POLINSAR 2013

The 6th International Workshop on Science and Applications of SAR Polarimetry and Polarimetric Interferometry

Snow property extraction based on polarimetry and differential SAR interferometry

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Earth Observation and Remote Sensing | ETH Zürich | FMI | NASA JPL | Environment Canada | WSL SLF | GAMMA REMOTE SENSING

28 January - 1 February 2013 | ESA-ESRIN | Frascati (Rome), Italy

European Space Agency

TerraSAR-X and TanDEM-X

A fantastic playground with many options.

SAR: Synthetic Aperture Radar

$\sigma_0 \cdot e^{i\phi}$
Single Look Complex (SLC)

$\phi_{VV} - \phi_{HH}$
polarimetic phase difference

$\phi_1 - \phi_2$
Interferometry

$\phi_{t+11d} - \phi_t$
multi pass interferometry

D-InSAR (change detection)

$\phi_{1,t} - \phi_{2,t}$
single pass interferometry

DEMs

σ_0: backscatter signal (microwave), single-, **dual-**, quad-pol (VV, HH, VH, HV)

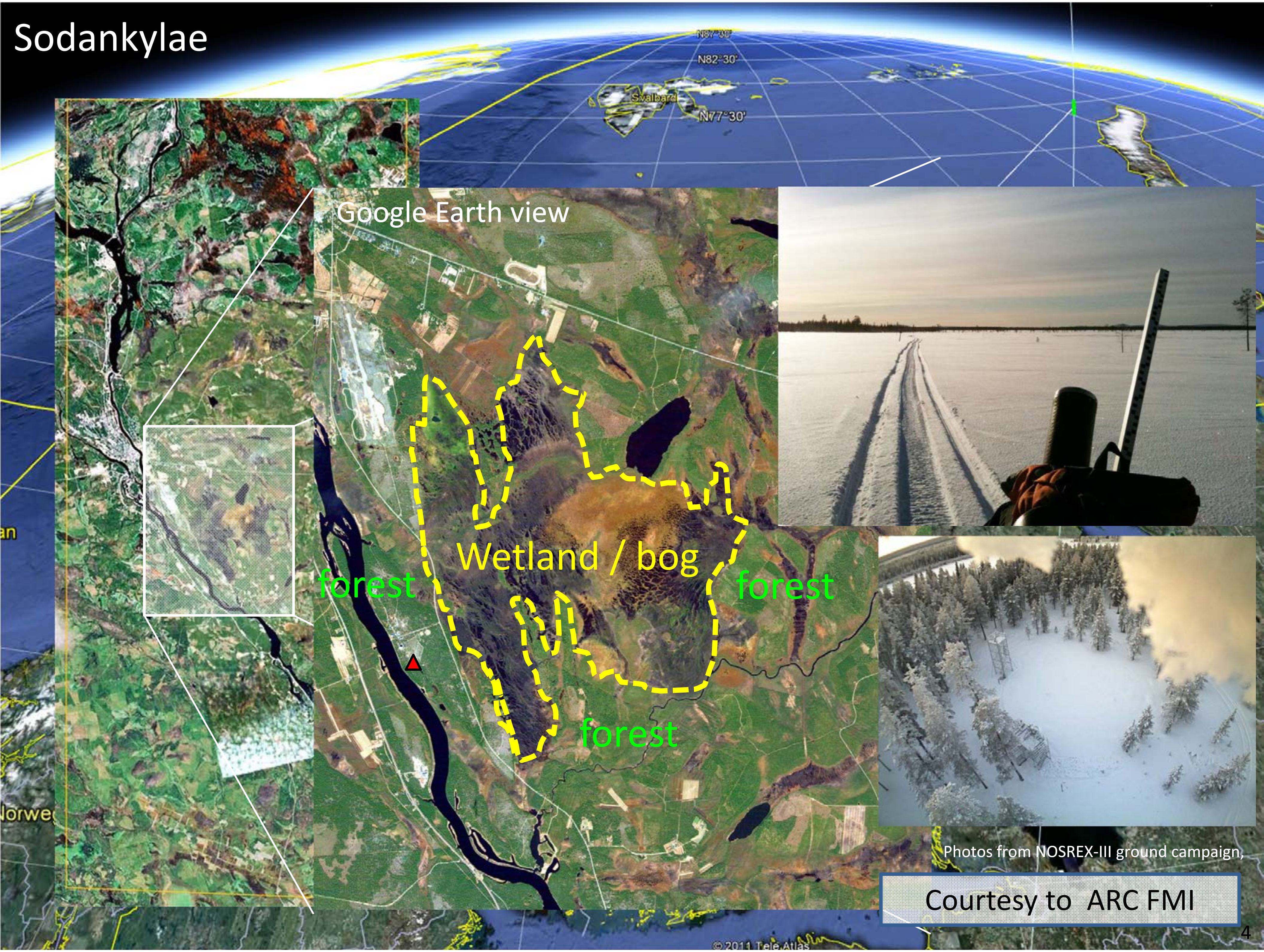
- X-Band: ν = 9.65 GHz, λ = 3 cm, Resolution: 3 m, Repeat cycle: 11 days
- Monostatic **multi-pass** Interferometry: Δt = 11 days
- Bistatic **single-pass** Interferometry: Δt = 0

Why Radar techniques for Snow?

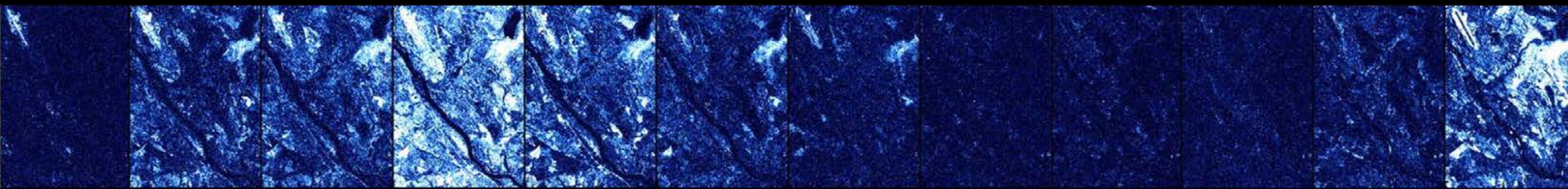
- Snow is a thin volume layer which is mostly transparent for microwave (T ≪ 0°C).
- High frequency required to get interaction and to avoid total penetration: 5 - 20 GHz.
- How can we characterize snow by means of the complex **interferometric coherence**?

$$\hat{\gamma} = \gamma \cdot e^{i\varphi} = \frac{\langle S_1 \cdot S_2^* \rangle_{\text{ens.}}}{\sqrt{\langle |S_1|^2 \rangle \langle |S_2|^2 \rangle}}$$

- What causes **polarimetric phase differences** and **temporal decorrelation**?
- Under which conditions can we characterize snow?
  - ➢ Snow fall, melting, temperature change and wind drift cause high **temporal variations**!
  - Which parameters do we get?
    - Snow / no snow?
    - Snow depth?
    - Snow water equivalent?
    - Water content?
    - Stratigraphy?
    - Soil information?


Sodankylae
N87°30'
N82°30'
Svalbard
N77°30'
Google Earth view
Wetland / bog
forest
forest
forest
Photos from NOSREX-III ground campaign,
Courtesy to ARC FMI
© 2011 Tele Atlas

Sodankylae 2012: Repeat pass coherence (Δt = 11 d)

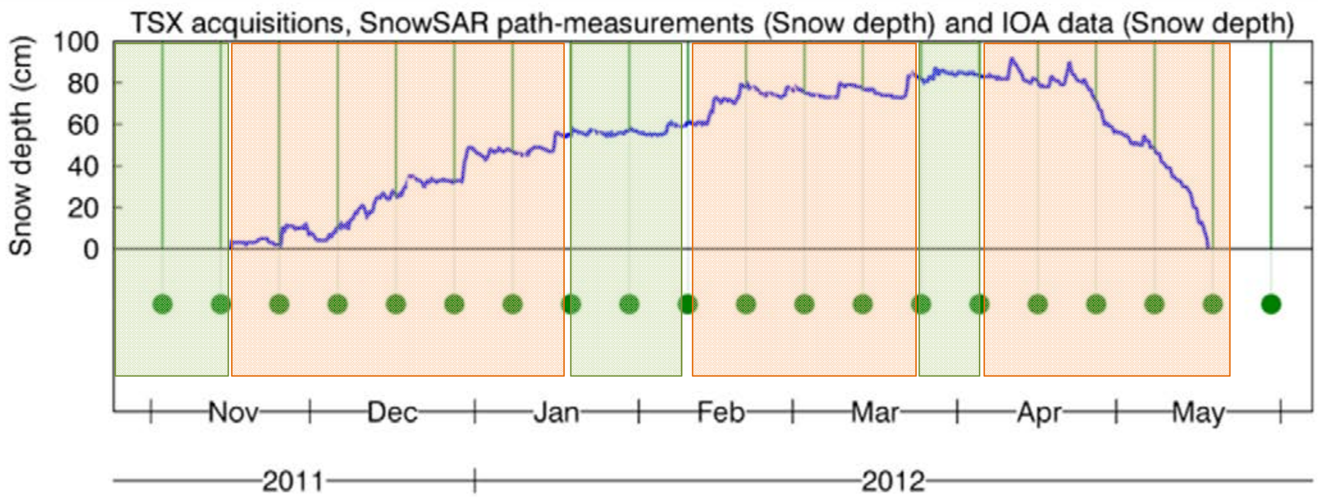


May | Oct. 01 | Oct. 12 | Oct. 23 | Nov. 03 | Nov. 14 | Nov. 25 | Dec. 06 | Dec 17 | Dec. 28 | Jan. 08 | Jan. 19 | 30th

+3°C, no snow

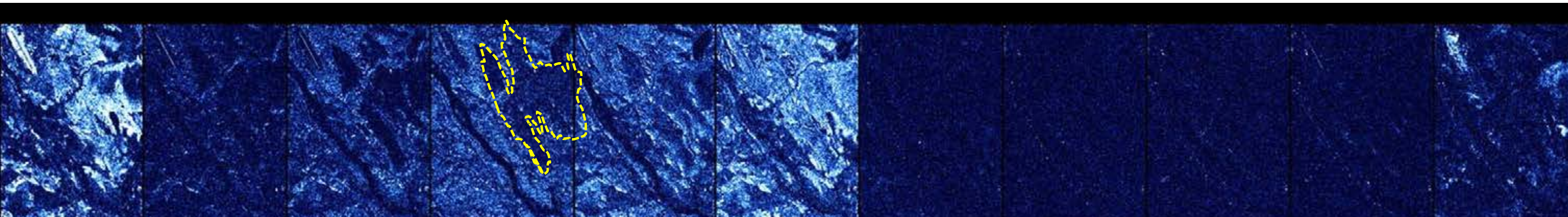
Accumulating snow … . . . .

-10°.. -30°C



Meadows and frozen wetland:

- low coherence → snowing or melting.
- Further interpretation (RVoG, etc.) difficult due to γ_{temp}.



30th | Feb. 10 | Feb. 21 | Mar. 03 | Mar. 14 | Mar. 25 | Apr. 05 | Apr. 16 | Apr. 27 | May 08 | May 19 | 30th

stable weather

+20 cm snow

+10 cm snow

+10 cm snow

cold stable weather, snow depth: 80 cm

Setting …

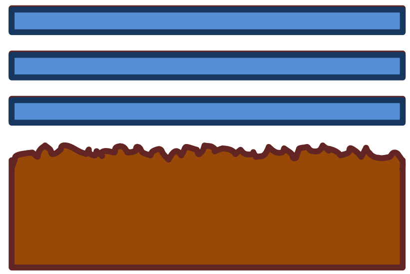
. . . . Melting… . . . .

No snow left, +10°C

Polarimetric Phase Difference (PPD)

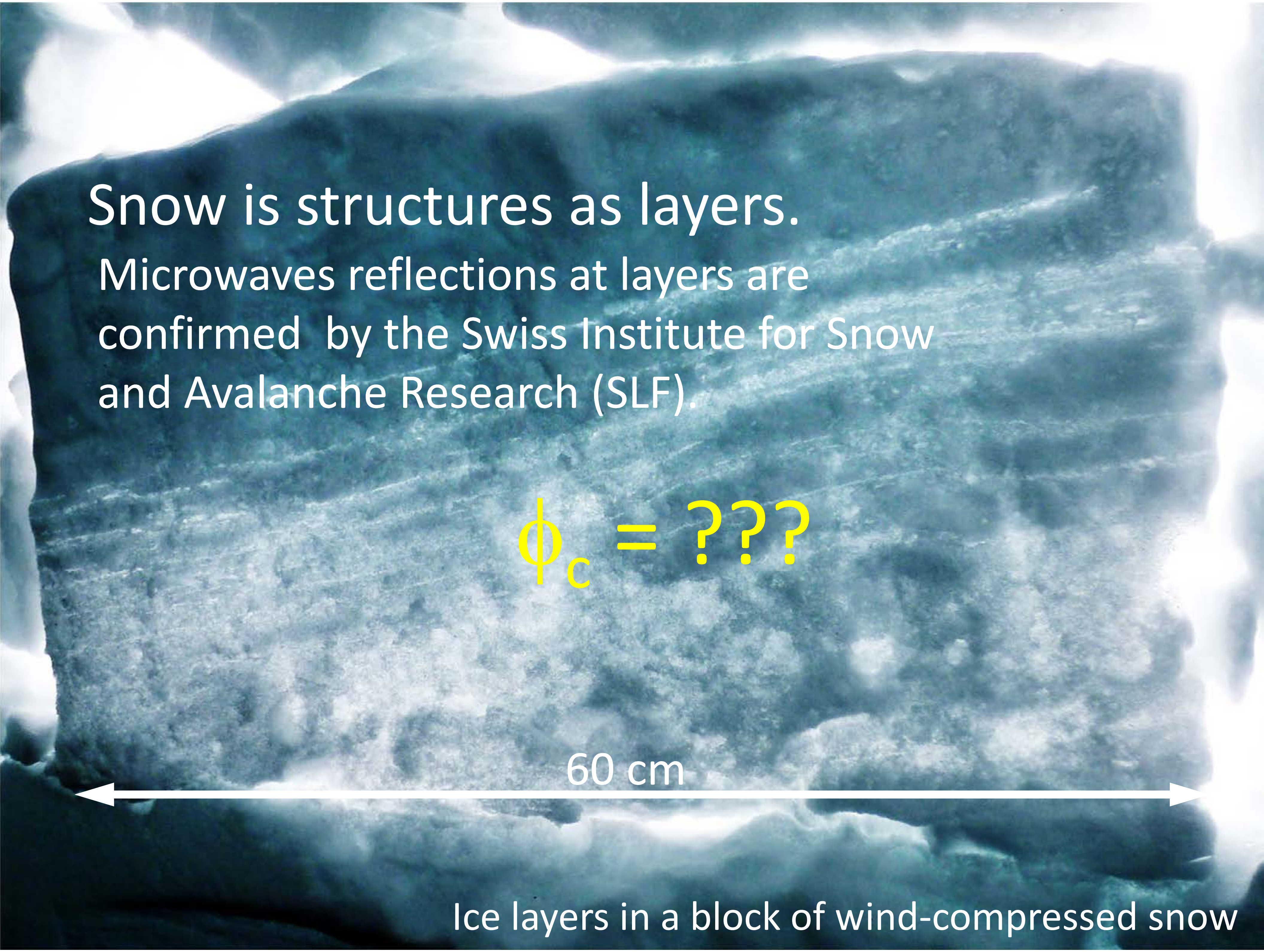
$$\hat{\gamma} = \gamma \cdot e^{i\varphi} = \frac{\langle S_1 \cdot S_2^* \rangle_{\text{ens.}}}{\sqrt{\langle |S_1|^2 \rangle \langle |S_2|^2 \rangle}} \longrightarrow \phi_c = \phi_{VV} - \phi_{HH} \quad \text{(co-polar)}$$

What about this:



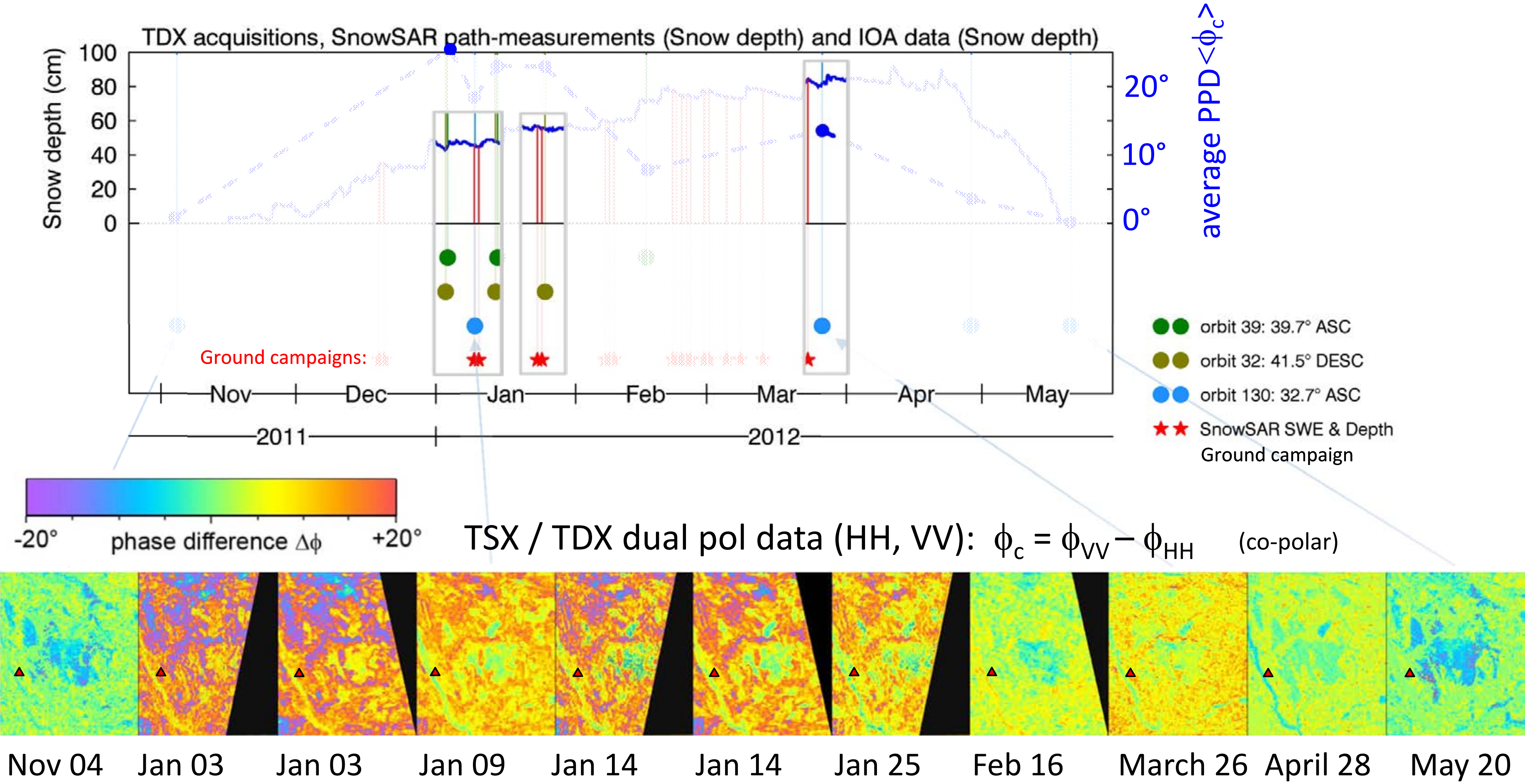
ϕ_c = ???

