)? But why related to accumulation rate?

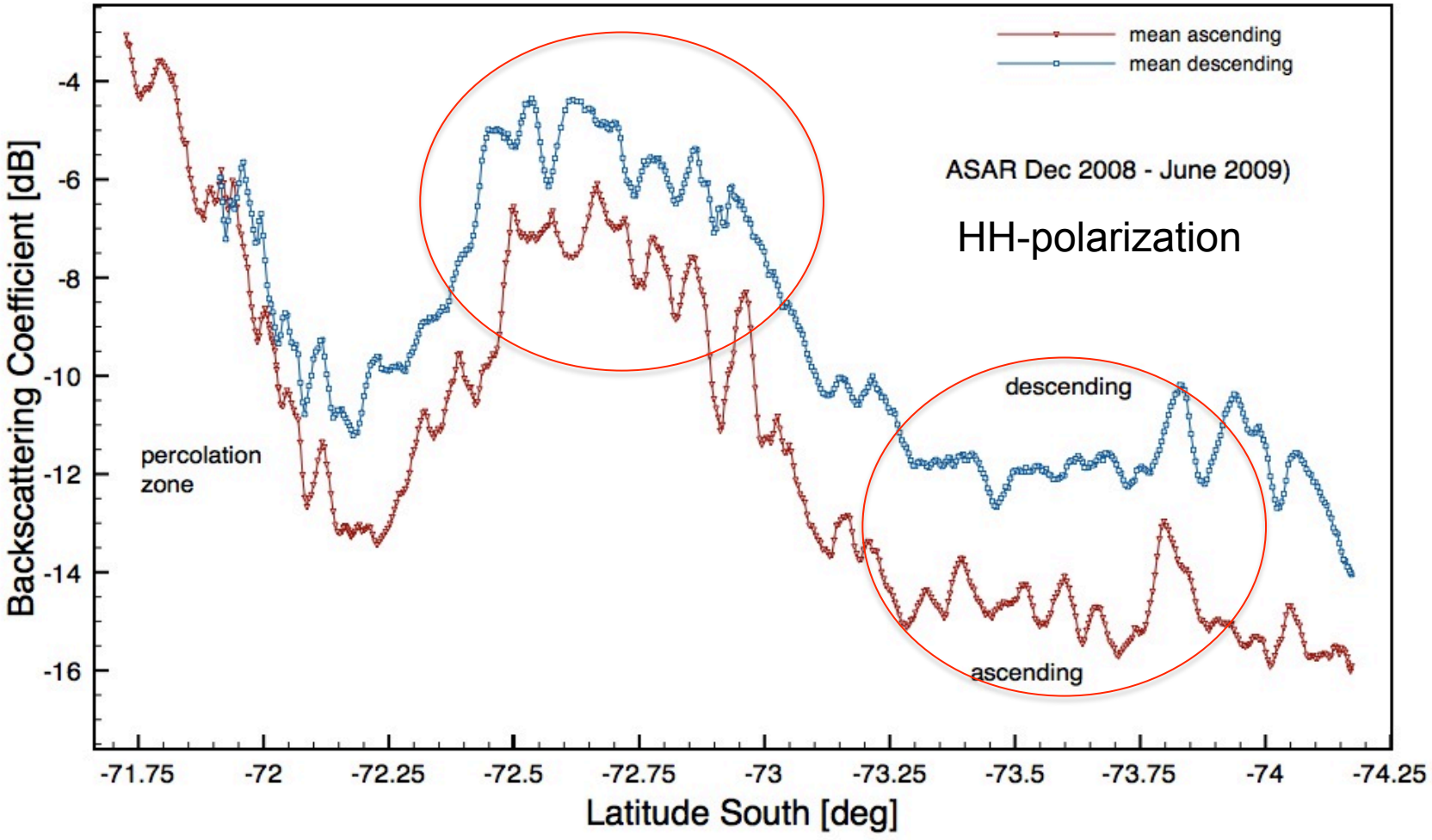
X-Band Radar Intensity Over Kottas-Traverse

TerraSAR-X SM Dual-Pol.



