Processing and Calibration of Continuous Measurements of the Snowpack at Davos Switzerland During the 2018-2019 Winter Season using the WBSCAT Polarimetric Microwave Scatterometer

GAMMA REMOTE SENSING

Charles Werner[1], Rafael Caduff[1], Andreas Wiesmann[1], Urs Wegmüller[1], Othmar Frey[1], and Martin Suess[2]

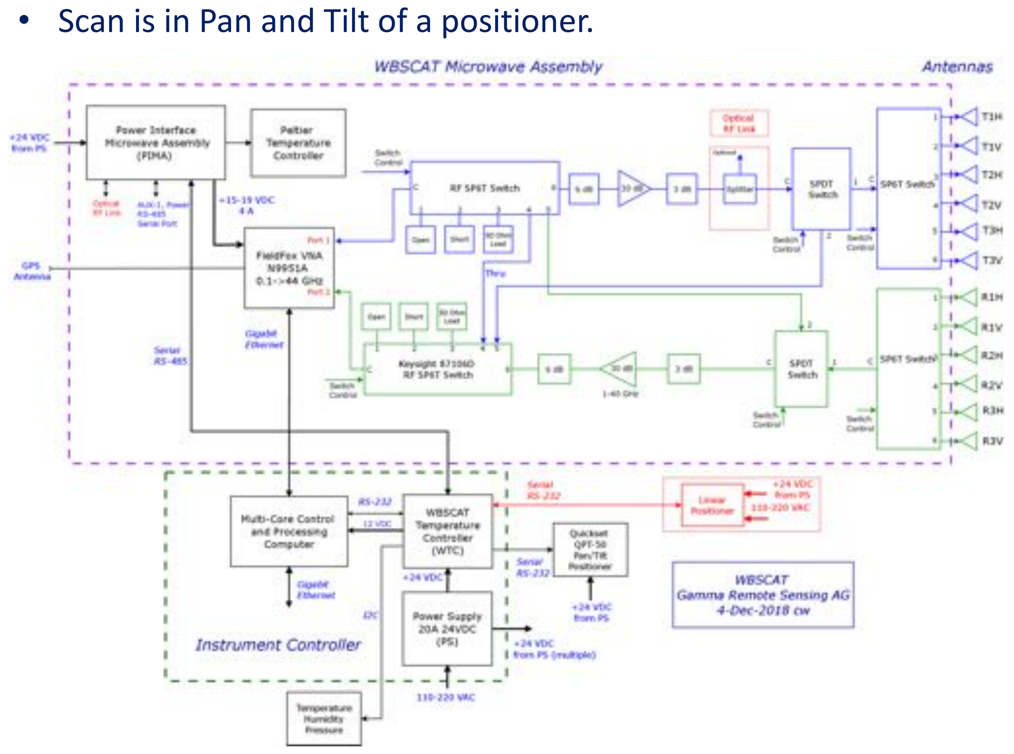
[1] Gamma Remote Sensing, CH-3073 Gümligen, Switzerland, http://www.gamma-rs.ch, cw@gamma-rs.ch [2] European Space Research and Technology Center (ESTEC), Noordwijk, The Netherlands