Is there any signature of snow? Snow as a layered structure?

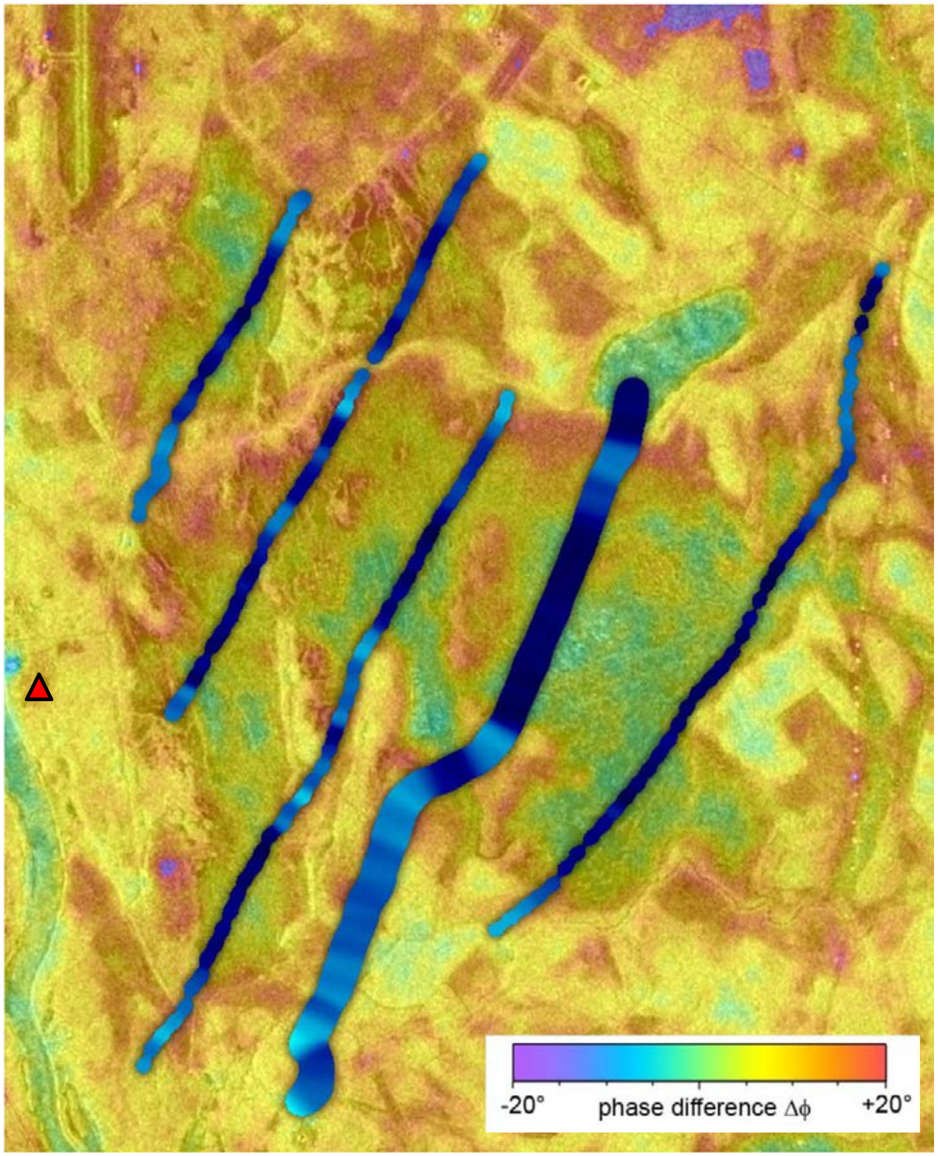


Ice layers in a block of wind-compressed snow

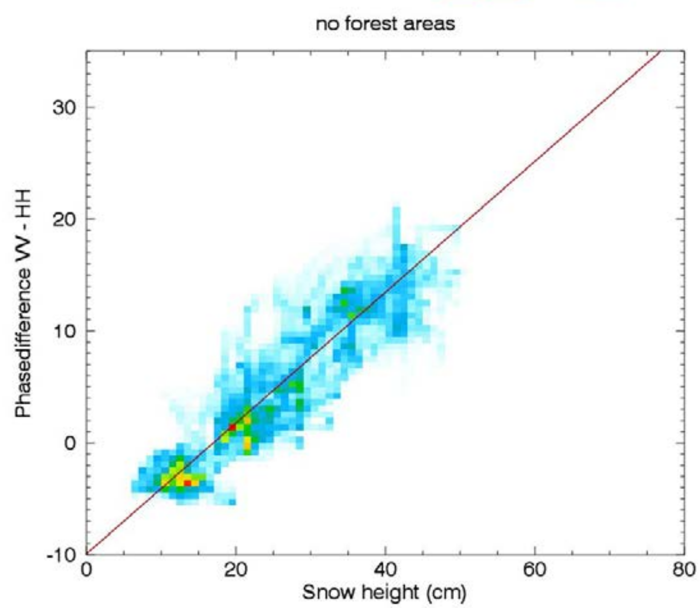
co-polar PPD over the winter

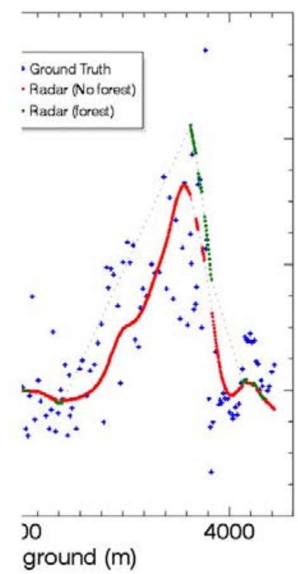


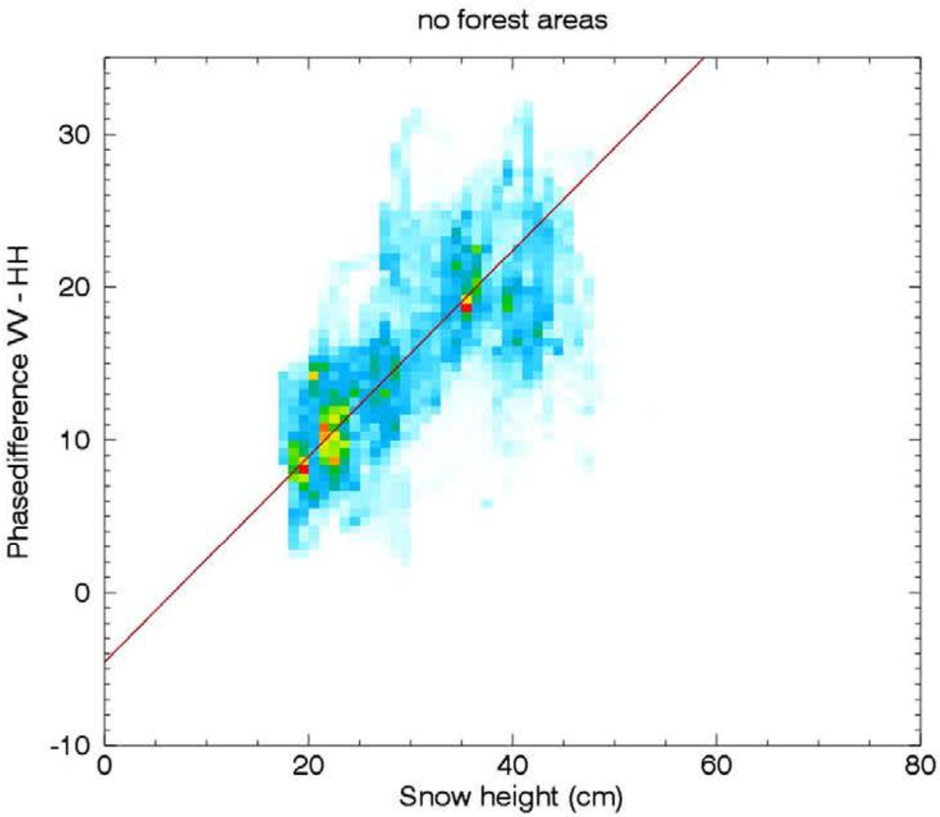
Ground truth vs. PPD ϕ_c

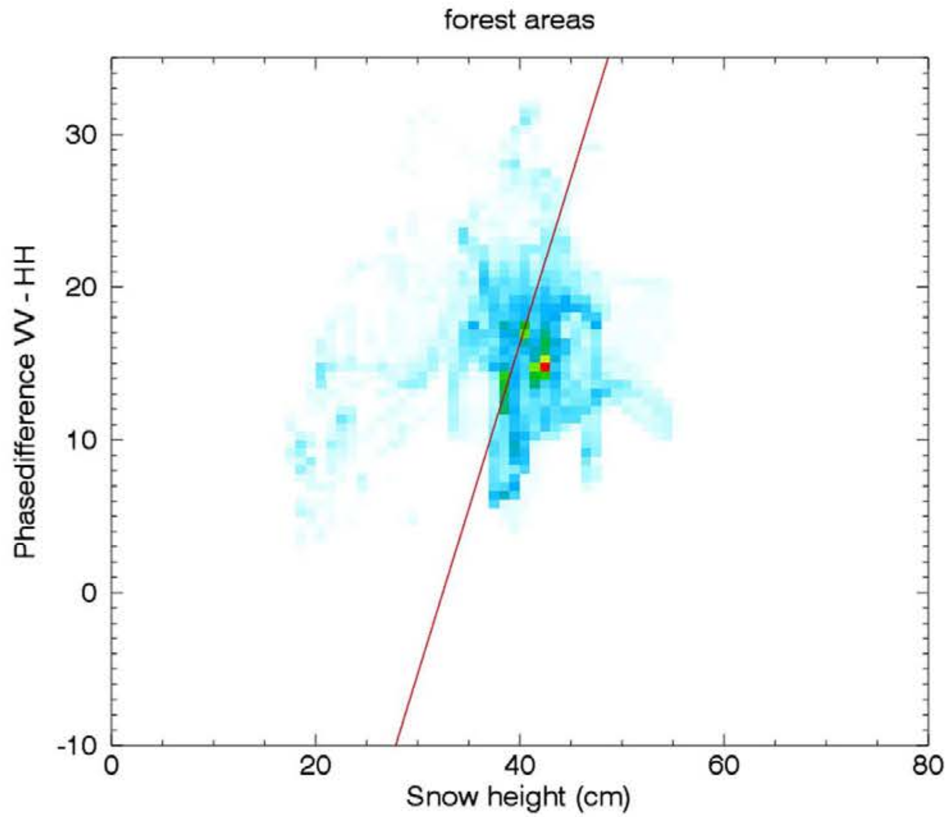


1) Measure snow depth in the field.
2) Classification: no Forest / Forest.
3) Calculate PPD: $\phi_c = \phi_{VV} - \phi_{HH}$
4) Compare PPD with snow depth.
5) Plot correlations for acquisitions.





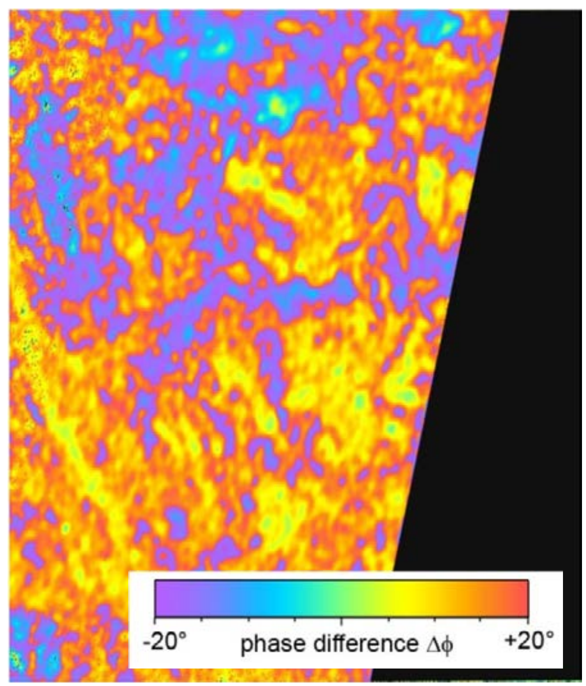


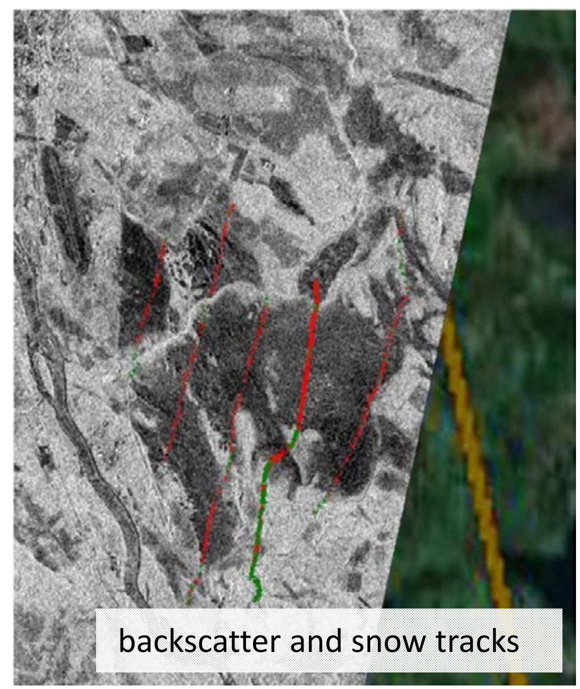


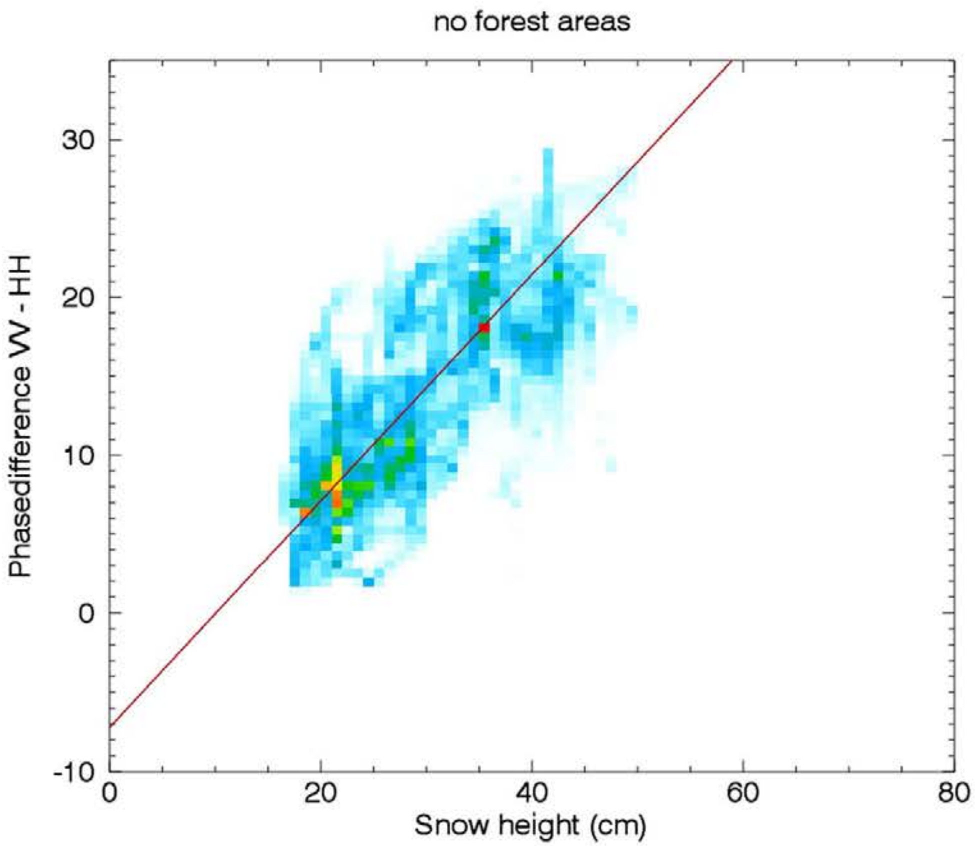
Acquisition date:
03 Jan 2012, orbit 32

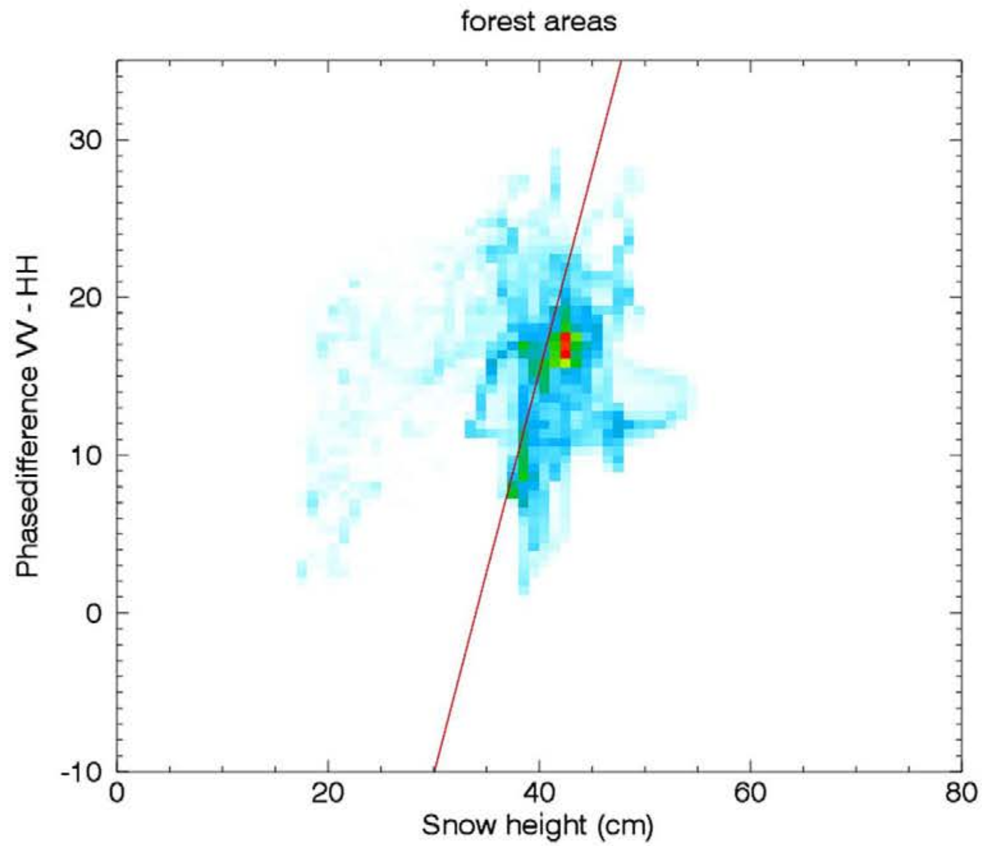
Ground data takes:
9th + 10th Jan, 2012

Correlation between snow height and Polarimetric phase difference $\phi_{VV} - \phi_{HH}$ for forested and not forested areas.