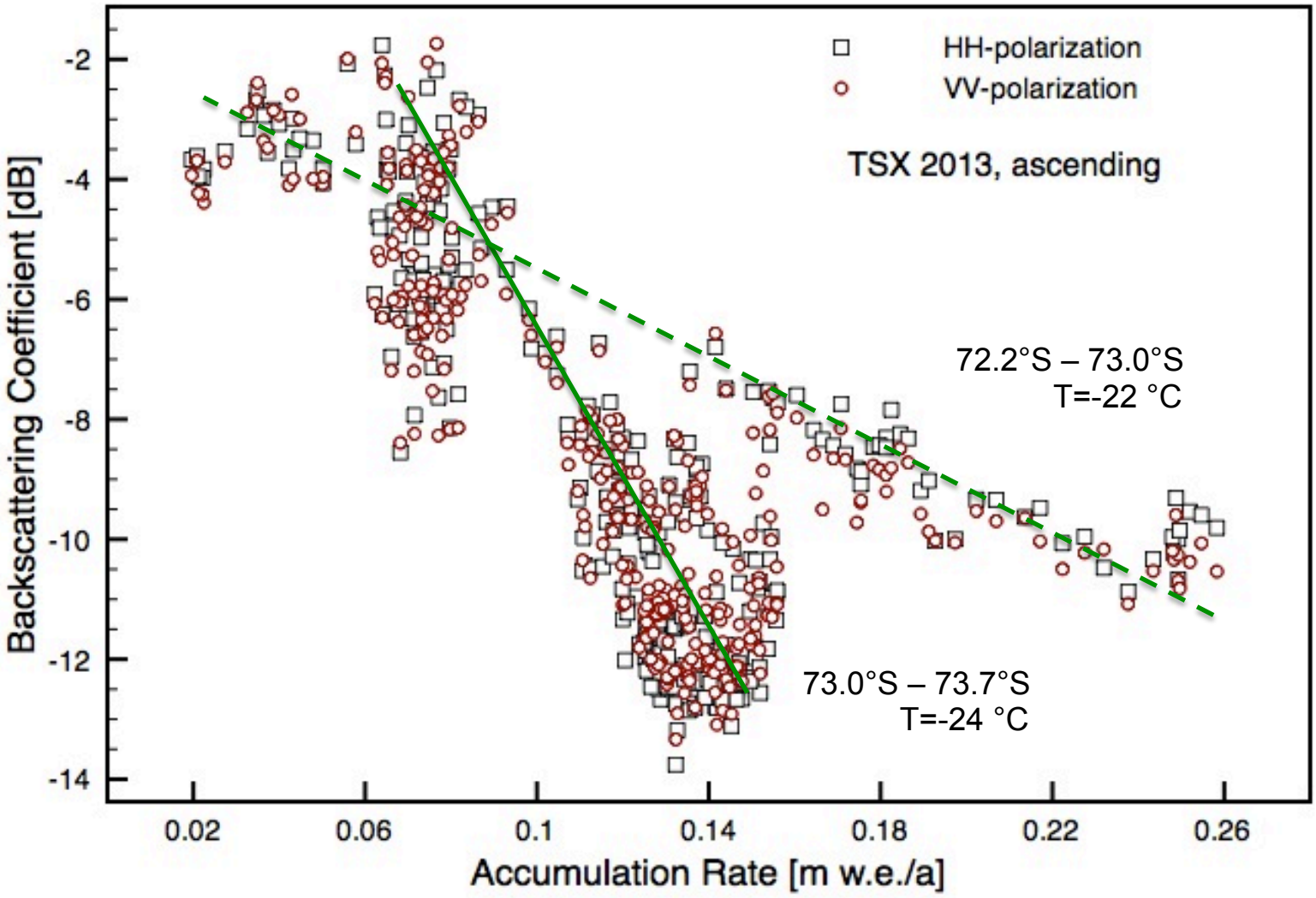
Difference Ascending – Descending (C-Band)

