Enhancement of SnowScat for tomographic observation capabilities

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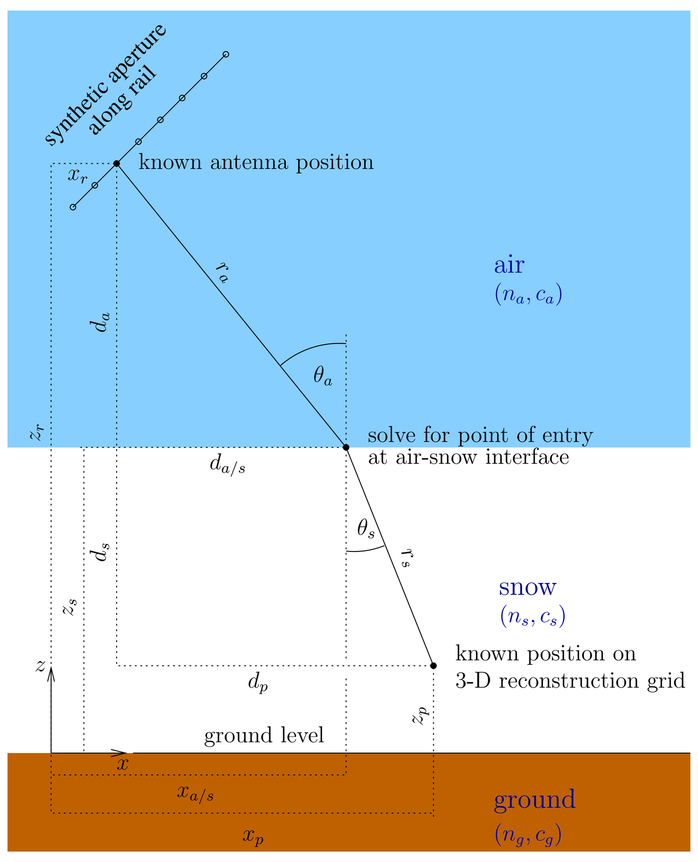
Motivation / Goals

- The SnowScat instrument has originally been designed as a tower-mounted fully polarimetric scatterometer for measurements of the radar cross-section of snow at X-band up to Ku-band over a frequency range of 9.15 – 17.9 GHz.
- Here, we present an extension of SnowScat for tomographic profiling capabilities.
- This extension aims at enhancing the SnowScat device in order to better respond to the ESAC recommendations made on the deselected CoReH2O candidate following the User Consultation meeting in March 2013 for the 7 Earth Explorer mission.
- Such new capability allows for performing high-resolution tomographic profiling observations providing further insights into the complex electromagnetic interaction within snowpacks.
- We present and discuss first results of a series of tomographic profiles of a snowpack acquired at a test site of SLF in Davos, Switzerland, between Dec. 2014 and March 2015.

Methods: Simplified model and time-domain based reconstruction scheme



$$v(\vec{r}_i) = \sum_{k=1}^{M} g_k[R_v(\vec{r}_i, \vec{r}_k, n_s)] \cdot \exp[i\, 4\pi/\lambda R_v(\vec{r}_i, \vec{r}_k, n_s)] \,. \qquad (1)$$