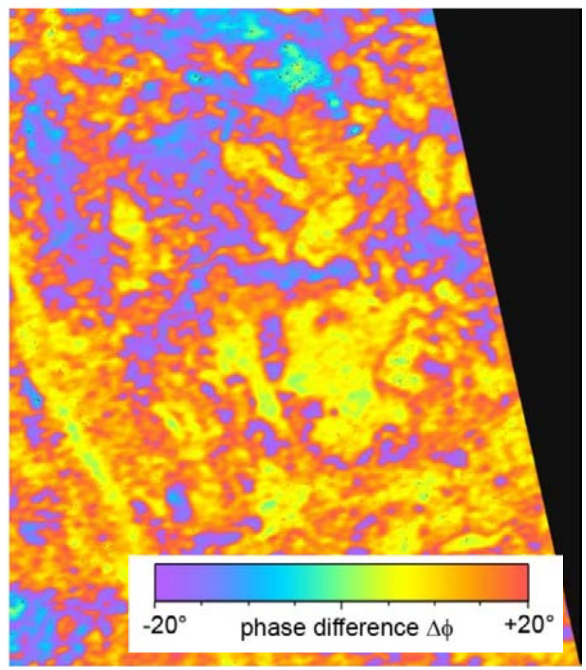


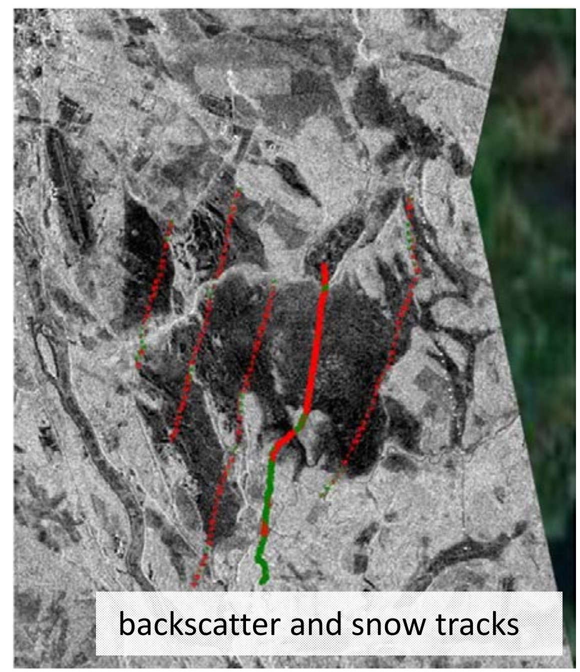




Acquisition date:
03 Jan 2012, orbit 39

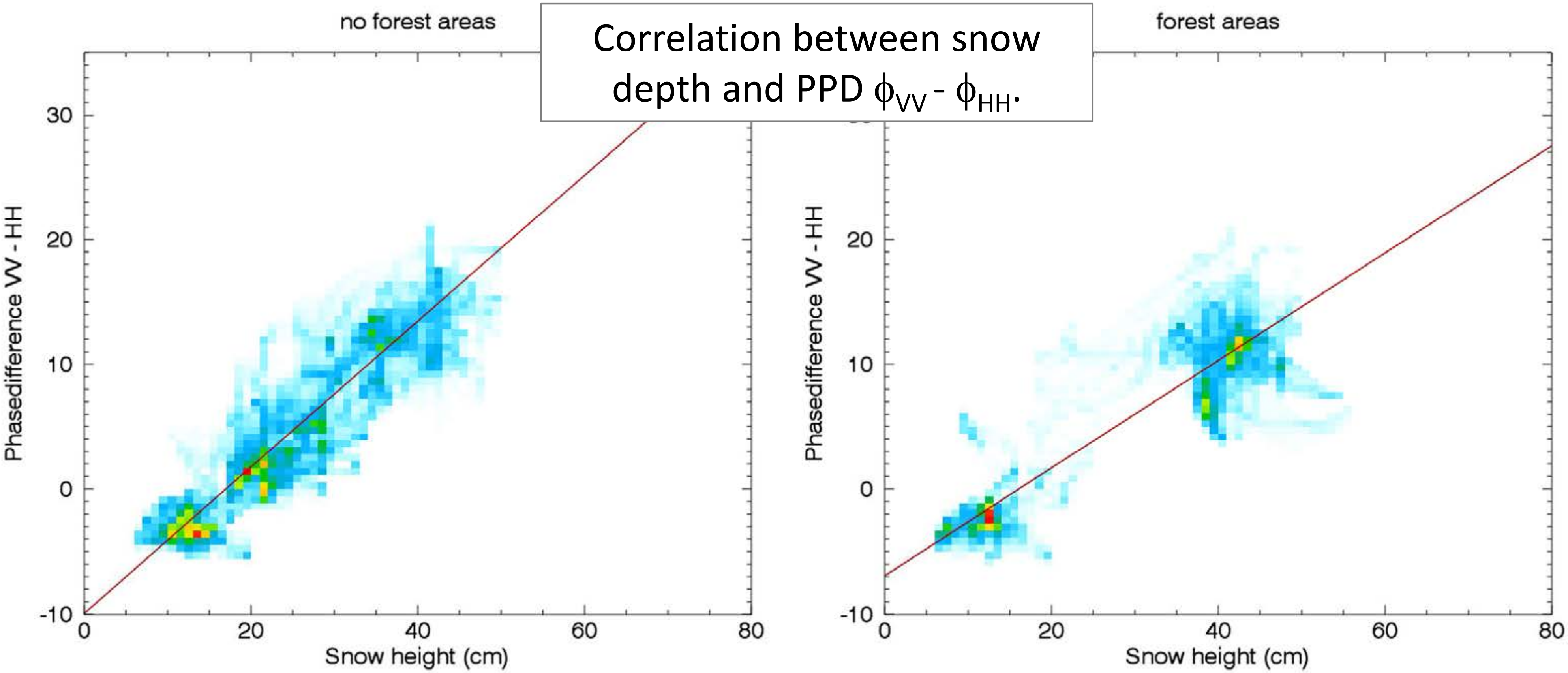
Ground data takes:
9th + 10th Jan, 2012





Correlation between snow height and Polarimetric phase difference $\phi_{VV} - \phi_{HH}$ for forested and not forested areas.

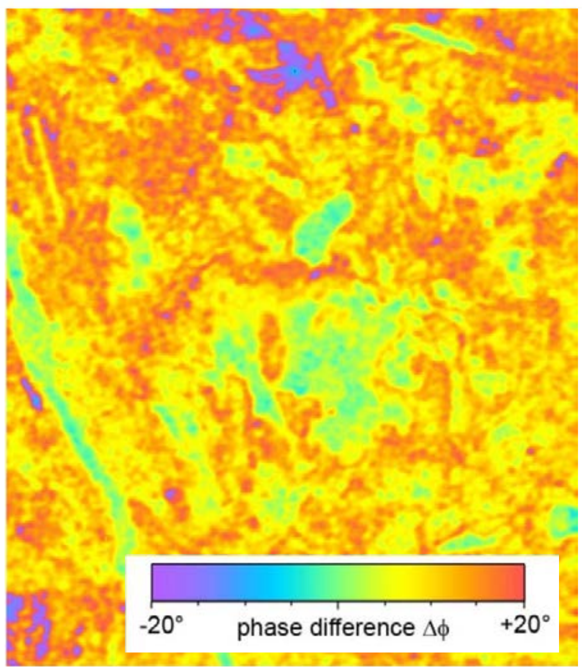
Correlation between snow depth and PPD $\phi_{VV} - \phi_{HH}$.

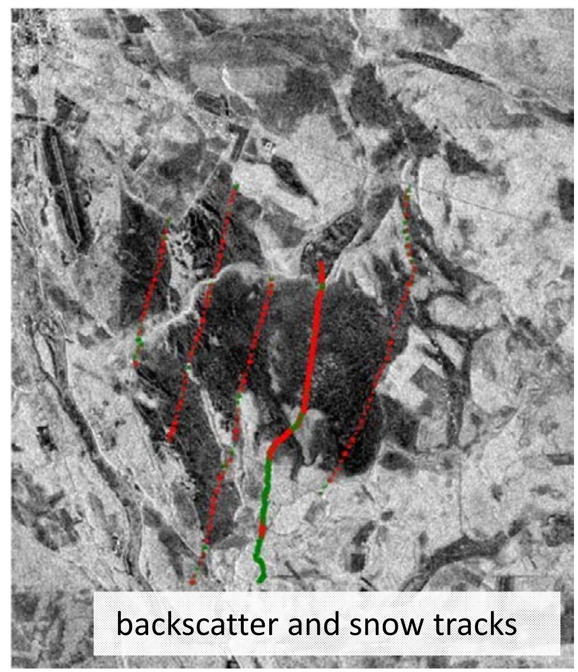


Acquisition date:
09 Jan 2012, orbit 130

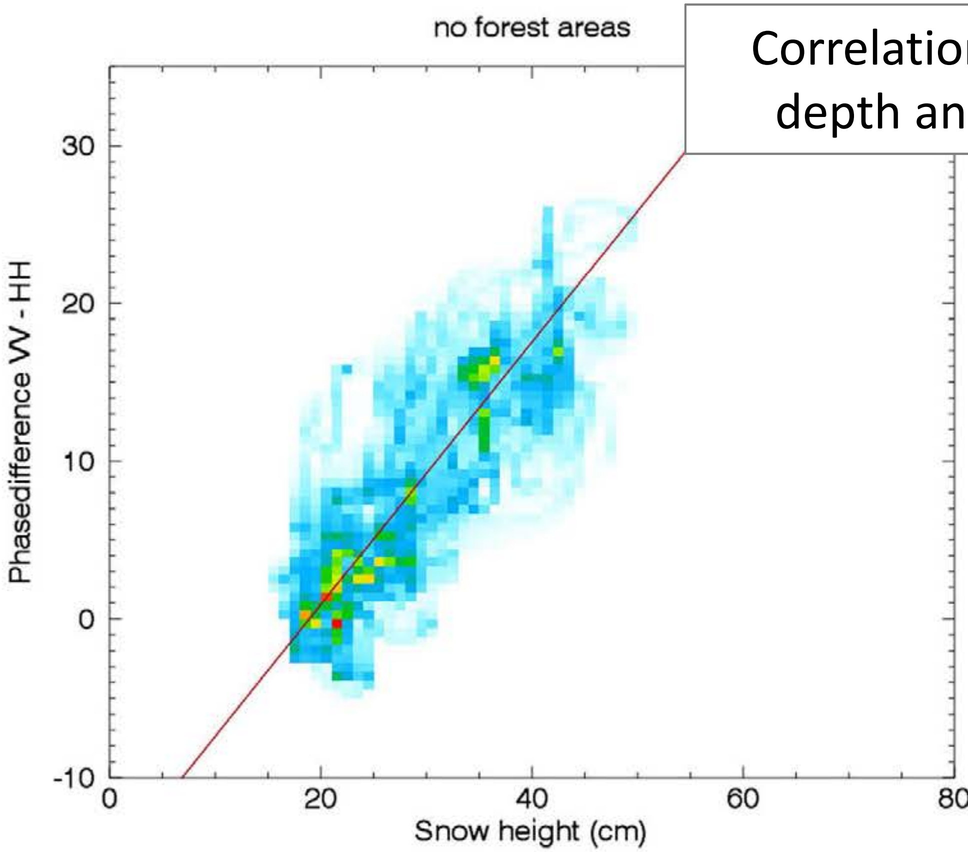
aoi = 32.7°

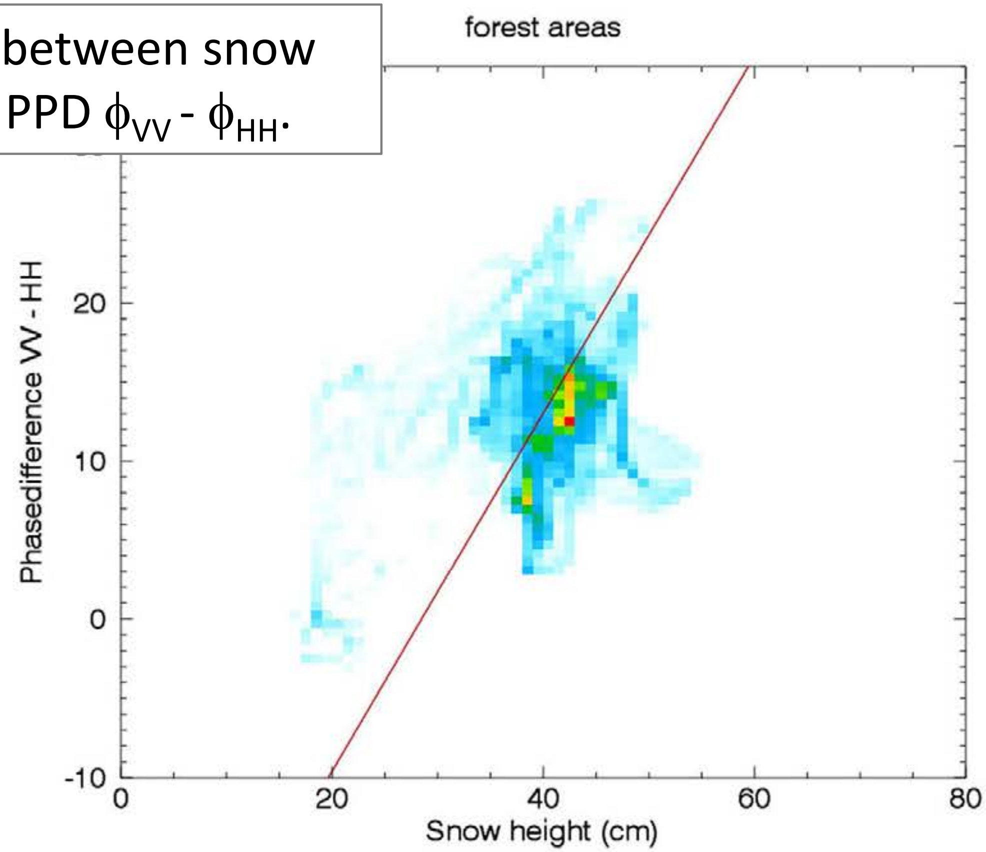
Ground data takes:
9th + 10th Jan, 2012





Correlation between snow depth and PPD $\phi_{VV} - \phi_{HH}$.