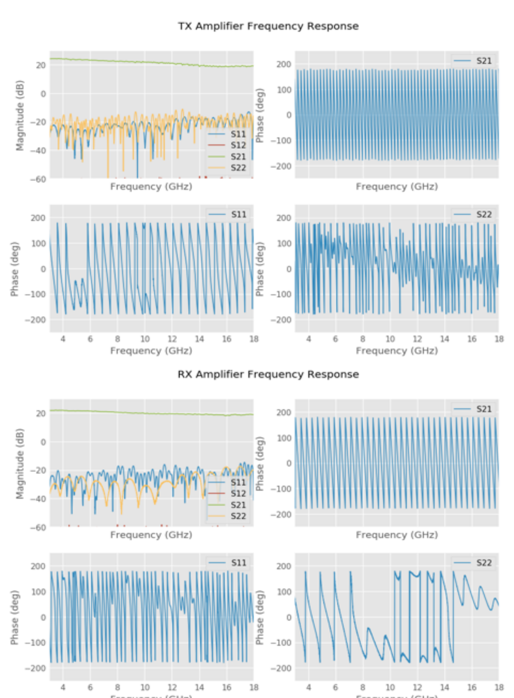
Motivation

- WBSCAT is a recently developed ground-based terrestrial microwave scatterometer was deployed during the 2018-2019 Winter season at Davos, Switzerland to make continuous measurements of the snowpack. This instrument measured the fully polarimetric radar backscatter over the frequency range of 1–40 GHz beginning in mid-December 2018 until the conclusion of observations in May 2019.
- WBSCAT has been developed for the European Space Agency (ESA) by Gamma Remote Sensing in Switzerland to support microwave studies of a wide range of ground covers including snow and ice. It is a component of Snowlab, a project including in-situ ground measurements of the snowpack characteristics, microwave radiometry, and active microwave backscatter measurements [1].
- The instrument is located at the Davos-Laret CryoNet Station (LAR) operated in cooperation with the WSL Institute for Snow and Avalanche Research SLF in Davos [1,2]. The Laboratory is located at 1514 meters altitude and is relatively level with grass ground cover.

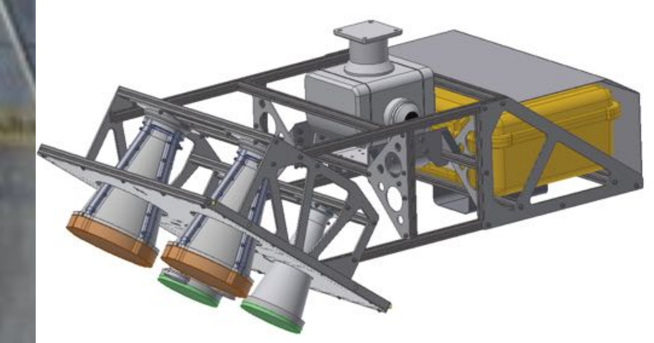
WBSCAT Instrument Hardware

- WBSCAT acquires fully polarimetric data in the frequency range 1-40 GHz in practically all-weather situations and temperatures -40 to +50C.
- A Vector Network Analyzer (Keysight FieldFox N9951A) is used for signal generation and coherent measurement of the backscattered signal.
- Short, Open, Load, Thru (SOLT) standards are used for VNA calibration
- and accurately measure the broad-band, low-noise amplifiers used in the receiver and transmitter. Quad-ridge horn antennas cover 1-6, 2-18, and 10-40 GHz with polarization isolation > 30 dB.
- Scan is in Pan and Tilt of a positioner.