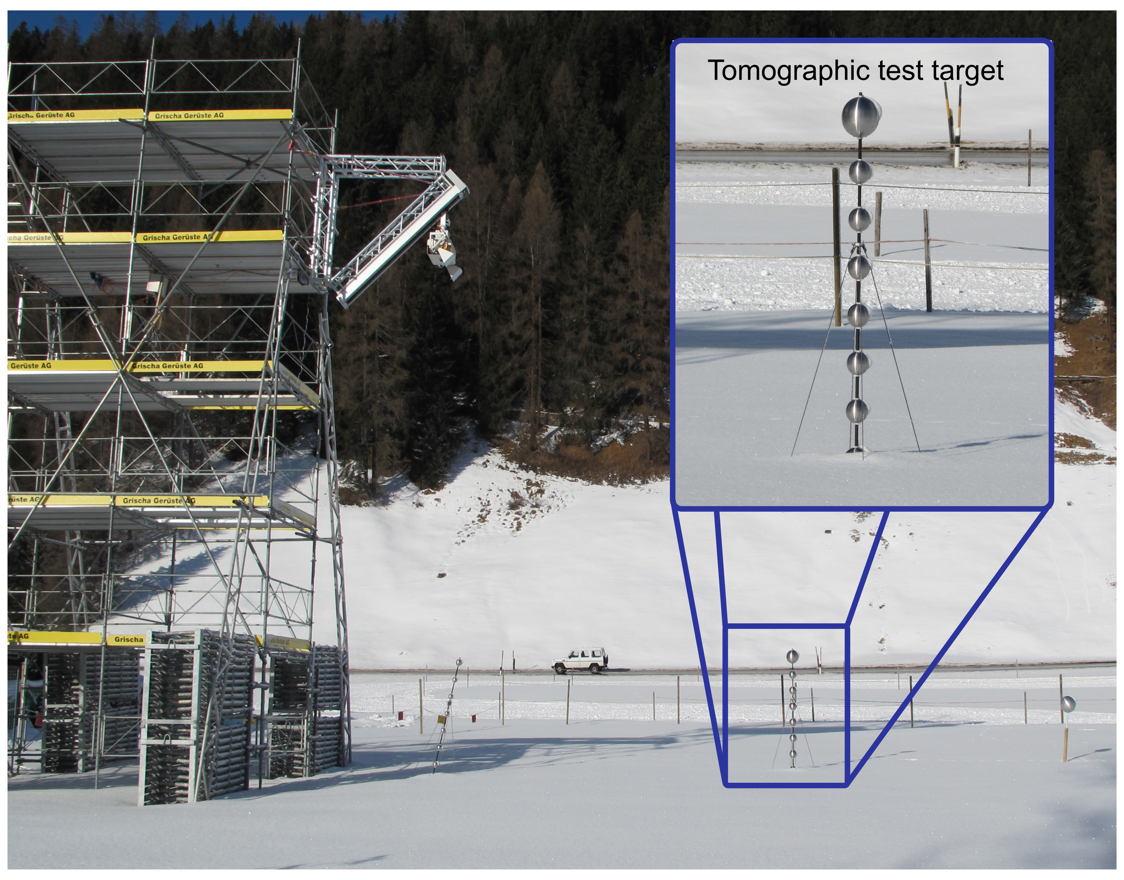
$\vec{r}_i$	: 3-D position vector of the target location for which the tomographic inversion is performed.
$\vec{r}_k$	: 3-D position vector of the antenna phase center at position k within the synthetic aperture.
$g_k(...)$	: Range-compressed signal at antenna position k.
λ	: Wavelength of the carrier signal.
$R_v(\vec{r}_i, \vec{r}_k, n_s)$	: (Virtual) range distance between antenna position k and the location $\vec{r}_i$ taking into account the refraction.
$v(\vec{r}_i)$	: Tomographically focused signal at location $\vec{r}_i$.

$$\sin\theta_a = \frac{d_{a/s}}{\sqrt{d_{a/s}^2 + d_a^2}} \qquad \text{Snell's law: } \frac{\sin\theta_a}{\sin\theta_s} = \frac{n_s}{n_a}$$

$$\sin\theta_s = \frac{d_p - d_{a/s}}{\sqrt{(d_p - d_{a/s})^2 + d_s^2}}$$

→ solve for $d_{a/s}$

Experiment: Tomographic measurement setup at the SLF test site in Davos, Switzerland



- SnowScat device is moveable along a rail tilted by 45 degree.
- Maximal synthetic aperture (PLOS) L = 2.22 m.
- Pointing direction of antennas is adjustable in elevation and azimuth
- Assuming an incidence angle of 45 degree and the SnowScat antennas positioned at the center of the synthetic aperture the SnowScat antennas are pointing to the center of the tomographic test target with its vertical array of metal spheres.