Envisat ASAR



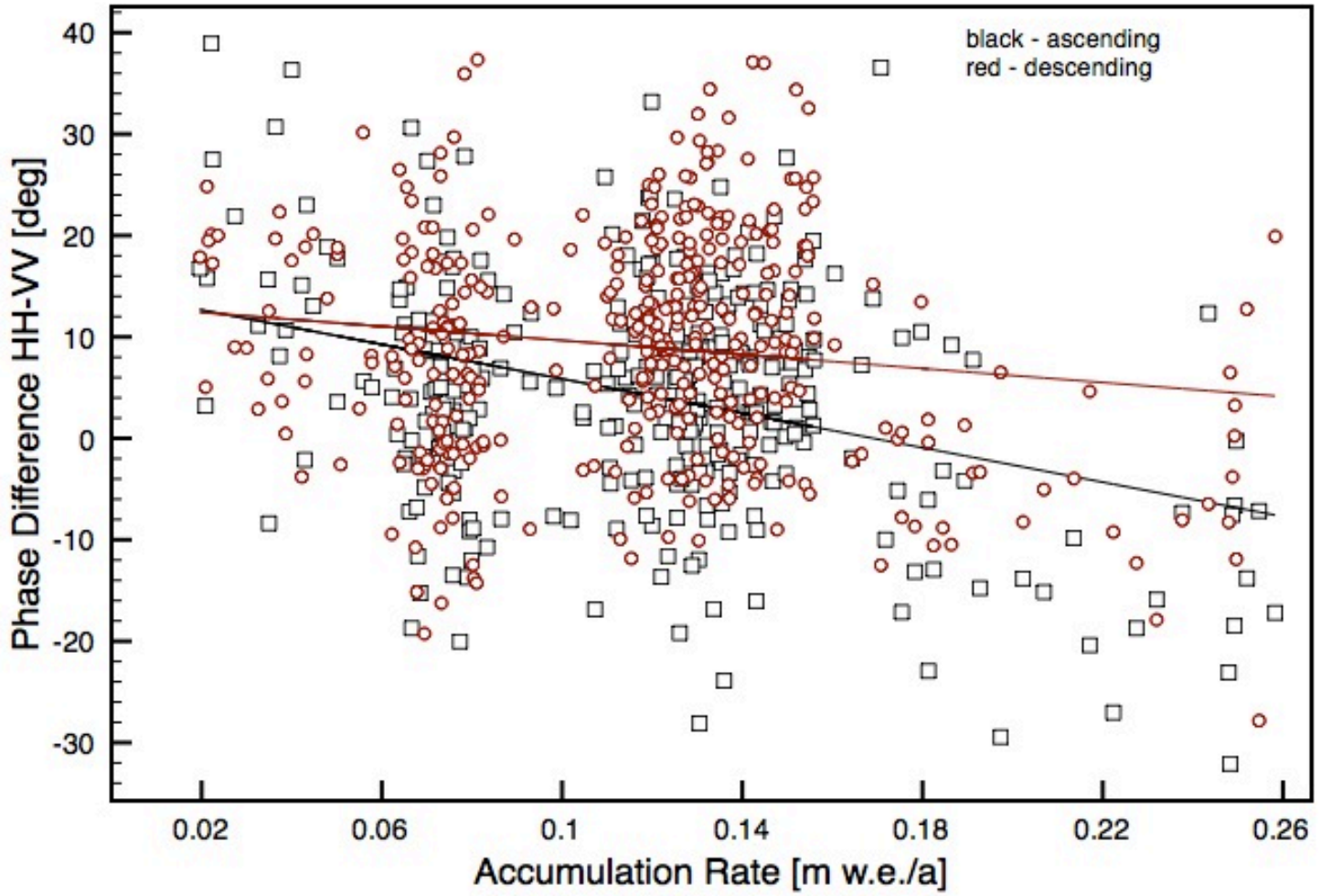
Radar Intensity Versus Accumulation Rate

TerraSAR-X



Phase HH-VV vs. Accumulation Rate

TerraSAR-X



Summary

Results from RS-2 and TSX-images

- Sensitivity to accumulation rate:
  Snow-regime dependent ?
  C-band: cross-pol more sensitive than like-pol.
  C- and X-band like-pol comparable

- Azimuthal modulation:
  Different between X- and C-band

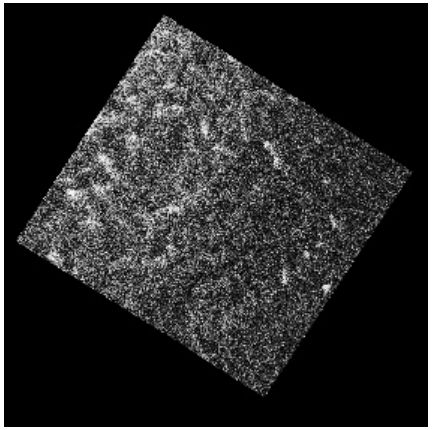
- Phase difference HH-VV: change as function of accumulation rate is significant at C-band, but not at X-band.