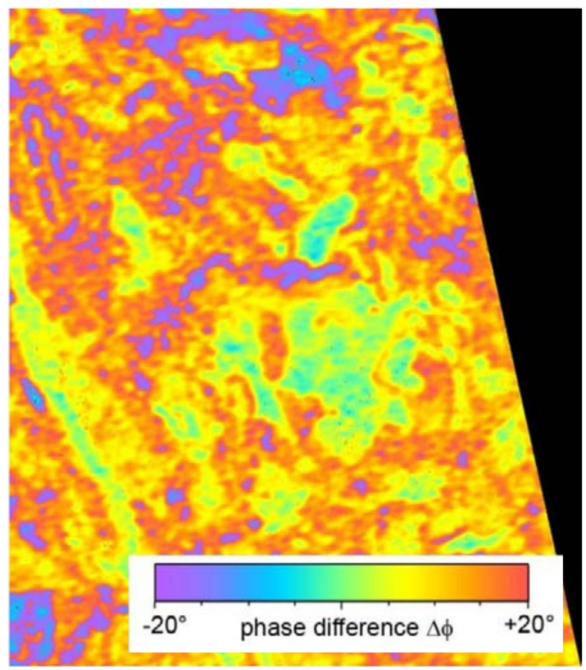


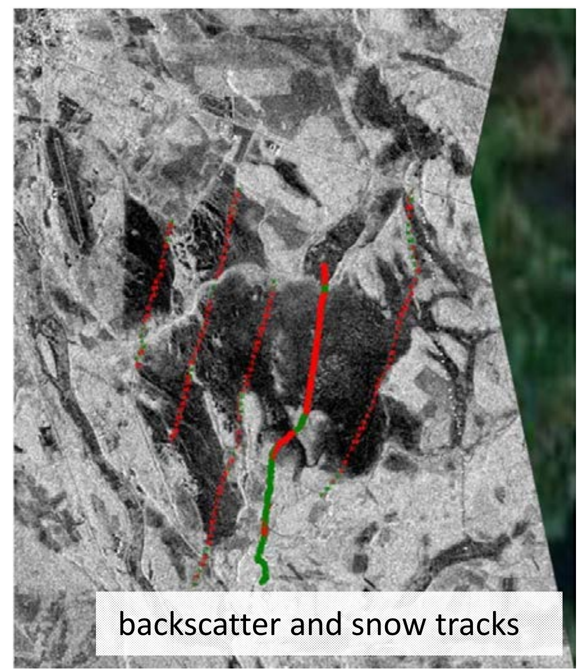


Acquisition date:
14 Jan 2012, orbit 39

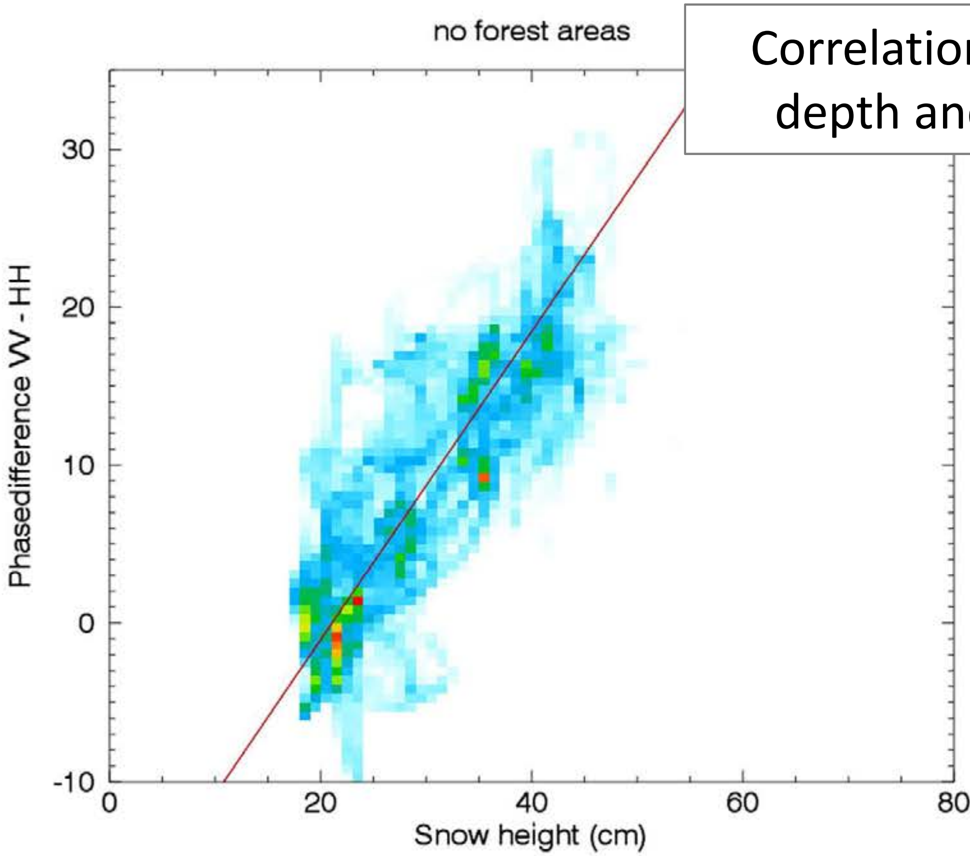
aoi = 39.7°

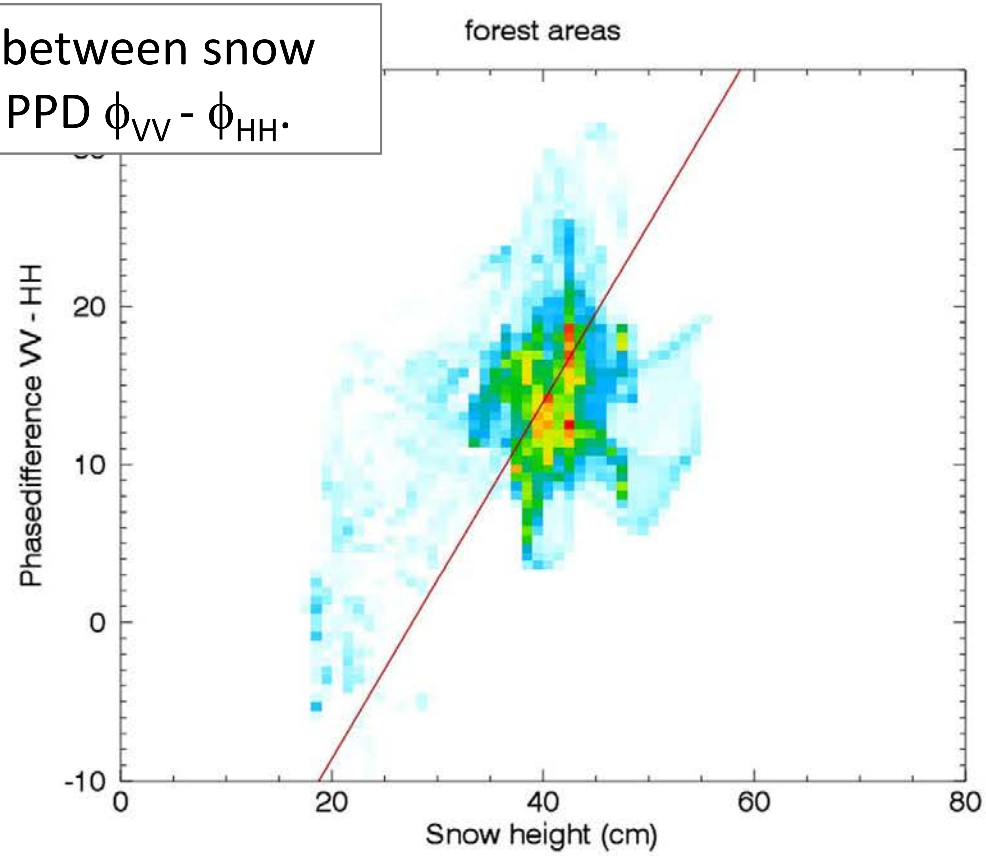
Ground data takes:
9th + 10th Jan, 2012





Correlation between snow depth and PPD $\phi_{VV} - \phi_{HH}$.

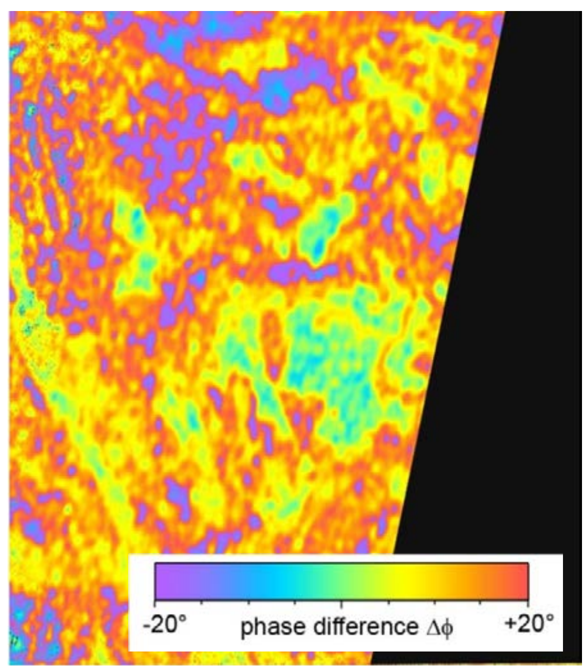


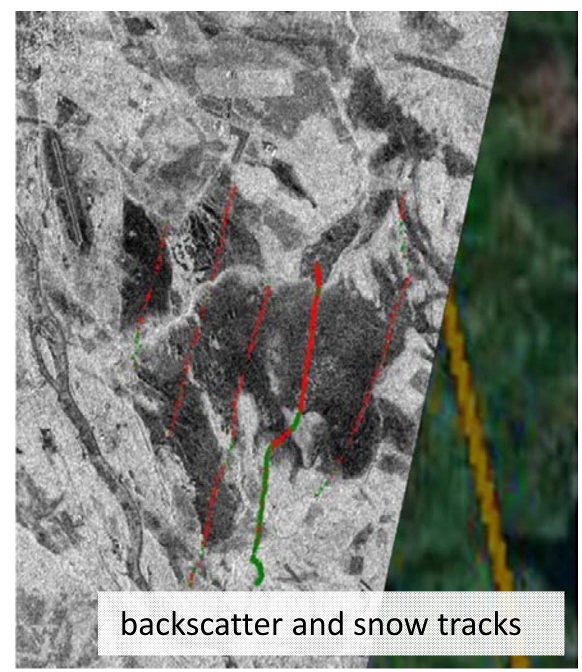


Acquisition date:
14 Jan 2012, orbit 32

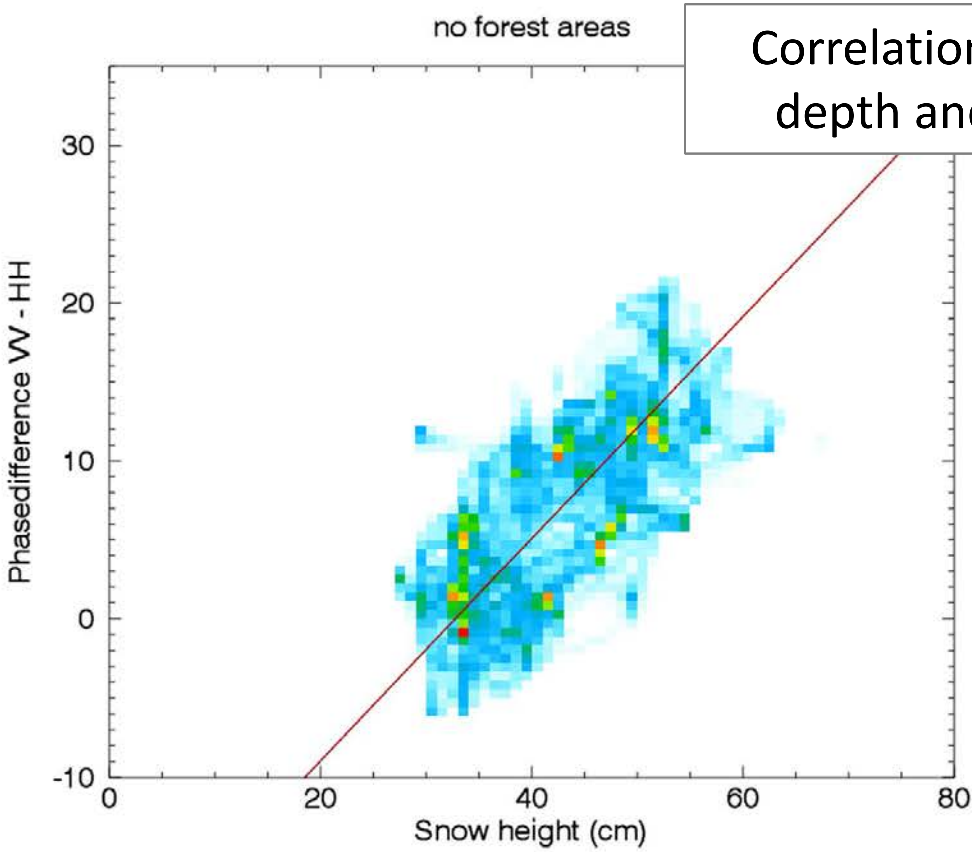
aoi = 41.5°

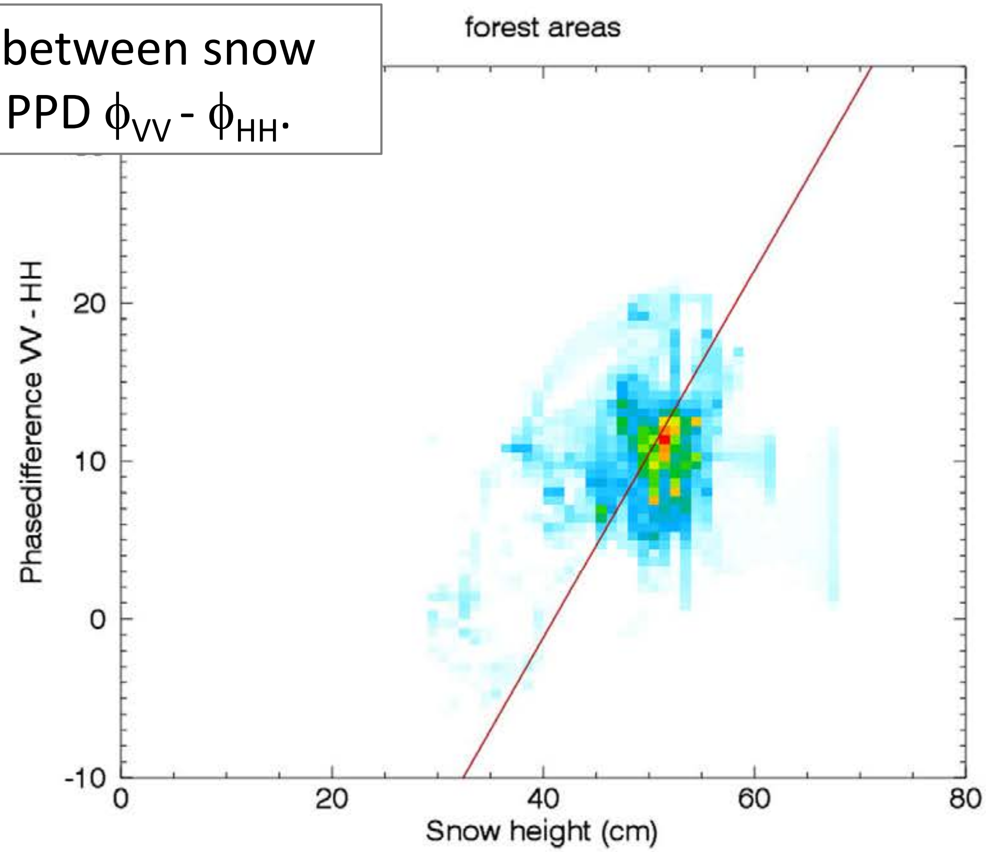
Ground data takes:
9th + 10th Jan, 2012





Correlation between snow depth and PPD $\phi_{VV} - \phi_{HH}$.

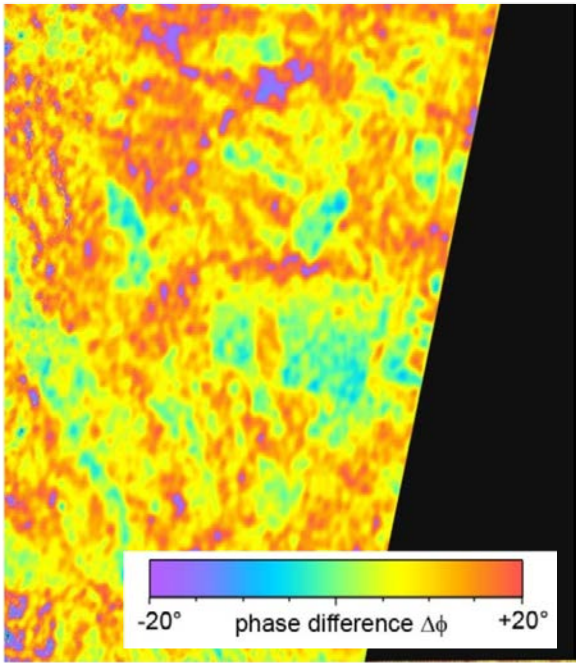


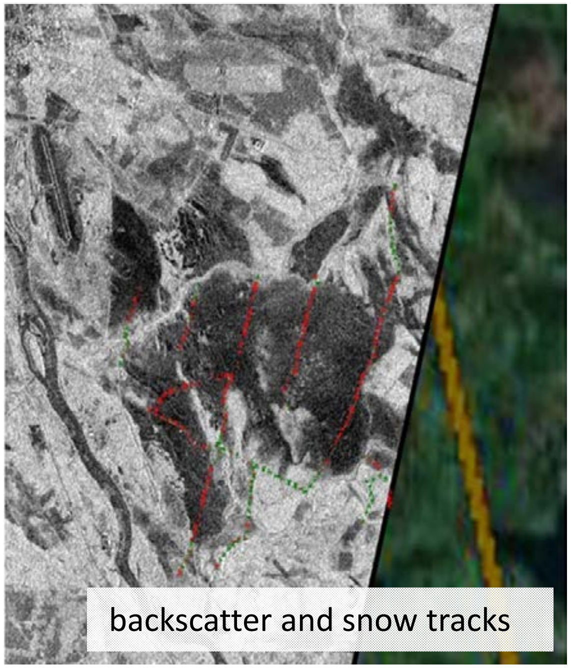


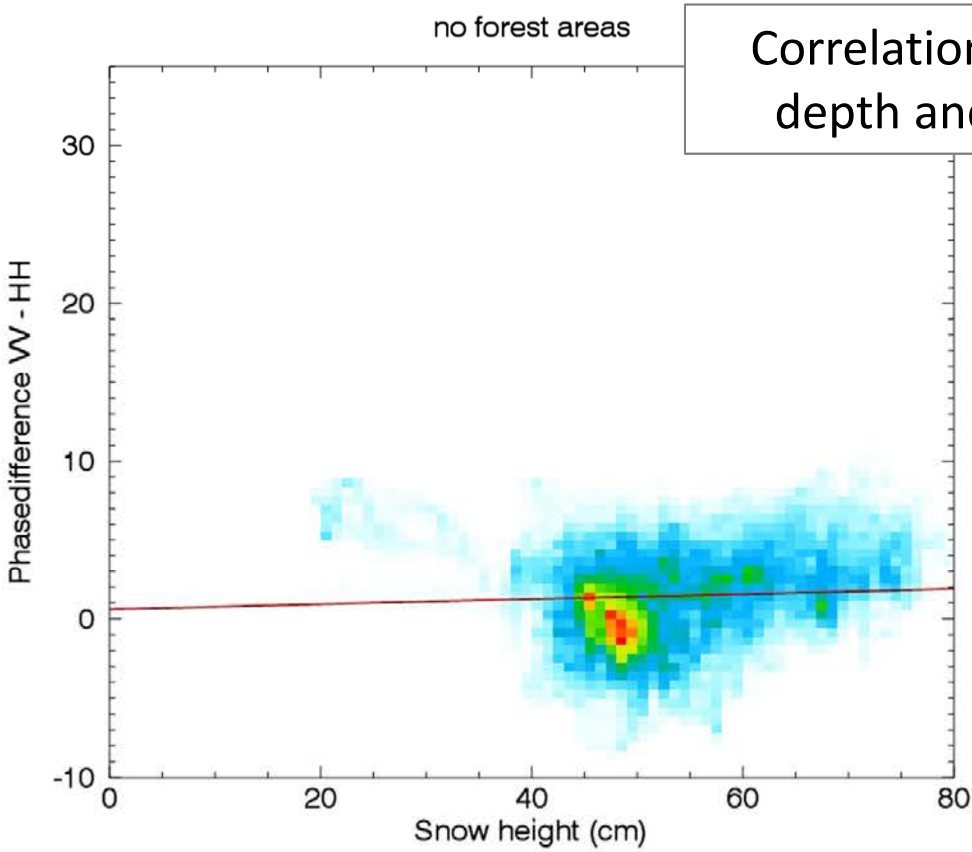
Acquisition date:
25 Jan 2012, orbit 32

aoi = 41.5°

Ground data takes:
23th + 24th Jan, 2012

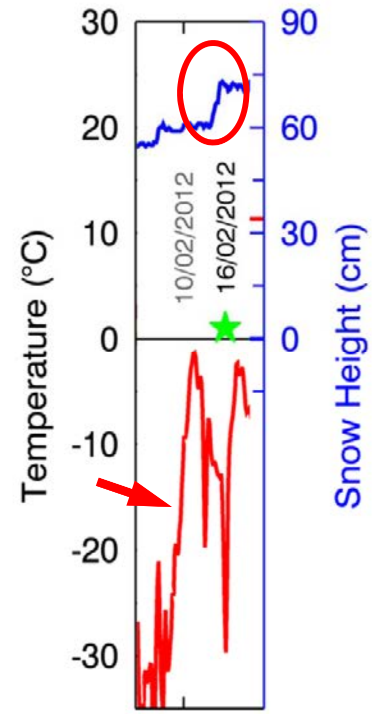






Correlation between snow depth and PPD $\phi_{VV} - \phi_{HH}$.

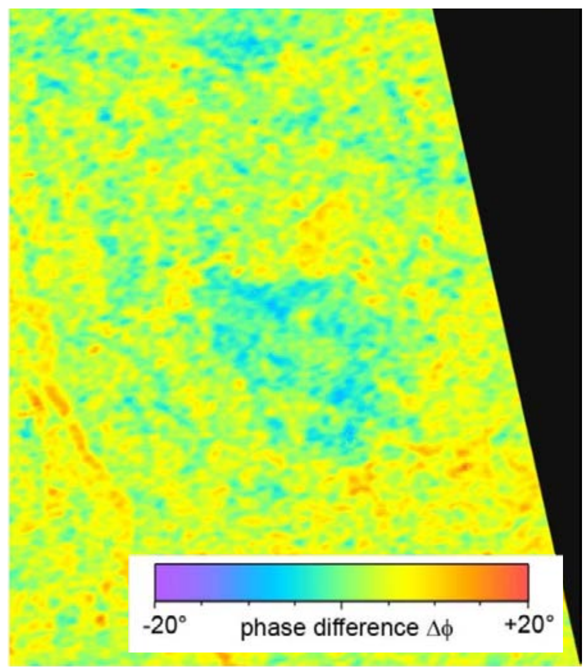
- Extrem increase of temperature.
- +20 cm of fresh humid snow.
  -> no layers visible.
  (small penetration.)