Stripmap-mode resolution

$$\delta_n = \frac{\lambda_c r_0}{2L} (= 0.05m),$$

max. synth. apert. L=2.22m.
Range @ PCA: r_0 = 9 m,
for unconstrained beamwidth.
BUT, $\theta_{bw} = \lambda/D$ of SnowScat: [9.0°, 4.6°].
So, for r_0 = 9 m → $L_{st} = 0.72m$ based on $\theta_{bw} = 4.6^o$
⇒ Max. resolution in elevation:

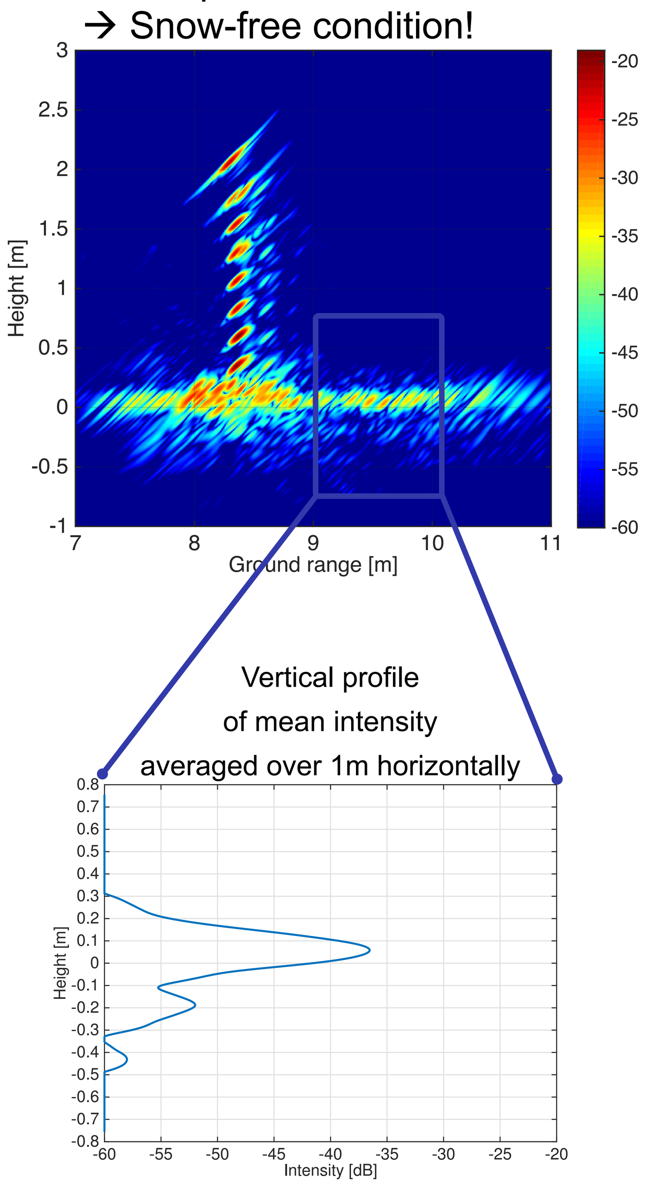
$$\delta_{n_{st}} = \frac{\lambda_c r_0}{2L_{st}} = 0.15m$$