Problems

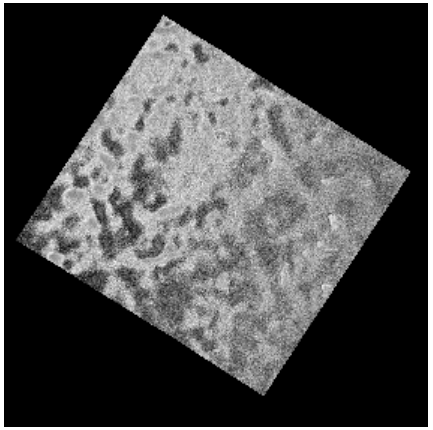
- Noisy data! Problem for robust retrieval.
- Is sensitivity of σ^0 to accumulation rate large enough?
- Modelling: Checking “bridging“ zone
- Azimuthal modulation, difference C+X-band: reason?
- Model for explaining azimuthal modulation?
- Snow metamorphosis: parameterization of snow regimes?
- Phase difference HH-VV: Explanation for observations?

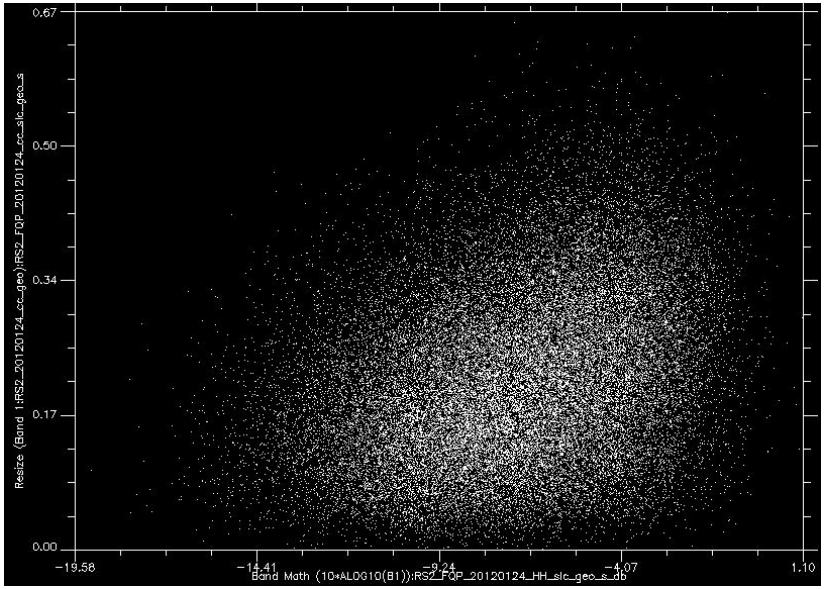

Thank you for your attention!