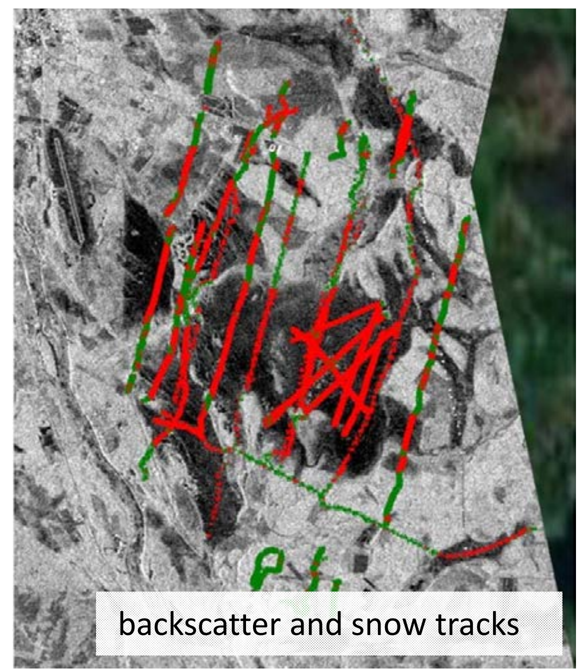


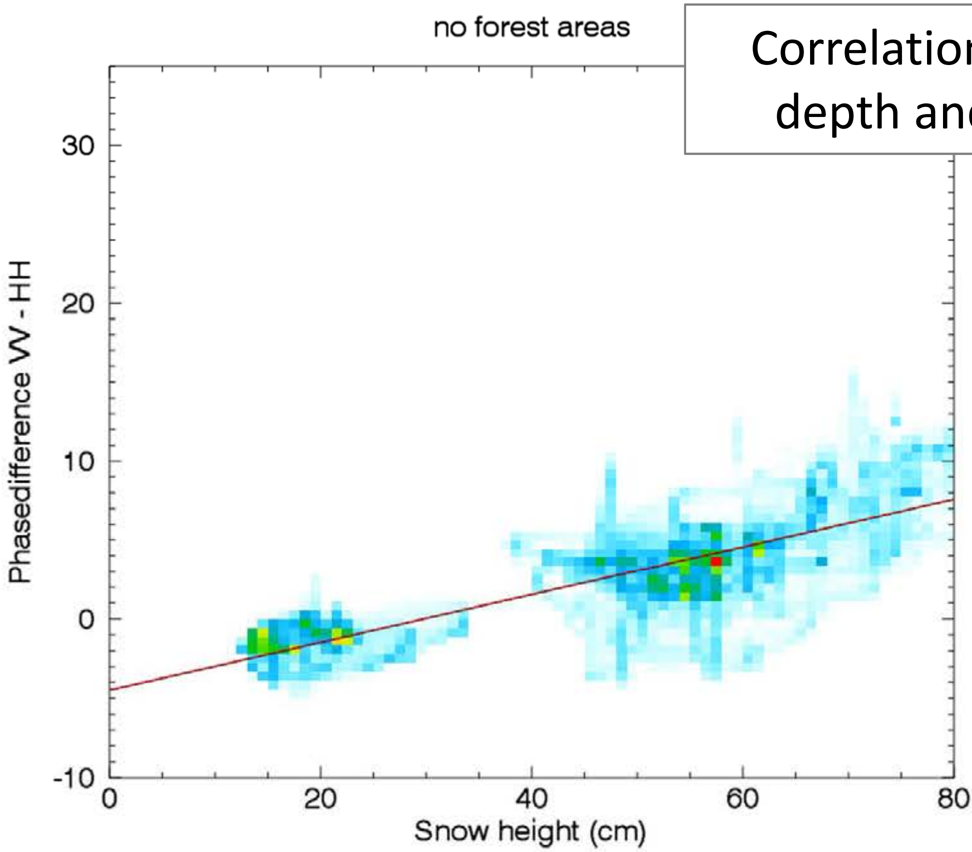
Acquisition date:
16 Feb 2012, orbit 39

aoi = 39.7°

Ground data takes:
7th - 9th Feb, 2012
22nd - 26th Feb, 2012
(heavy snowfall between campaign and acquisition)

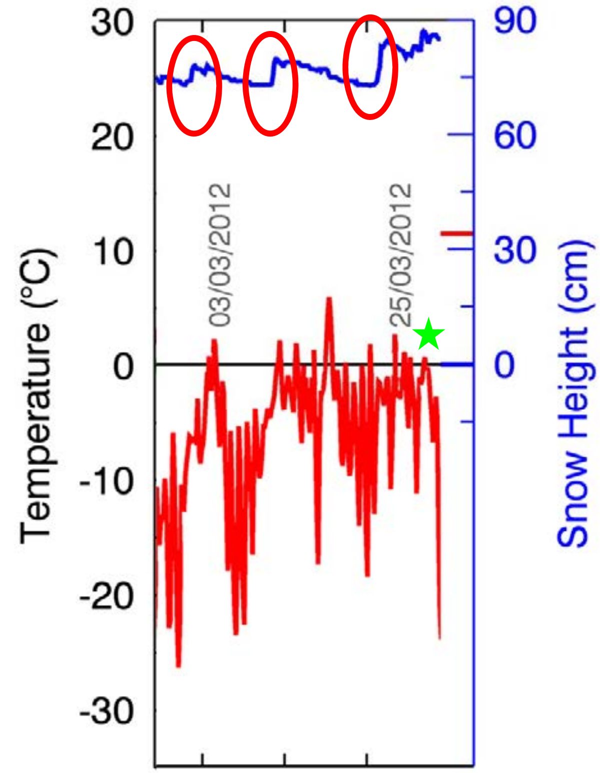






Correlation between snow depth and PPD ϕ_{VV} - ϕ_{HH}.

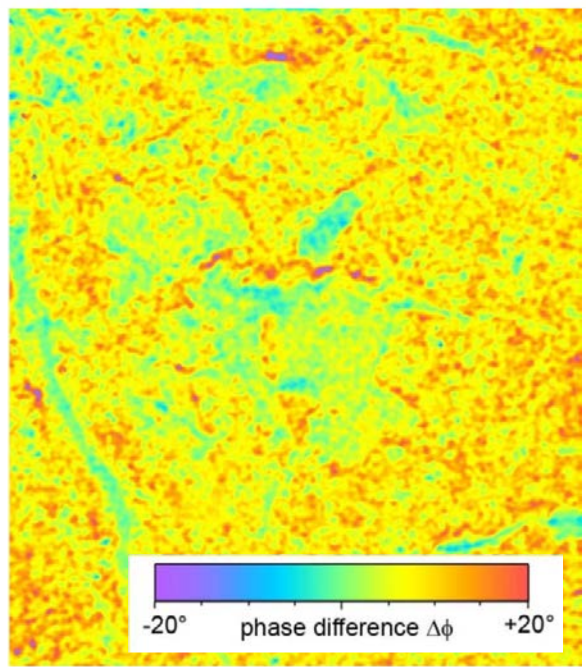
- frequent humid snow fall, 0°C.
- only a few layers visible.
- penetration only in top layer.

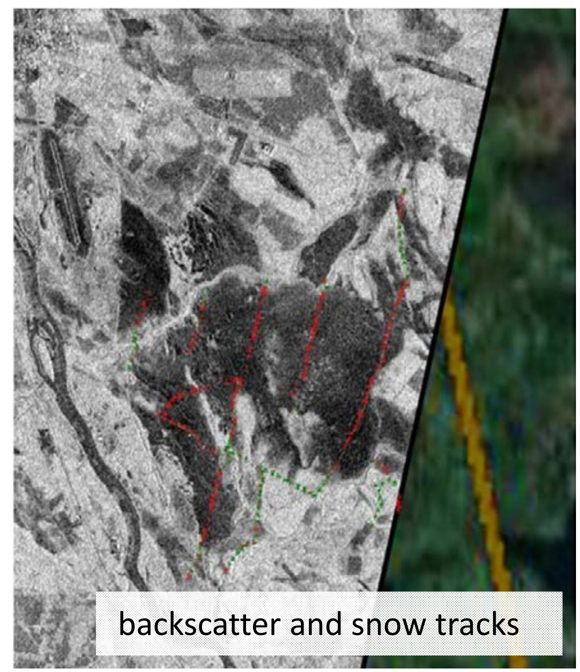


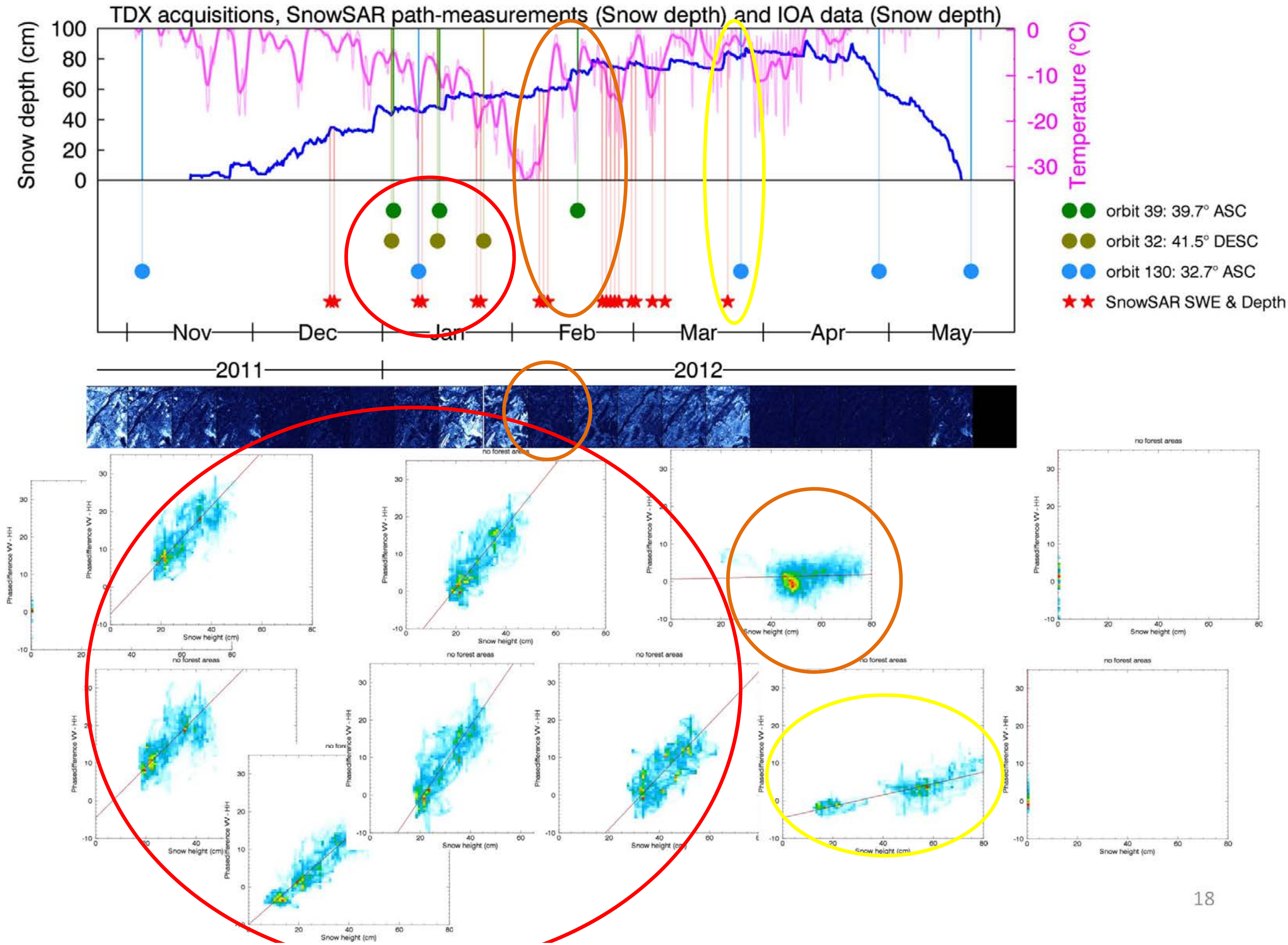
Acquisition date:
26 March 2012, orbit 130

aoi = 32.7°

Ground data takes:
23rd March, 2012







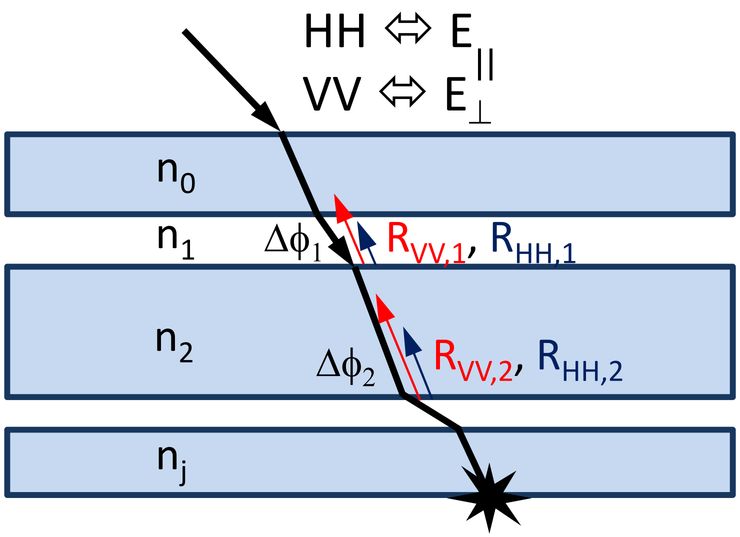
TDX acquisitions, SnowSAR path-measurements (Snow depth) and IOA data (Snow depth)
Snow depth (cm)
Temperature (°C)
orbit 39: 39.7° ASC
orbit 32: 41.5° DESC
orbit 130: 32.7° ASC
SnowSAR SWE & Depth
Nov
Dec
Jan
Feb
Mar
Apr
May
2011
2012
no forest areas
Phasedifference VV - HH
Snow height (cm)

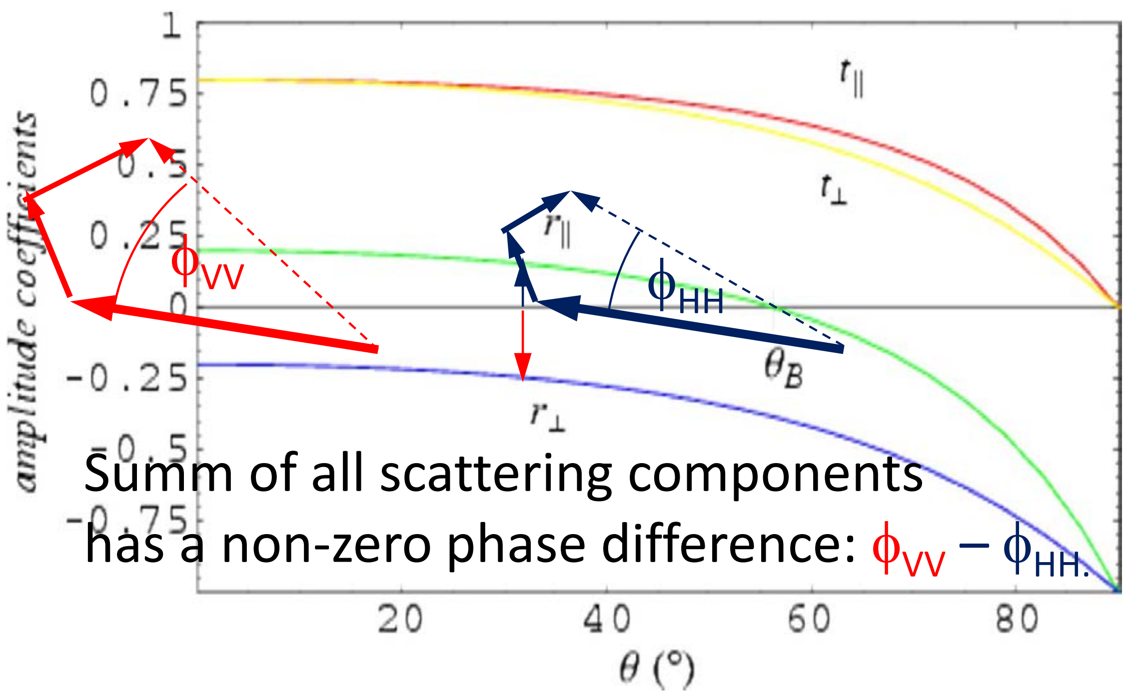
Why is Snow depth proportional to (ϕ_{VV} - ϕ_{HH})?

Suggestions:

1. Propagation speed differs for HH and VV.
2. Different penetration depth for HH and VV.
3. Linear combination of phase-jumps at different layers.

#2 is supported by different Fresnel-coefficients at snow layers for polarizations.

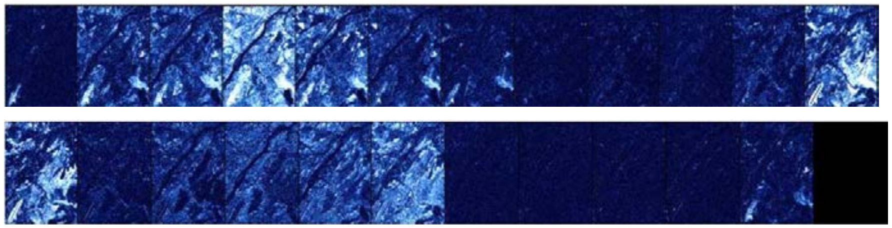




Summ of all scattering components has a non-zero phase difference: $\phi_{VV} - \phi_{HH}$.

Conclusion

Repeat pass InSAR:

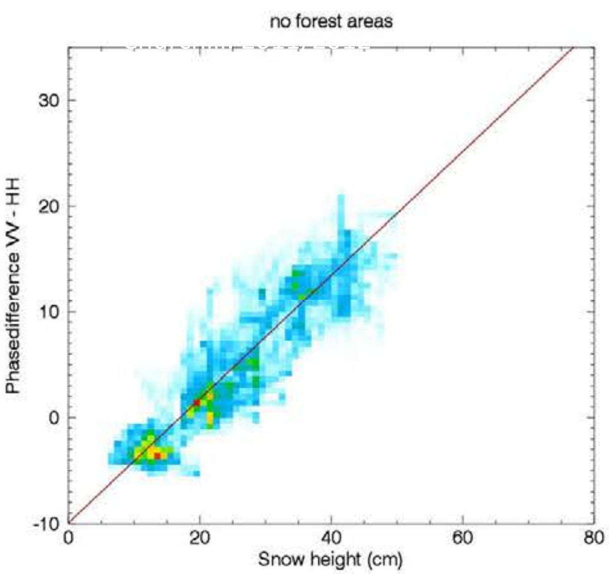


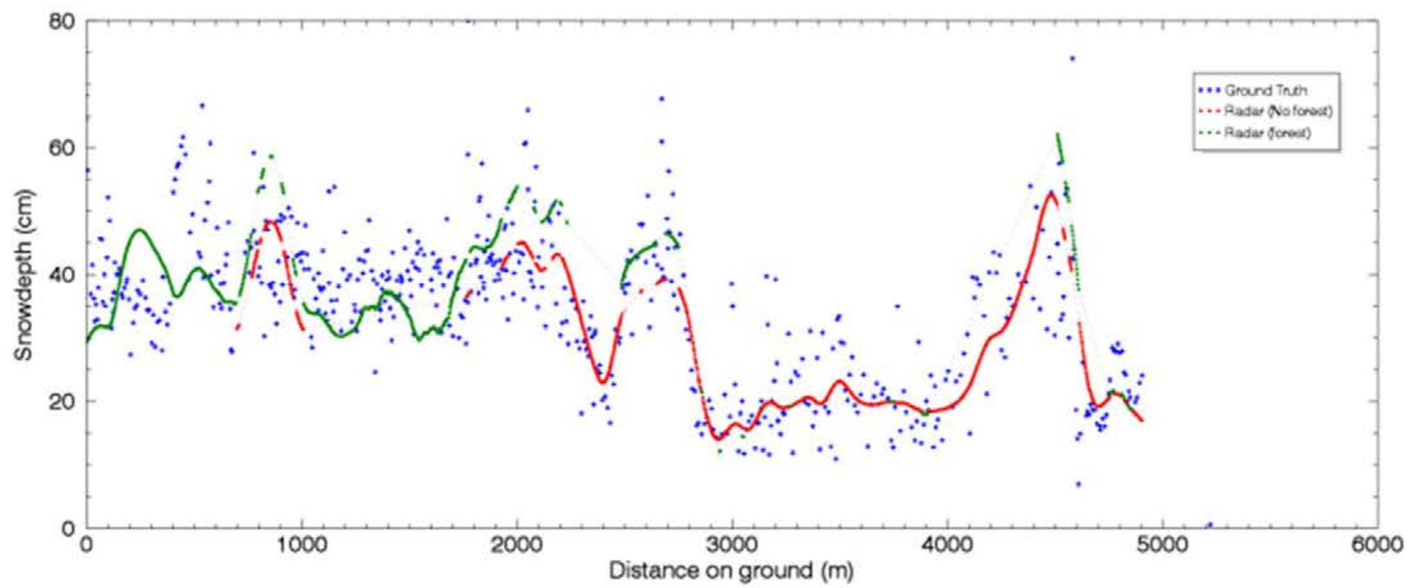
Snowfall and melting events cause strong decorrelation of repeat pass Interferometric coherence.