System Specification of SnowScat

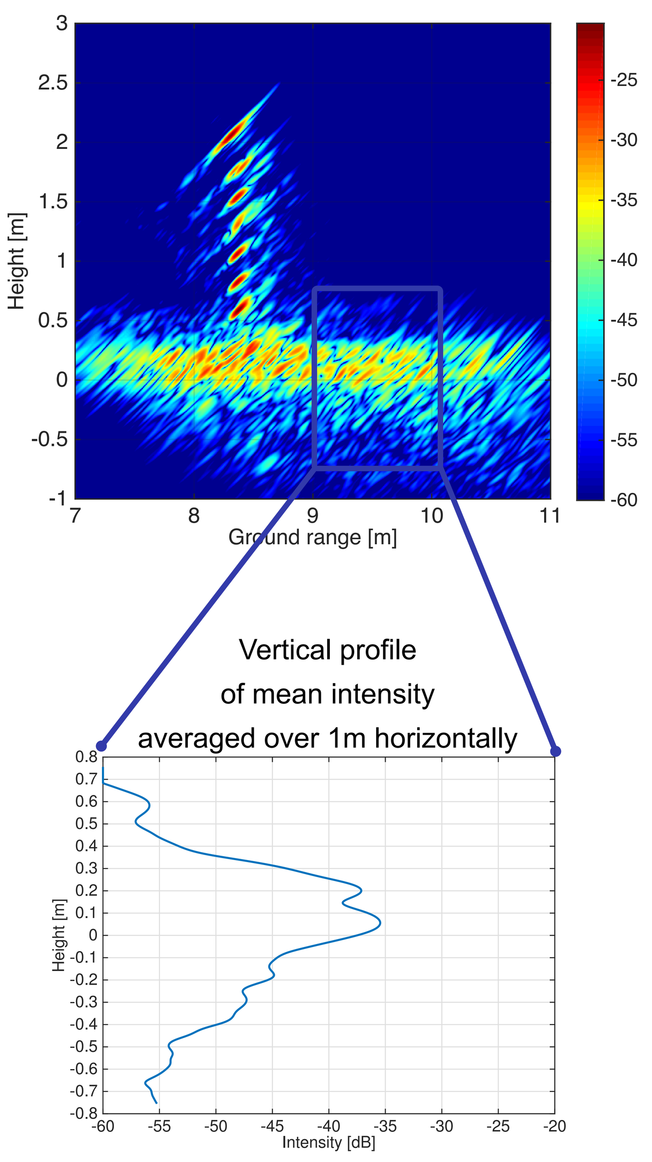
Power	230V, max ∼ 60W
Weight	∼ 40 kg
Temperature range	-40°C to 40°C
Antennas	Dual pol, < 10° (3dB)
Antenna cross-pol	< -25 dB
Frequency	SFCW from 9.15 to 17.9GHz
Incidence angle	-40° to 110°
Azimuth angle	-180° to 180°
Polarization	HH, HV, VV, VH
Dynamic range	Receiver dynamic range > 80 dB with the 16bit ADC
Signal bias	< 0.5 dB
Gain characterization	Internal calibration, Calibration sphere (Ø25 cm)
Control	Remote control through Ethernet, standalone
Data storage	Internal, external through Ethernet
RFI	Frequency blacklist

First results: Tomographic profiles of a snowpack

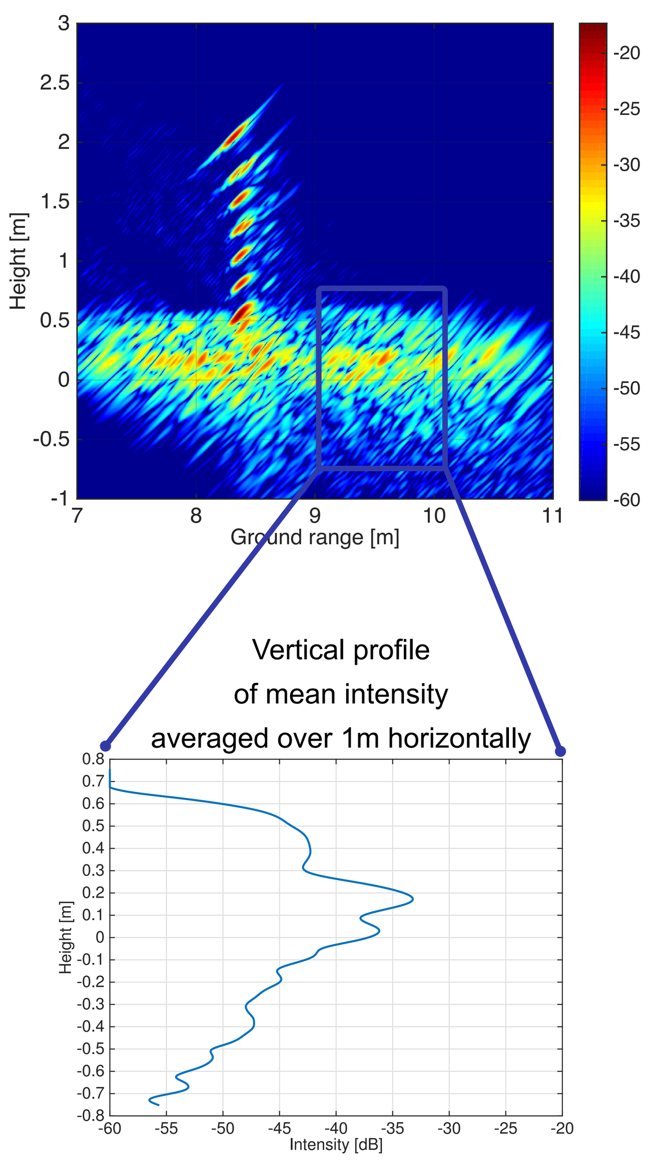
- Acquisition date: 14. Nov. 2014
- Acquisition time: 00:04h – 03:47h
- Snow height (SLF2) = 0 cm
- Air temperature = ~0°C
→ Snow-free condition!