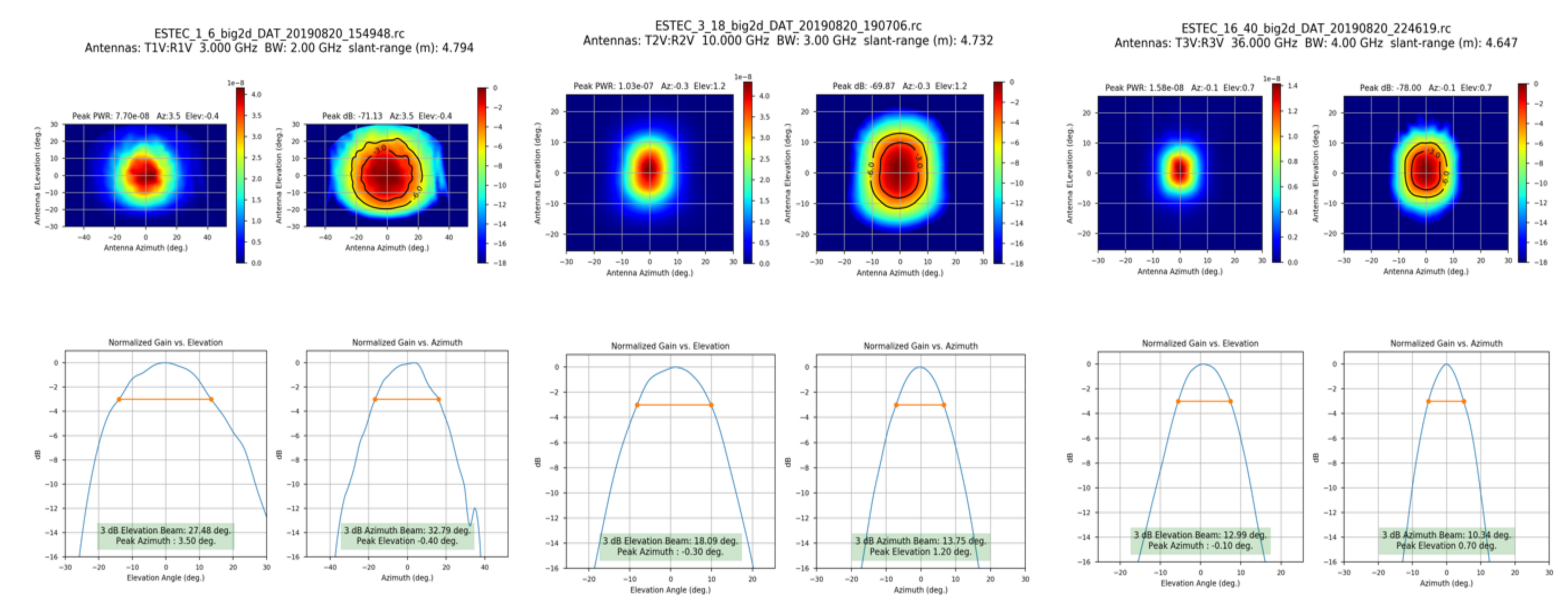




WBSCAT mounted on the 10m Tower.
Transmit and Receive antennas cover 1-6, 3-18, and 16-40 GHz



WBSCAT with Pan/Tilt positioner



Data Processing to Estimate σ_0

- WBSCAT acquires measurements of the radar cross-section coefficient σ_0 of the surface as a function of slant range
- For level terrain, incidence angle is directly related to slant-range distance
- Combine N independent samples of radar backscatter ("looks") to reduce radar speckle and thermal noise sources.

$$\Delta\sigma^0_{\mathrm{dB}} = \sqrt{(\sigma^2_{\mathrm{vna\_dB}} + (10\log(1\pm K_p))^2)} \qquad K_p = \frac{1}{\sqrt{N}}\left(1+\frac{2}{\mathrm{SNR}}+\frac{1}{\mathrm{SNR}^2}\right)^{\frac{1}{2}}$$

- The looks are obtained by a combination of **spectral** and **azimuth diversity**
- **Spectral diversity** uses data acquired over a bandwidth *B* to measure backscatter from samples spaced by ~c/2B in slant range
- **Spatial diversity** as implemented by SnowScat requires scanning the antenna beam over a range of azimuth angles.

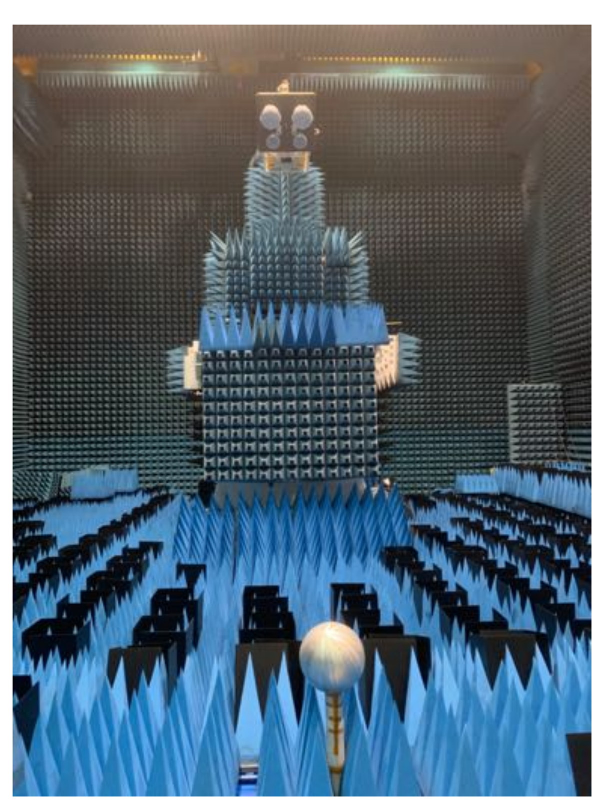
Data Acquisition Schedule

- Data acquisitions occurred 4 times each day (6,:30, 11:30, 17:30, 22:30) at incidence angles of 20, 30, 40, and 50 degrees
- The measurement field in azimuth consists of a span of 30 degrees with 6- degree azimuth step
- The number of looks is a function of the antenna azimuth beamwidth, span, and range-bandwidth
- Range bandwidth is 2 GHz for the 1-6 GHz band , 3 GHz 3-18 GHz band, and 4 GHz 16-40 GHz band
- Data were not acquired in the 8-11 GHz frequency range during the WEF conference in Davos