-> Microwave interaction with snow layer!

Polarimetry:

- Clear evidence for correlation between PPD ϕ_{VV}-ϕ_{HH} and snow over open area. (Volume scattering in forests destroys a clear phase signal).
- Model is under developement and ideas area welcome!

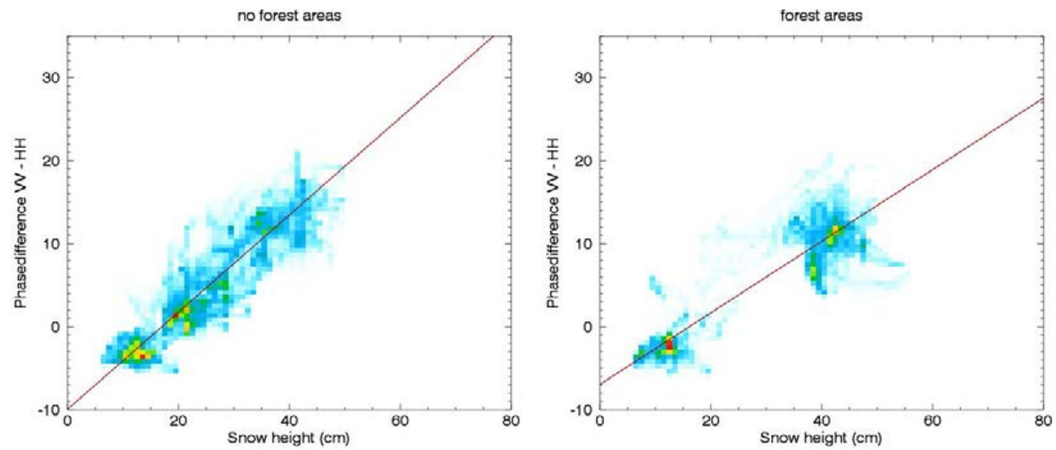


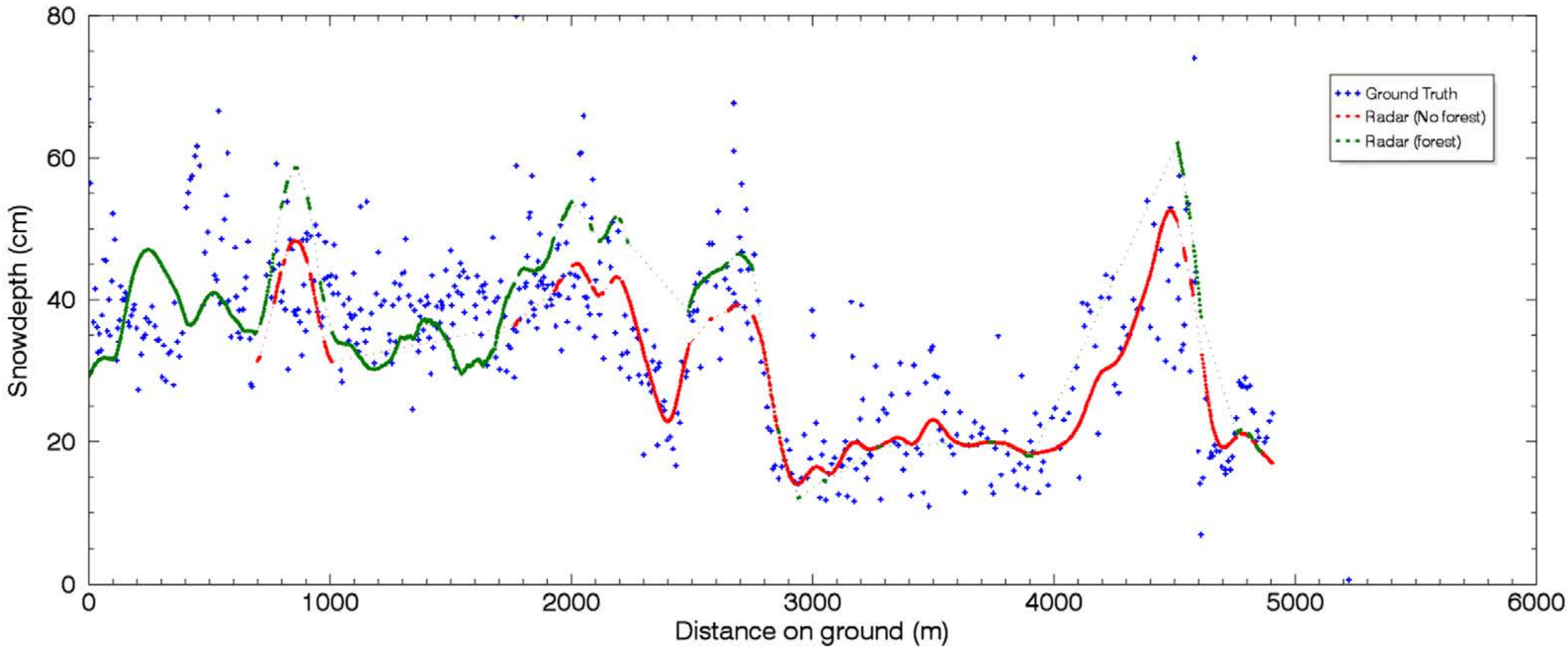


Special thanks to FMI, Enveo, Gamma Remote Sensing, EC, NASA JPL, WSL-SLF for ground campaigns.

Distributed measurements make incomparably better validations possible than fixed stations.

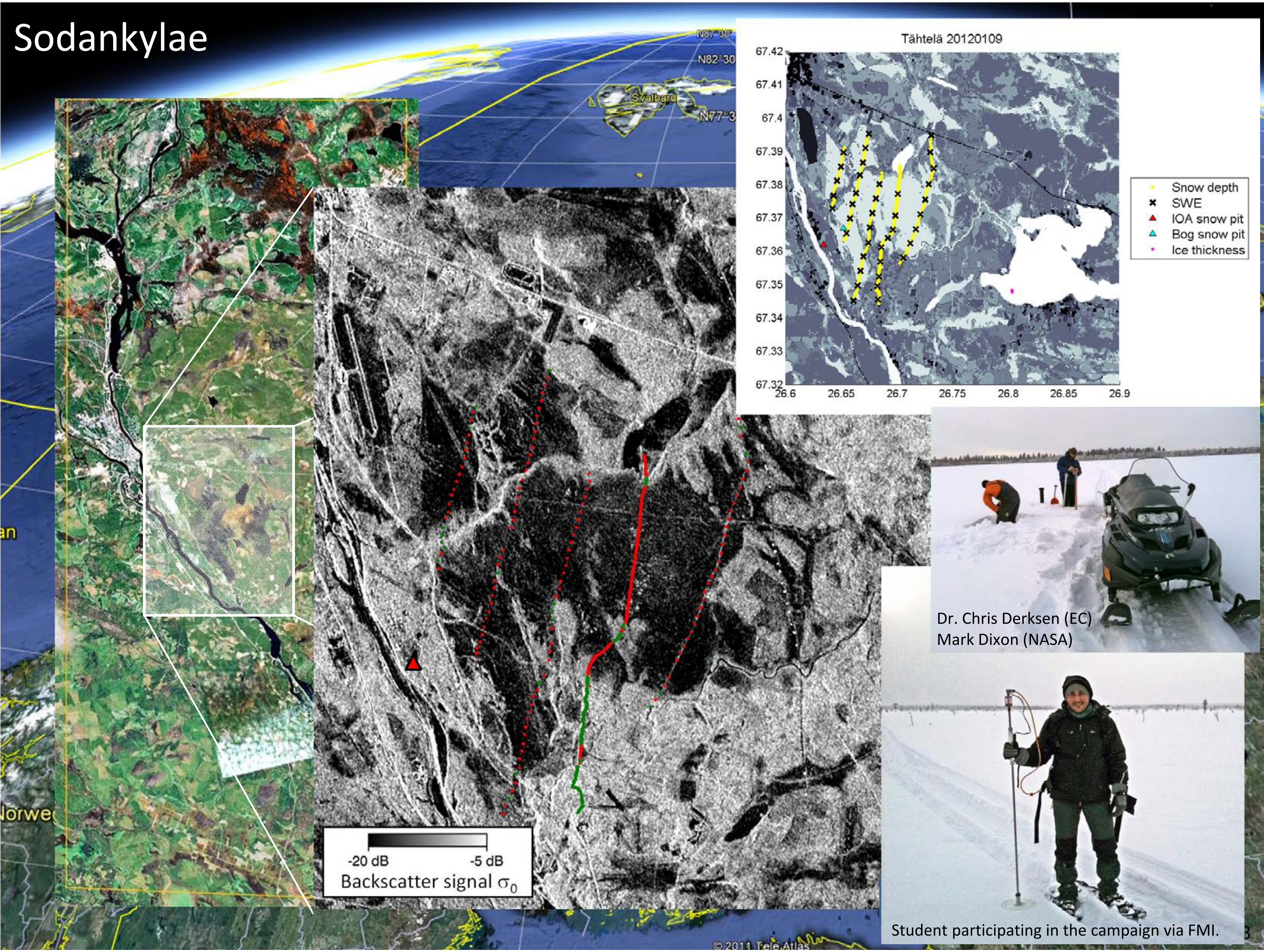
Spatial comparison of snow depth along transect with PPD.





Co-polar phase difference ϕ_c follows the snow depth along the transect.

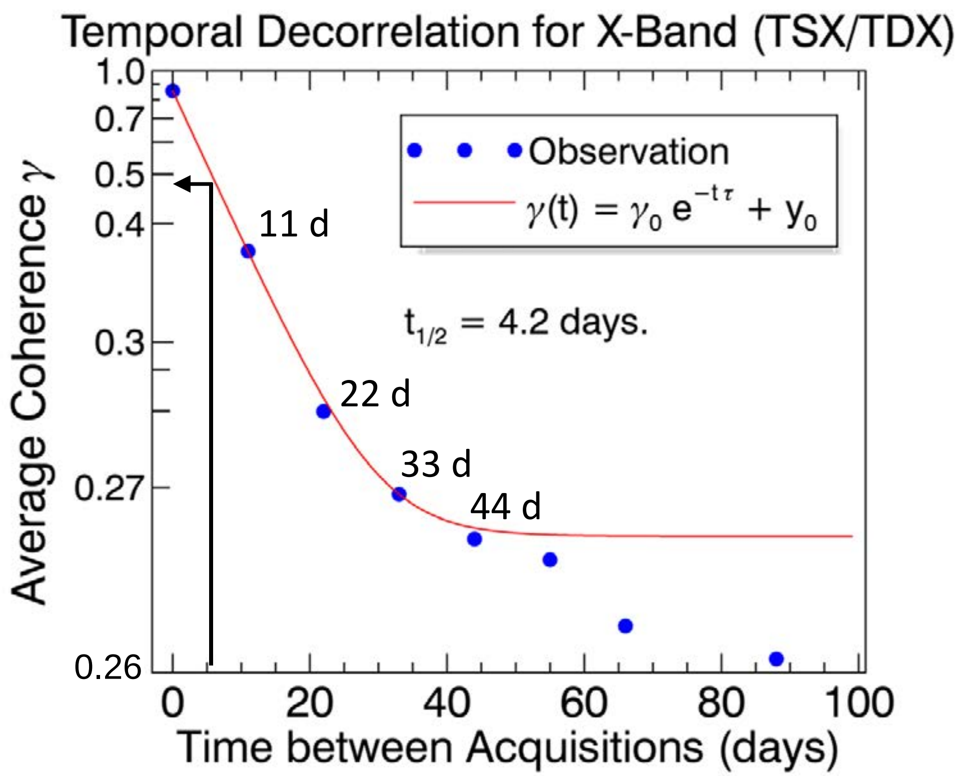
Sodankylae



Dr. Chris Derksen (EC)
Mark Dixon (NASA)

Student participating in the campaign via FMI.

Change detection by coherence decay:

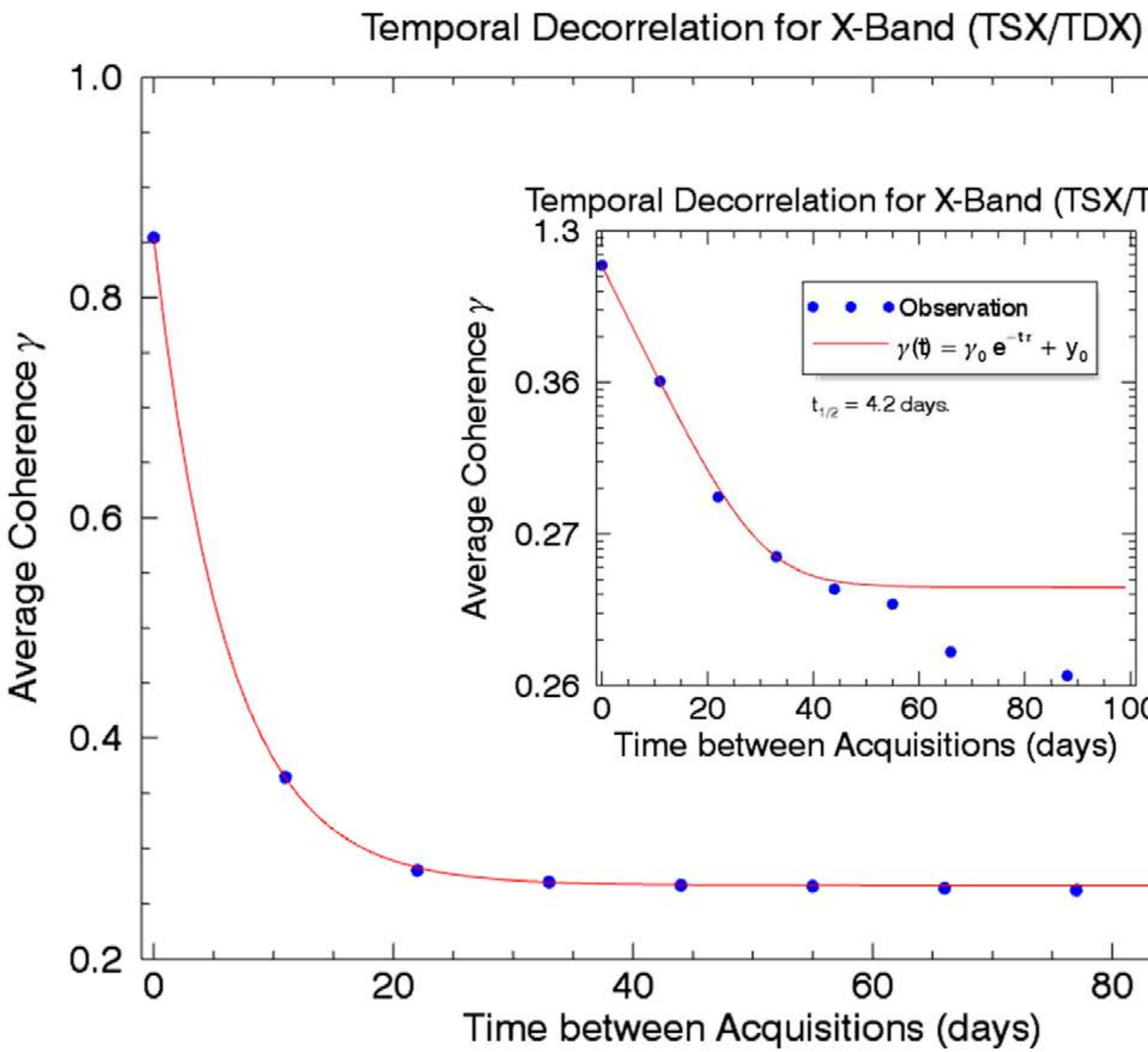


Strong temporal decorrelation in X-band caused by Snowfall, melting or strong wind drift.

For each point the coherences of at least 8 scenes of the same testsite were averaged.

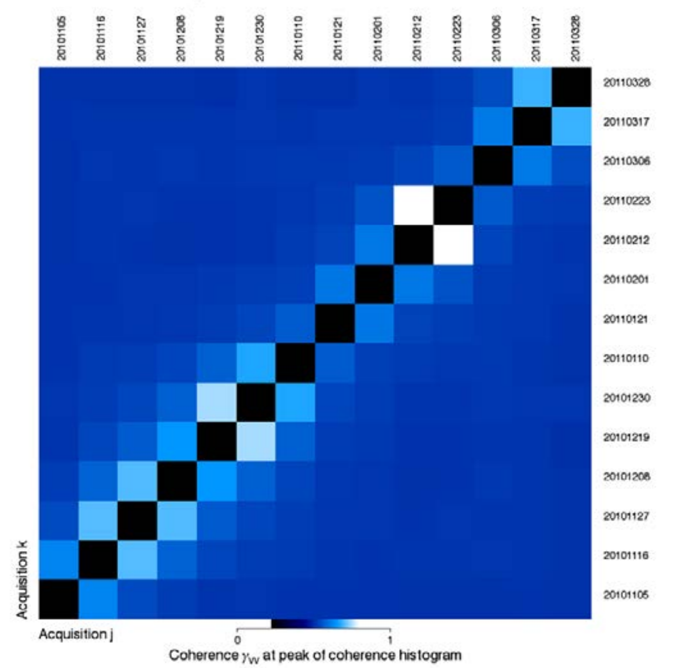
- Decay time of coherence: $t_{1/2}$ = 4.2 days.
- Repeat-times of *a few days* are favourable.