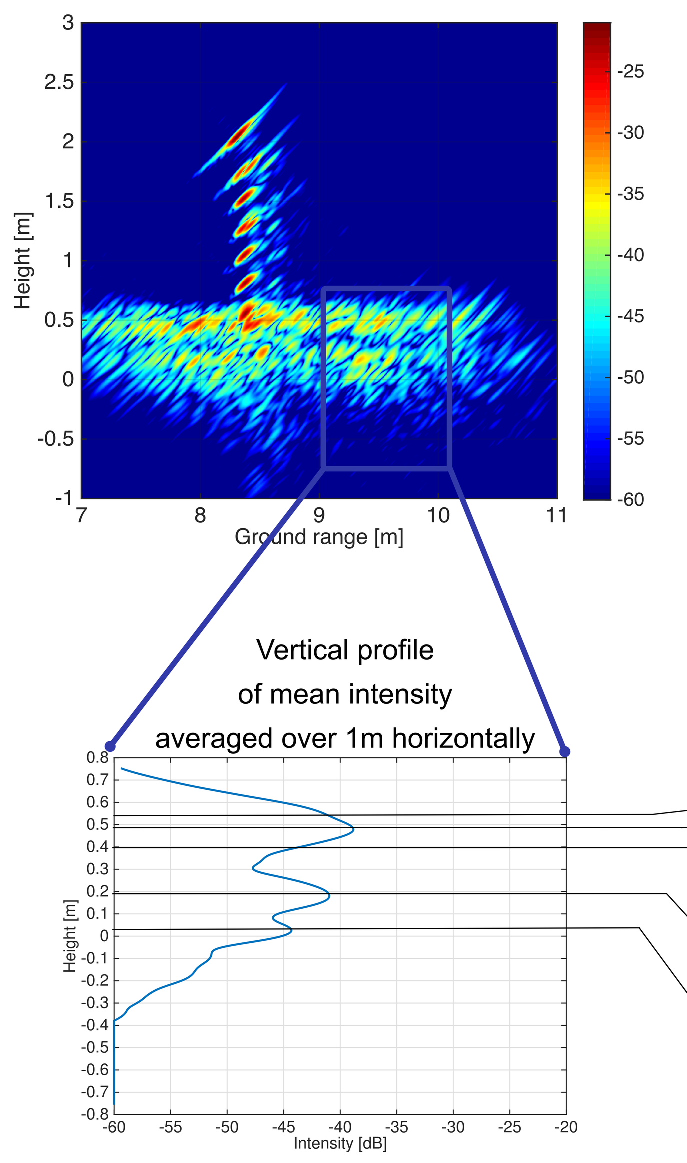
- Acquisition date: 29. Jan. 2015
- Acquisition time: 11:12h – 15:02h
- Snow height (SLF2) = 39 – 42 cm
- Air temperature = -4°C – -2°C



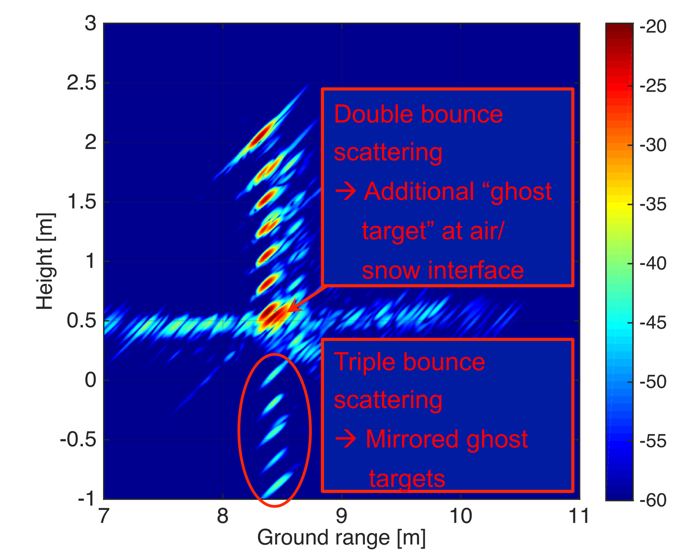
- Acquisition date: 01. Mar. 2015
- Acquisition time: 21:02h – 23:44h
- Snow height (SLF2) = 50 – 55 cm
- Air temperature = -1°C – 0°C