Correlation & Phase Versus Intensity

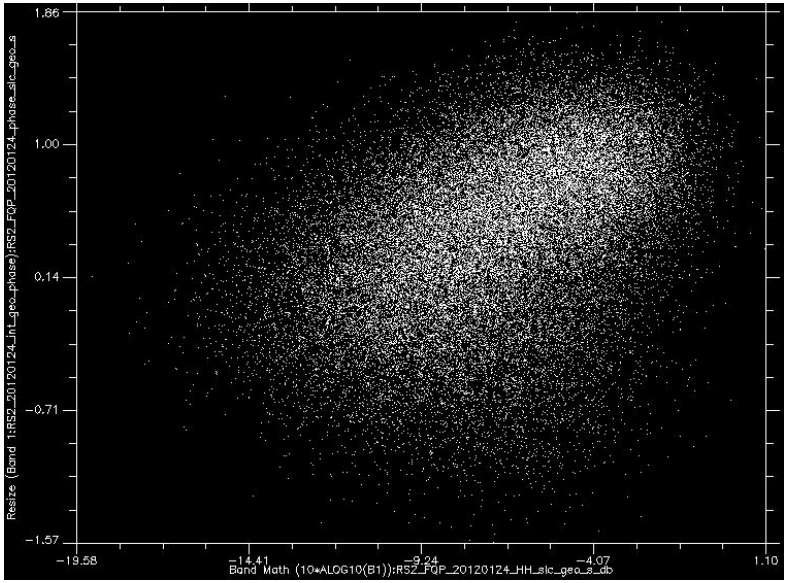


Radarsat-2





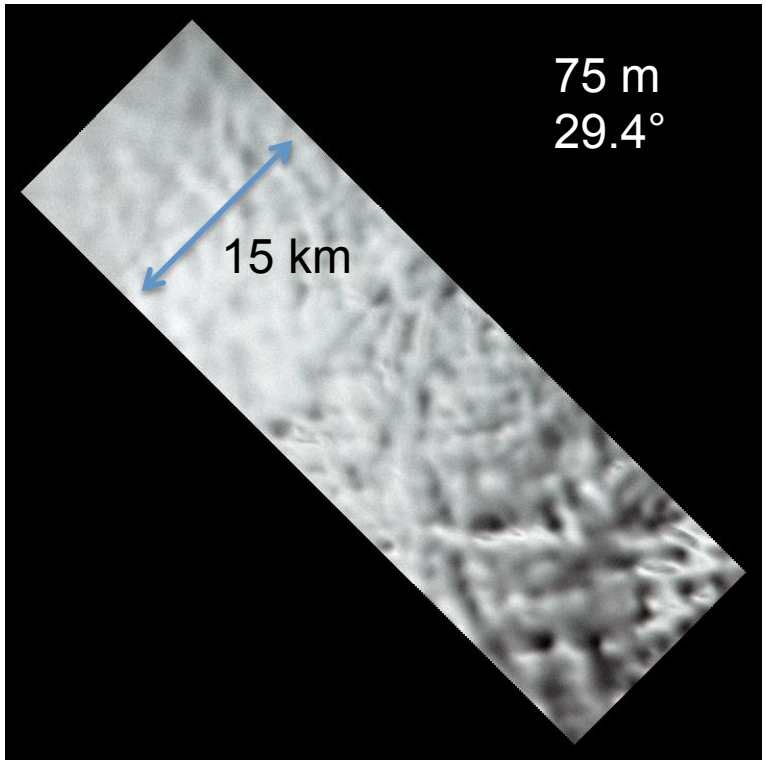
Correlation Coefficient

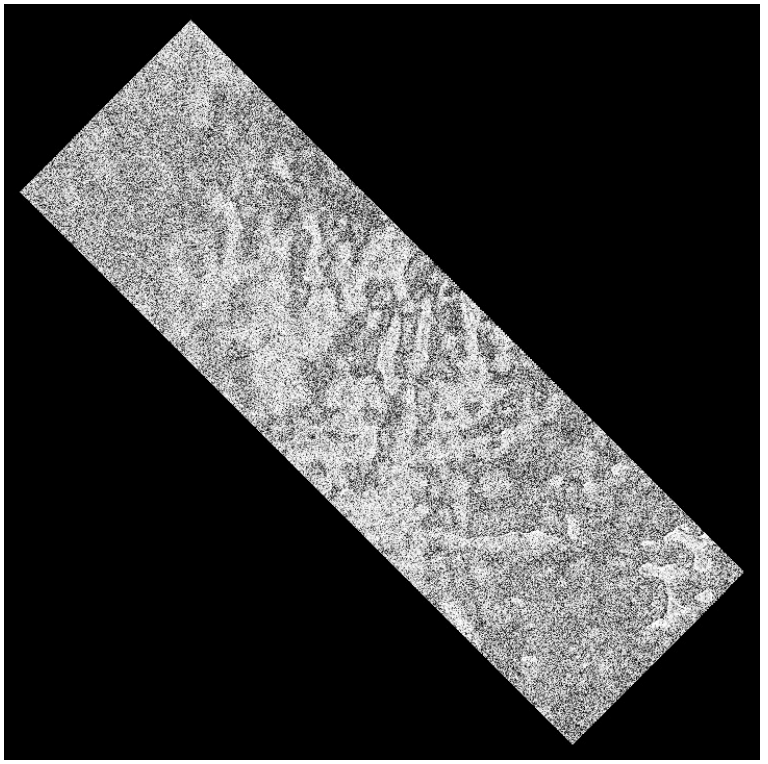


Phase Difference HH-VV [rad]