Decay of coherence for X-band TSX data



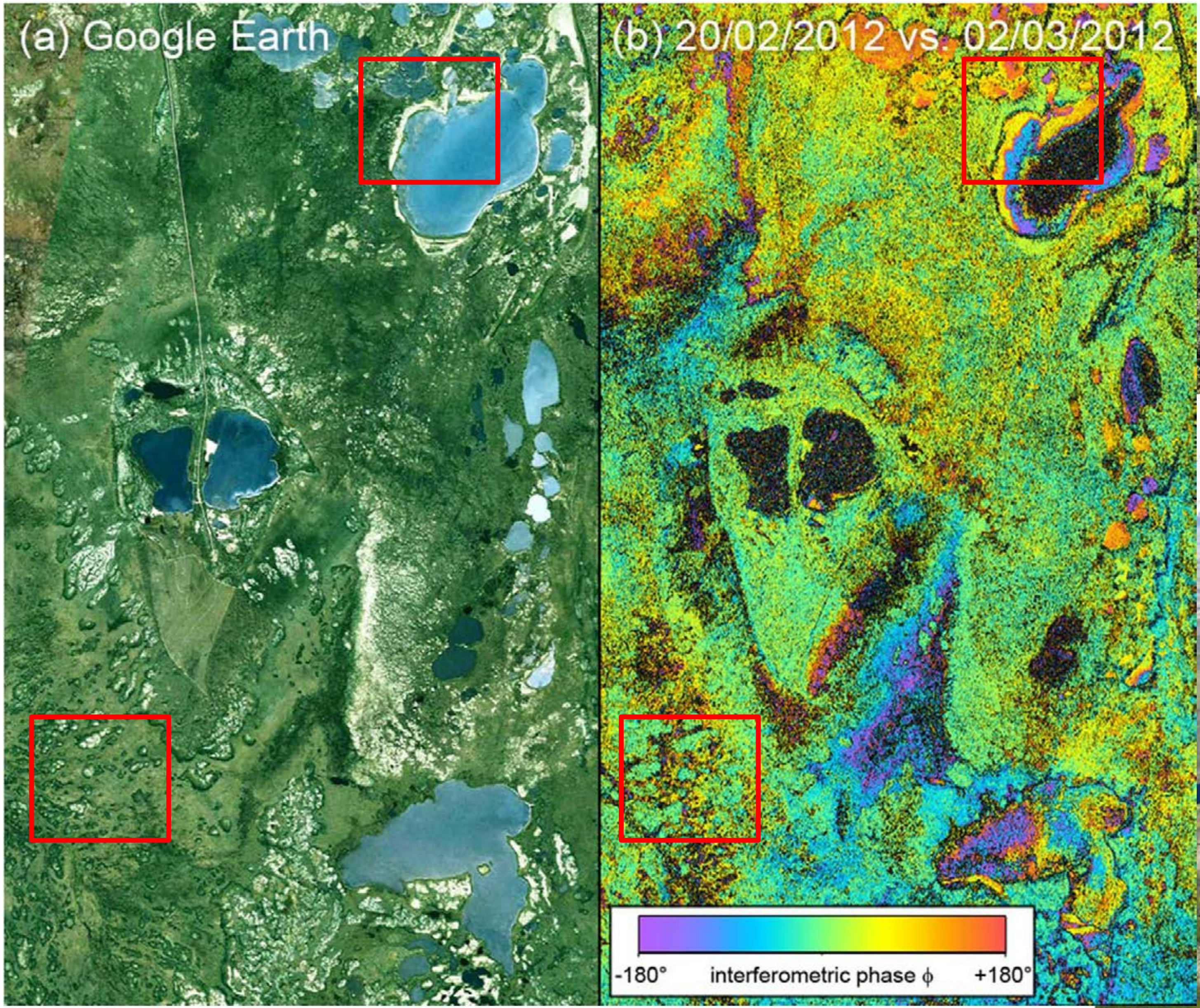
Decay time of Coherence: $t_{1/2}$ = 4.2 days

-> Very valuable if repeat-times of a few days are possible.



For each point 8 or more scenes of the same testsite were u
calculated from each scene were averaged. The red line is a

Differential-InSAR: Local phase patterns due to freezing?



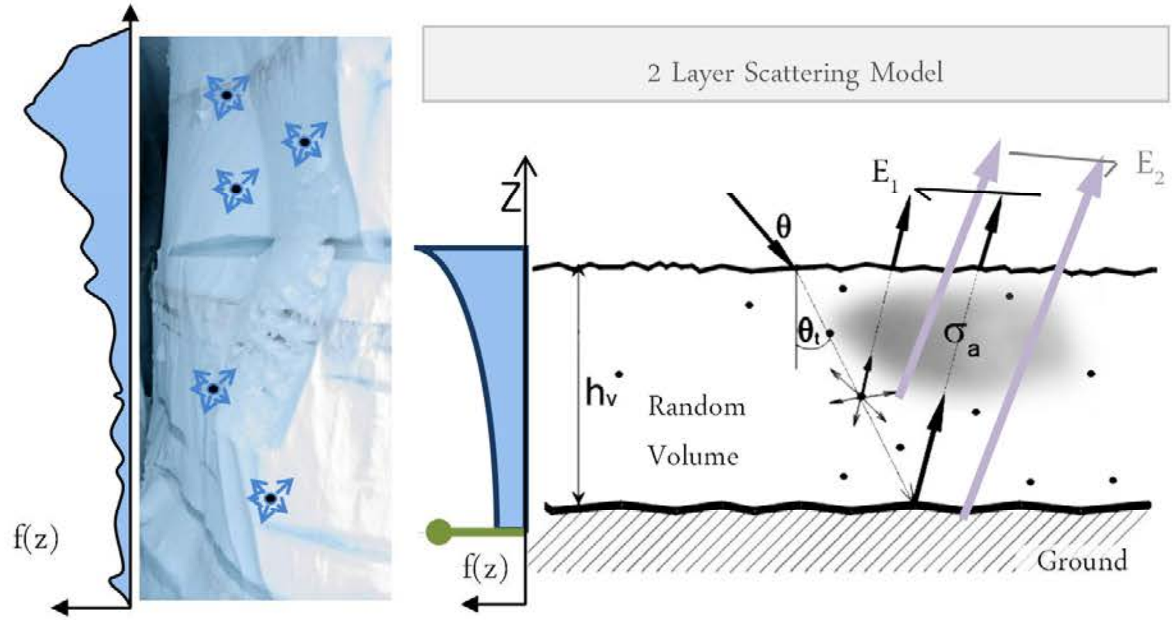
Local phase pattern correlate with freezing structures on the ground.
Up/down lift by freezing/thawing cycles?

InSAR: Random Volume over Ground Model

$$\widetilde{\gamma}_{Vol}(f(z)) = e^{i\kappa_z z_o} \frac{\int_o^{h_v} f(z)\cdot e^{i\kappa_z z}\,\mathrm{d}z}{\int_o^{h_v} f(z)\,\mathrm{d}z}$$

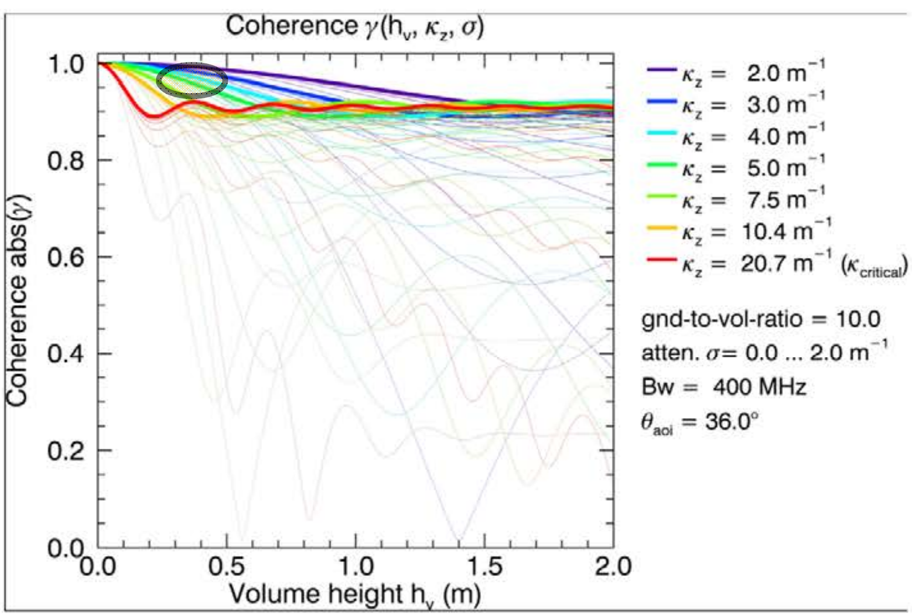
Expected volume coherence.

f(z): Vertical reflectivity function = "backscattered radiation per depth volume".



Realistic reflectivity function / modelled reflectivity function for a snow pack.

Expected coherence for homogeneous snow layer over ground:



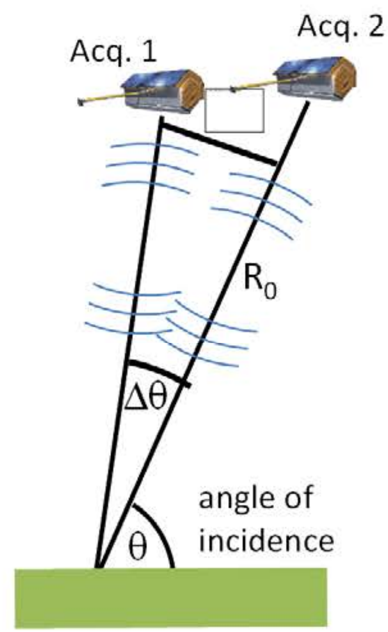
- Good sensitivity to snow volume can be archived for κ_z = ~2...7 m^{-1} corresponding to baselines of

$b_\perp$ = 5... 8 km -> terraSAR-X (h = 514 km)

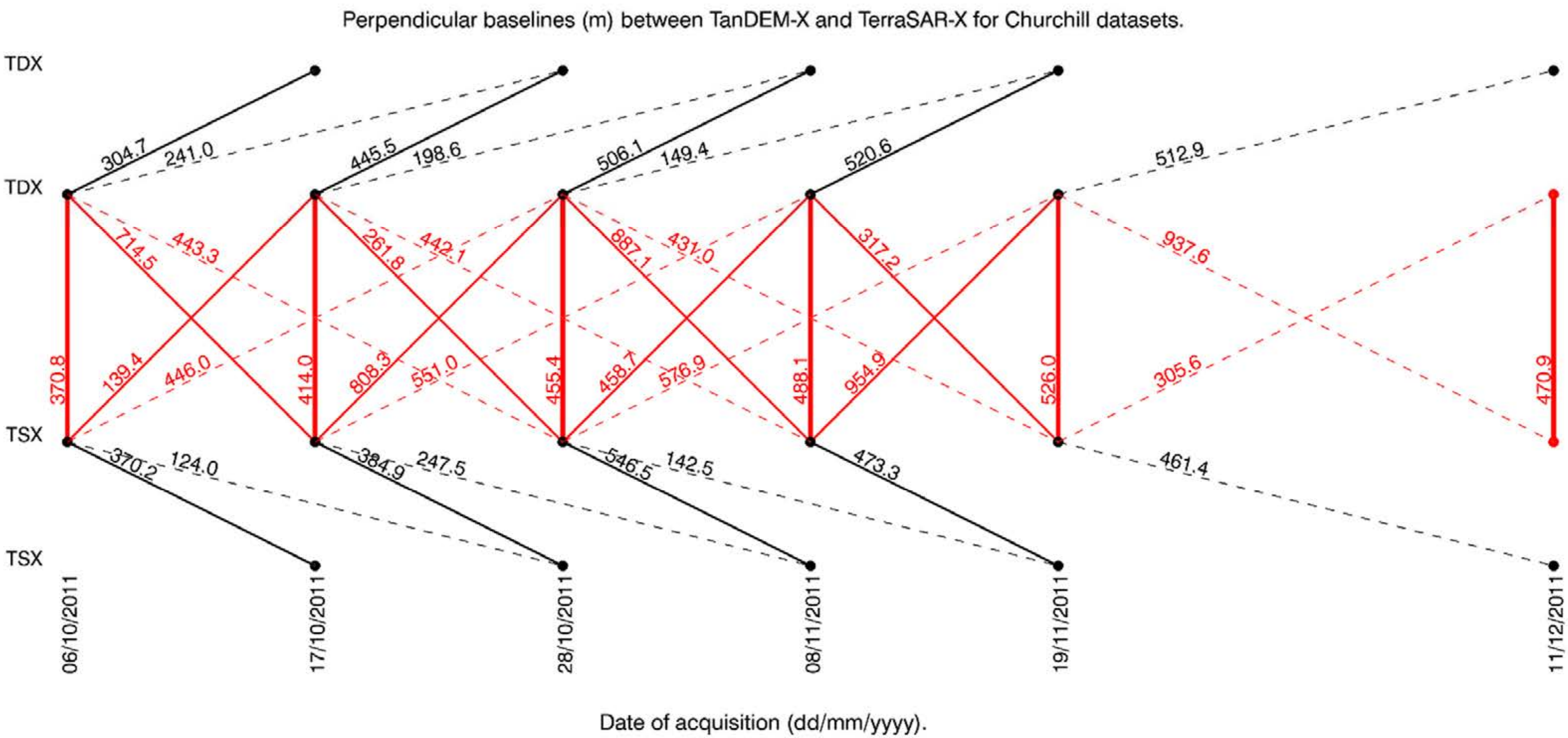
$b_\perp$ = 10...30 m -> airplane (h_{AGL}=2.5 km)

$b_\perp$ = 15...25 m -> airplane (h_{AGL}=1.5 km)

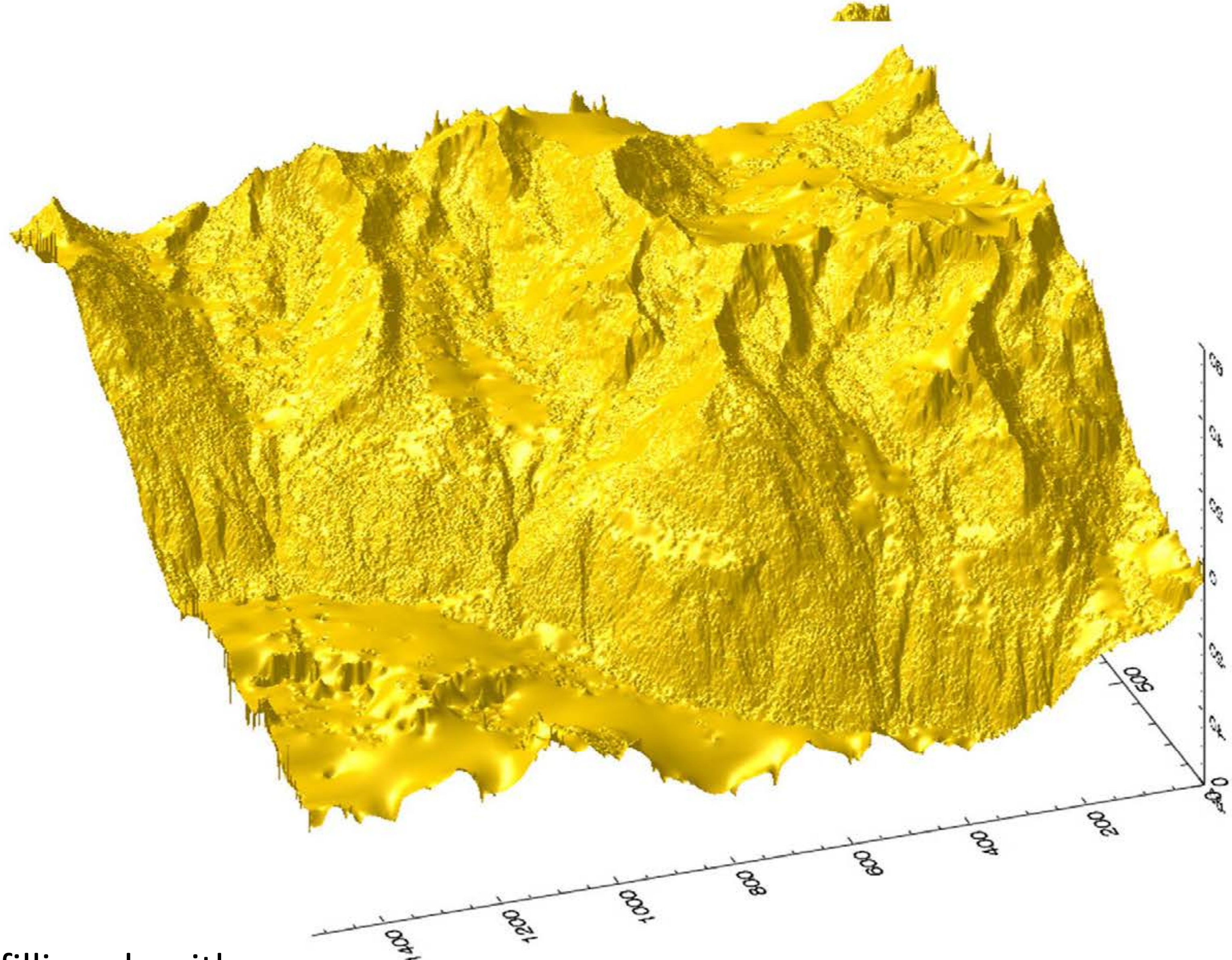
$$B_\perp = \Delta\theta \cdot R_0 = \sin\theta \cdot \frac{\kappa_z \lambda}{4\pi} \cdot R_0$$