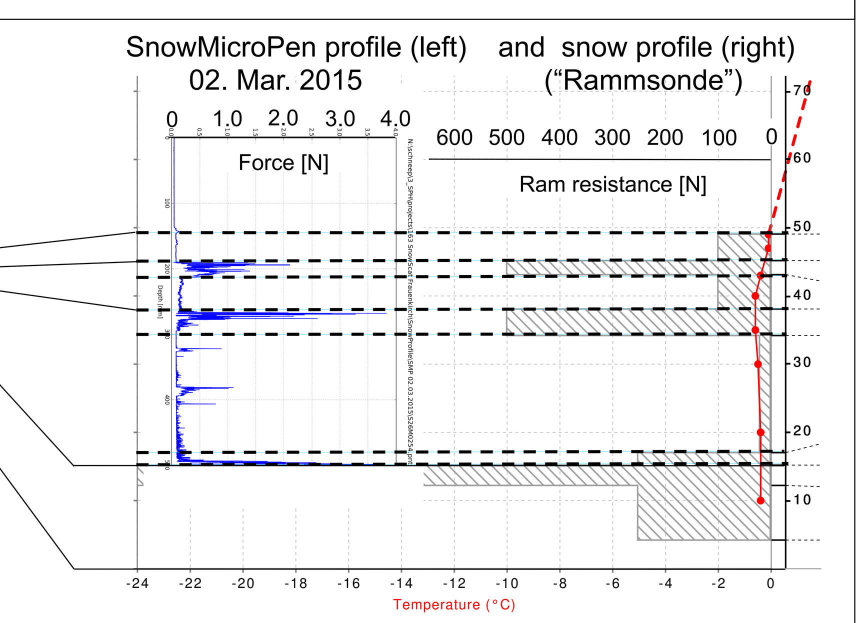


- Acquisition date: 03. Mar. 2015
- Acquisition time: 21:01h – 23:43h
- Snow height (SLF2) = 60 – 65 cm
- Air temperature = -4°C – -3°C



- Acquisition date: 15. Feb. 2015
- Acquisition time: 11:15h – 15:05h
- Snow height (SLF2) = 45 – 50 cm
- Air temperature = 4.3°C – 10.0°C





Discussion

- The new tomographic profiling observation capability of the enhanced SnowScat measurement setup was successfully demonstrated by means of:
  - a tomographic test target and
  - a first set of tomographic profiling measurements at a test site in Davos, Switzerland, under both snow-free and snow-covered conditions.
- The tomographic slices, obtained from 50 HH-polarized measurements along the rail, distinctly show
  - the ground surface layer in snow-free conditions and
  - different layers within the snowpack that were identified as melt-freeze crusts and ice layers in accompanying in-situ snow profile measurements.
- Tomographic profiles of average intensities reveal the most prominent layers in the snow pack.
- An interesting case was also found when a tomographic measurement was taken under a melted snow surface condition where virtually no penetration into the snowpack, but instead, double and triple bounce scattering can be observed resulting in "ghost targets" of the spheres of the tomographic test target.

Outlook

- Regarding tomographic imaging: Modeling of the refraction and the tomographic focusing need to be further refined for the case where multiple layers are present in a thick snowpack. This aspect requires further investigation and testing with SnowScat tomographic profiling data of a substantial snowpack.
- The new tomographic profiling capability of SnowScat now allows for investigating the complex electromagnetic interaction within snowpacks at **a high spatial resolution** at a dedicated test site over an extended period of time.

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