Spatial Distribution Intensity & Phase

TerraSAR-X



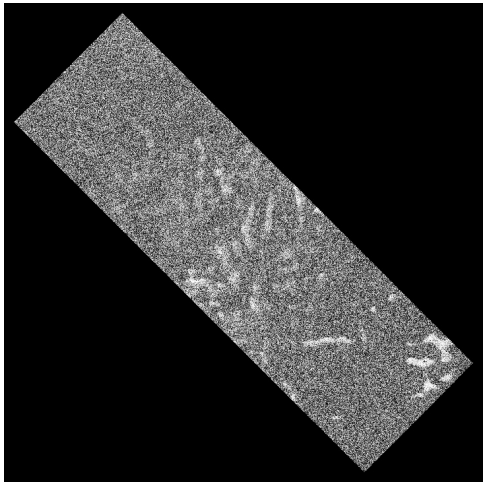


Backscattering Coefficient [dB]
R – VV, G-HH, B-HH

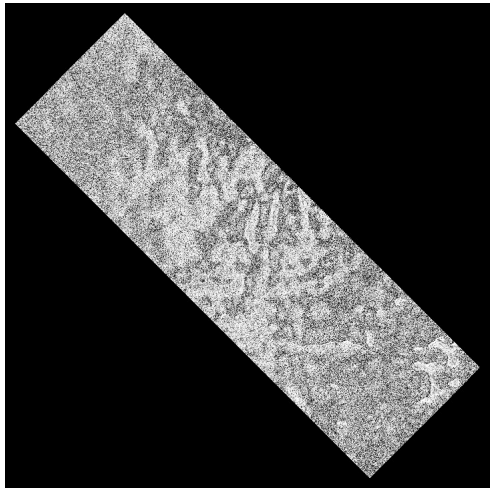
Phase Difference HH-VV [rad]

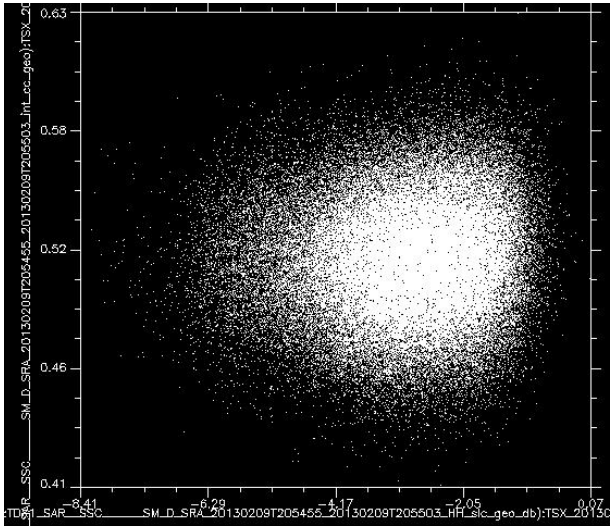
Kottas-Traverse, 2013/02/09 Center 72.65°

Correlation & Phase Versus Intensity

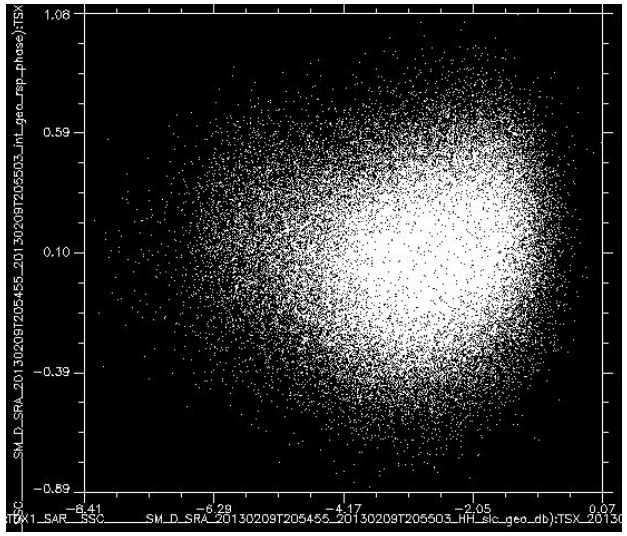


TerraSAR-X





Correlation Coefficient



Phase Difference HH-VV [rad]