Baseline overview for TanDEM-X

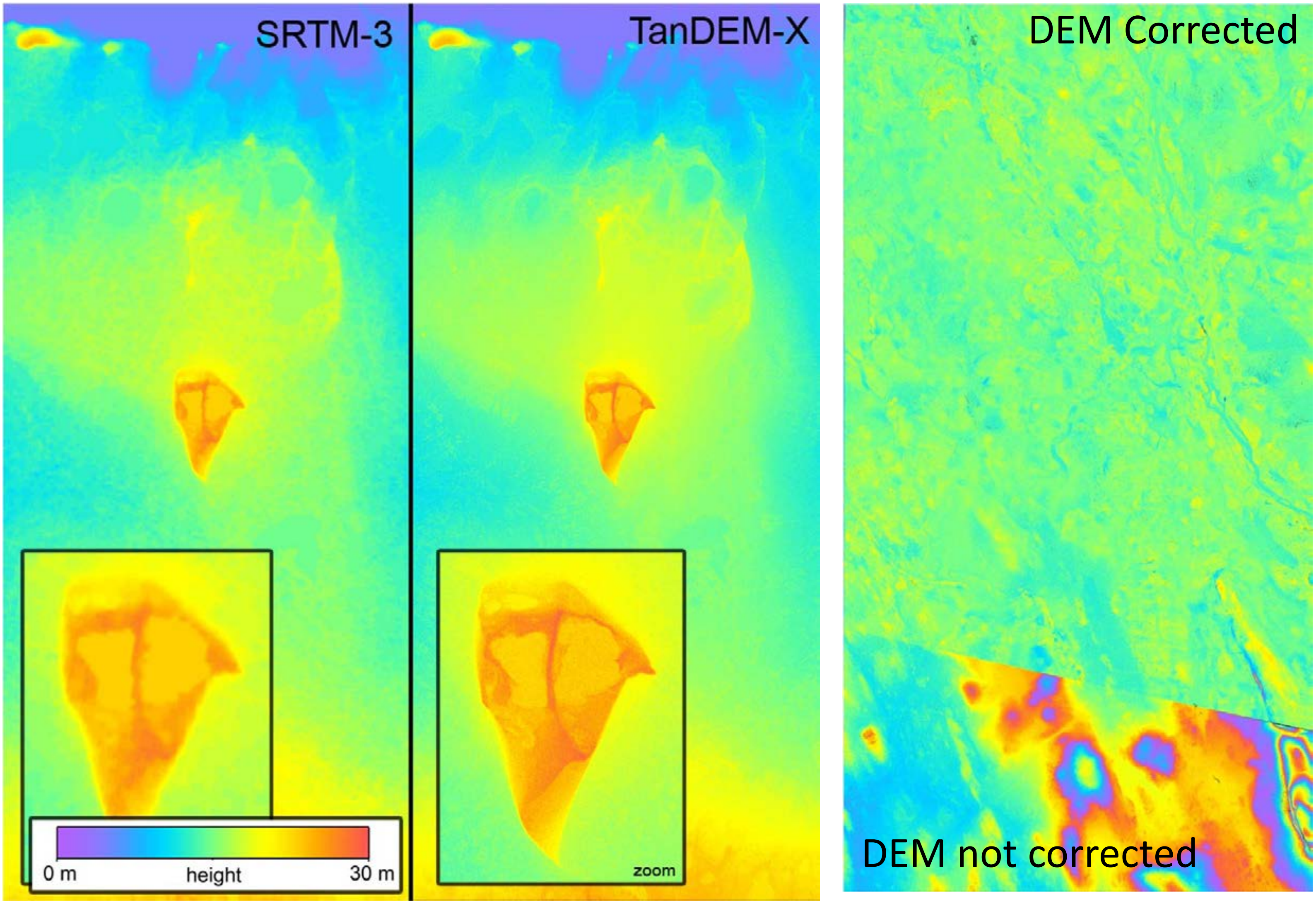


DEM generation with TDX

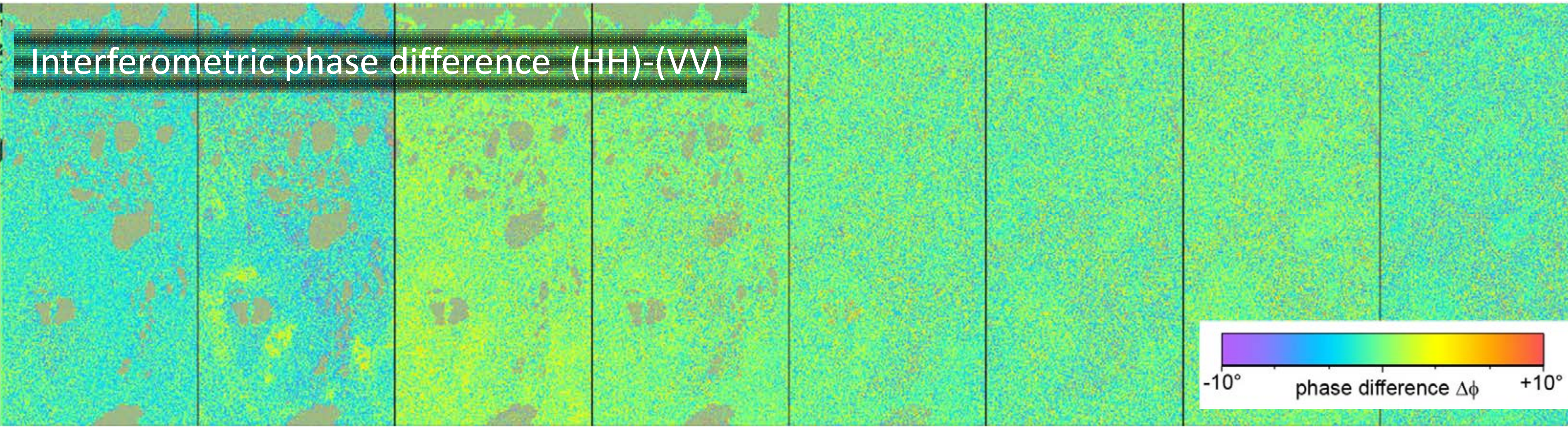


-> gap filling algorithm

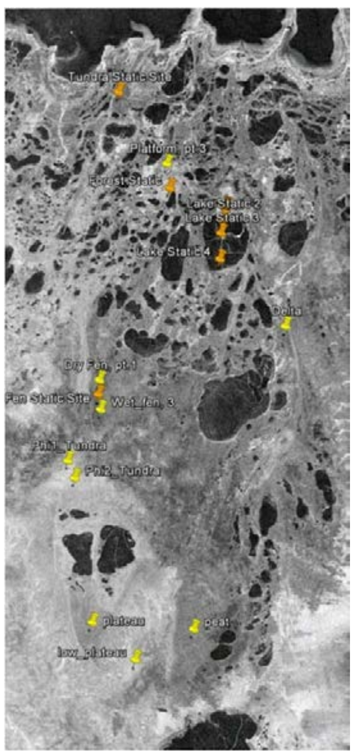
Generation of a DEM

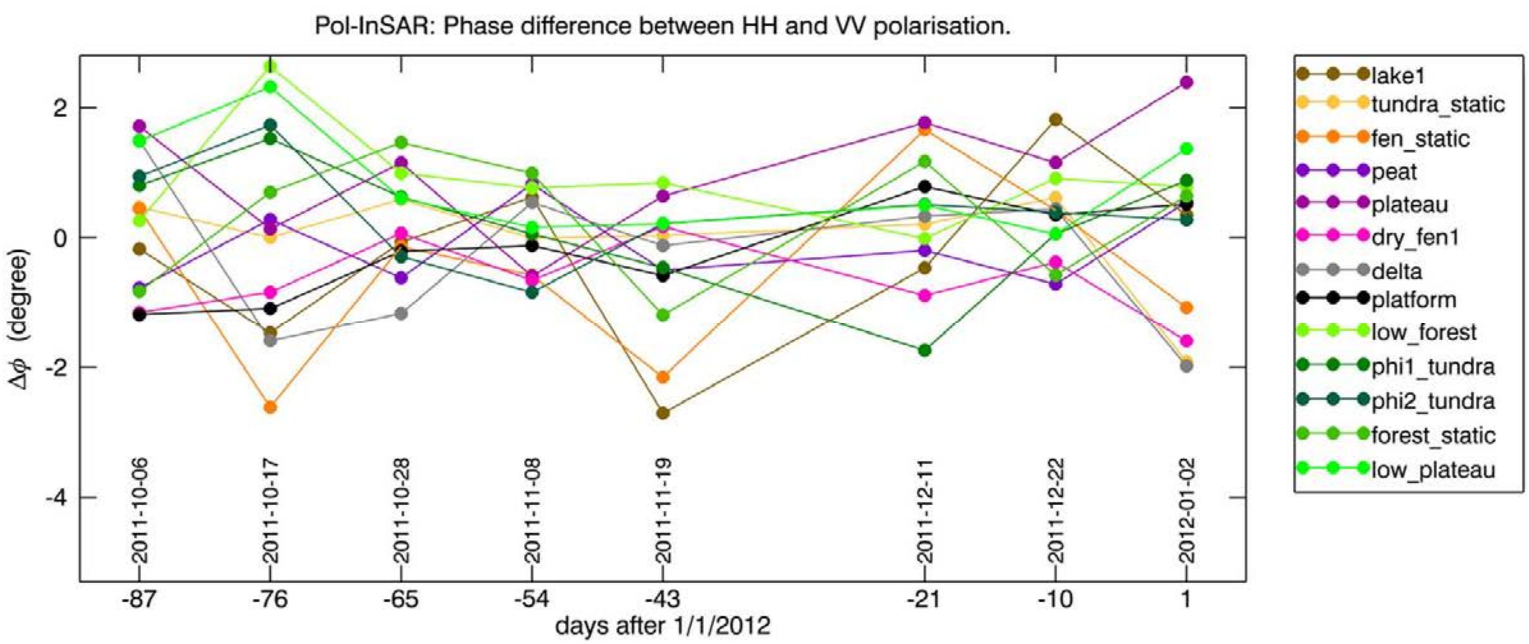


TanDEM-X Pol-InSAR: DEM(VV) vs. DEM(HH)



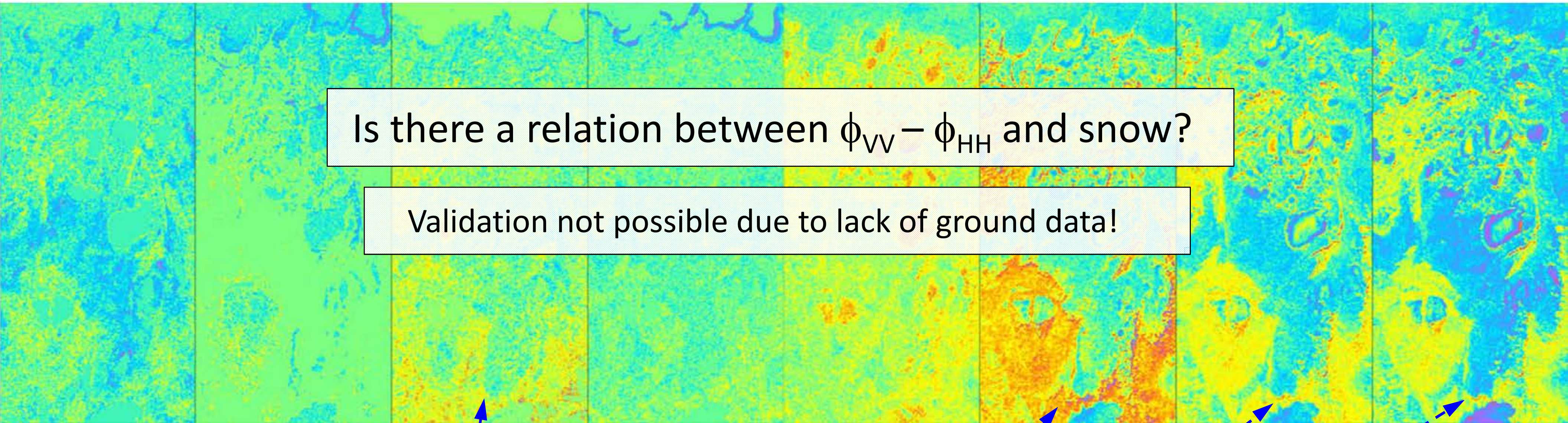
06-Oct 2011 | 17-Oct 2011 | 28-Oct 2011 | 08-Nov 2011 | 19-Nov 2011 | 11-Dec 2011 | 22-Dec 2011 | 02-Jan 2012





Polarimetry: Phase differences VV-HH

Values $\gamma < 0.4$ are masked and set to the average phase difference.

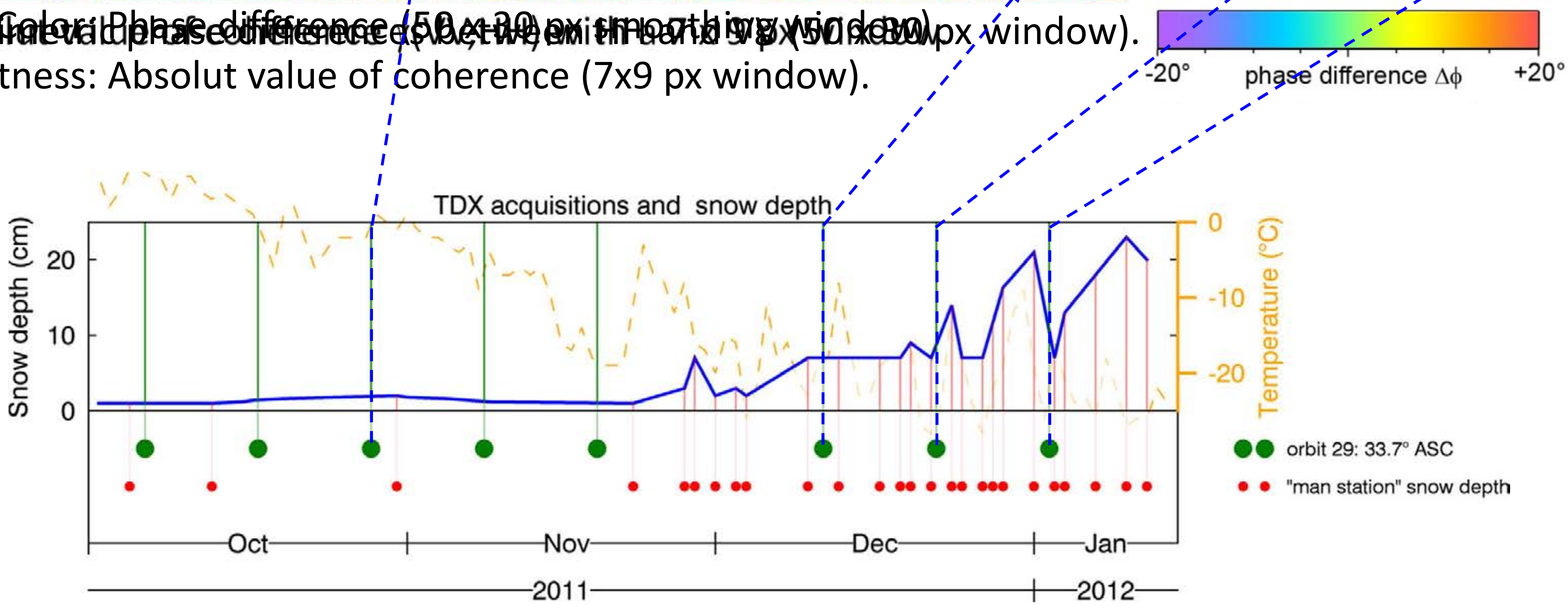


Is there a relation between $\phi_{VV} - \phi_{HH}$ and snow?

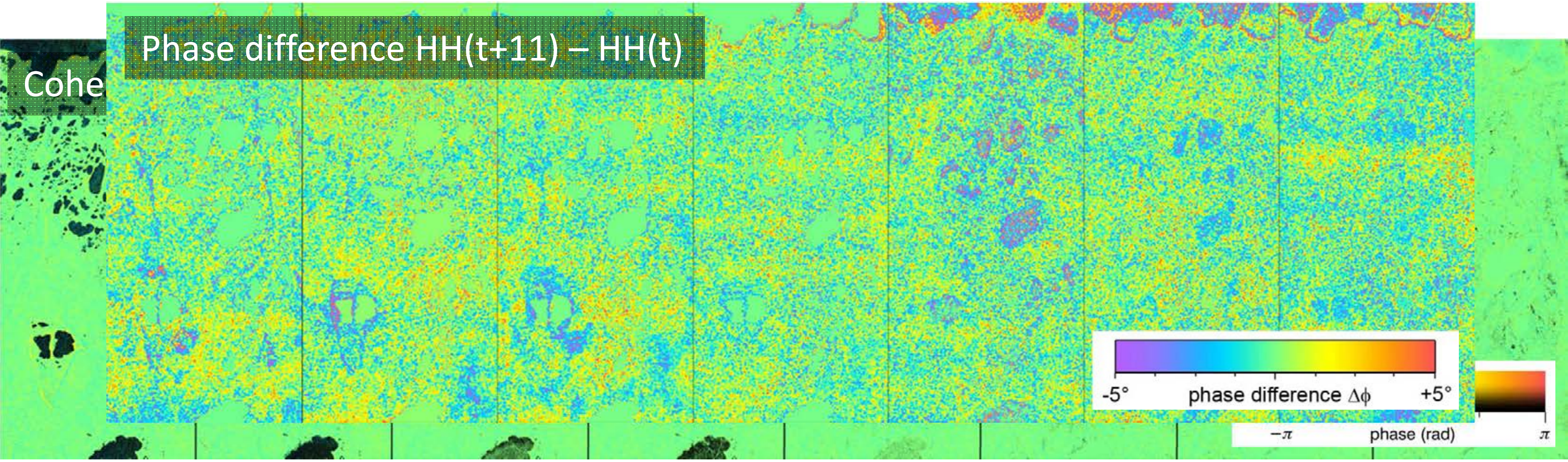
Validation not possible due to lack of ground data!

Color: Phase difference (50 x 20 px smoothing window).

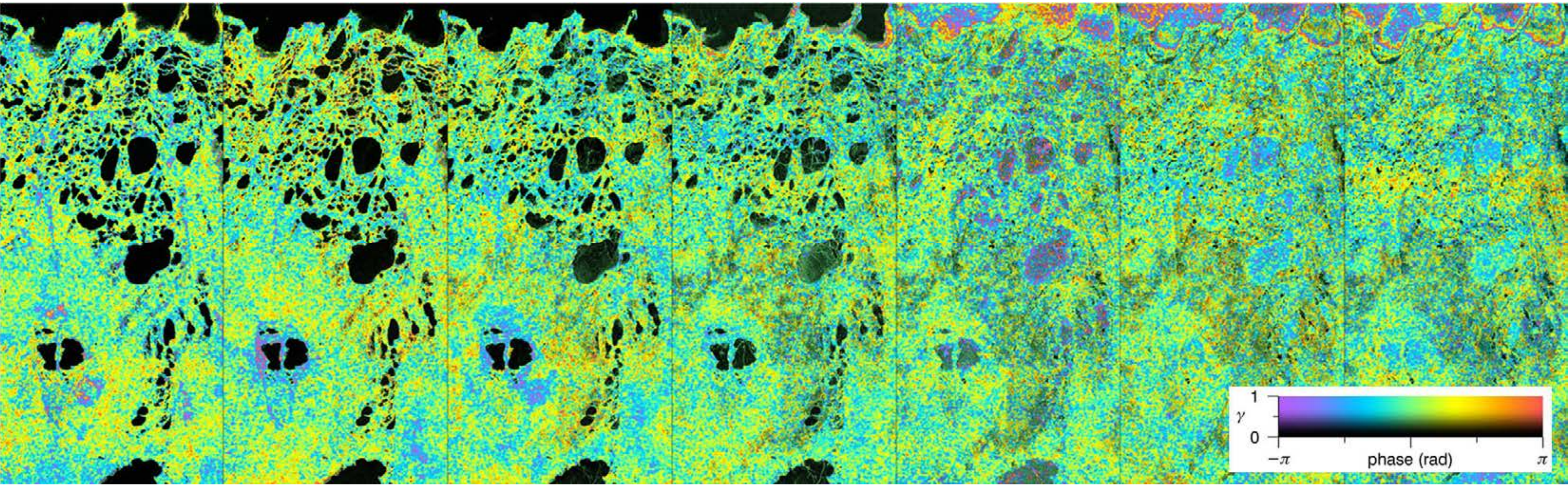
Brightness: Absolut value of coherence (7x9 px window).



TanDEM-X: Double D-InSAR



06-Oct 2011 17-Oct 2011 28-Oct 2011 08-Nov 2011 19-Nov 2011 11-Dec 2011 22-Dec 2011 02-Jan 2012



Differential complex coherence $\gamma_{HH}(t+11) * \bar{\gamma}_{HH}(t)$

Interferometry data churchill

- Abs_coherence
- complex interferogram.

(- interferogram)