Meteorological Measurements

- Continuous meteorological measurements are performed at Davos-Laret include snow height and snow surface temperature as part CryoNet
- Davos Laret is designated as CryoNet Station (LAR), site coordinates, snow height, temperatures and automated aux measurements are available from: http://globalcryospherewatch.org/cryonet/sitepage.php?surveyid=194

External Calibration of RCS



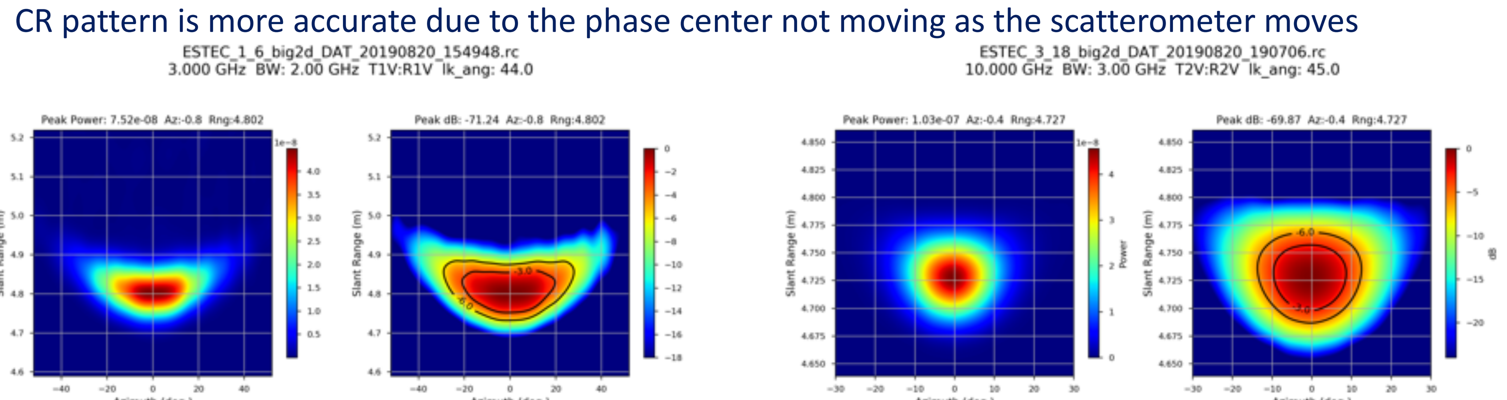
Calibration uses a metal sphere + target with strong cross-pol backscatter [3]

- Calibration Measurement Campaign at ESTEC HERTZ chamber during 18-23, August, 2020
- For a metal sphere or CR: $S_{hv}=0, S_{vh}=0$, and $S_{vv}=S_{hh}$ (CO-POL target)
- Requirement that the antennas have low cross-pol < -20 dB
- S_0 can be calculated, if r_0 is known to the reference standard
- For a dihedral or polarization grid rotated 45 deg. : $S^c_{hv}=S^c_{vh}$ (CROSS-POL target)
- Solve for S^u_{vv} and S^u_{hh} using known CO-POL target (Sphere or CR)
- Solve for S^u_{hv} and S^u_{vh} using known CROSS-POL target (Dihedral or Grid

Antenna Pattern Calibration

Measurement of RCS coefficient σ_0 requires knowledge of the 2-way antenna pattern!

- Measure 2D pattern of a strong CO-POL target such as Sphere or Corner-Reflector
- ESTEC HERTZ anechoic chamber exhibits low clutter permitting accurate antenna pattern measurement
- Small Bistatic Angle between the transmitter and receiver causes loss in the RCS of the CR
- CR RCS is still much greater(> 20 dB) than the sphere, even with bistatic loss factor
- Determine slant range of the calibration target and convert measurements in the pan/tilt geometry to azimuth and elevation in the antenna coordinate system
- Cross-calibrate the CR response with the Sphere response for low frequencies 1-6 GHz
- CR pattern is more accurate due to the phase center not moving as the scatterometer moves



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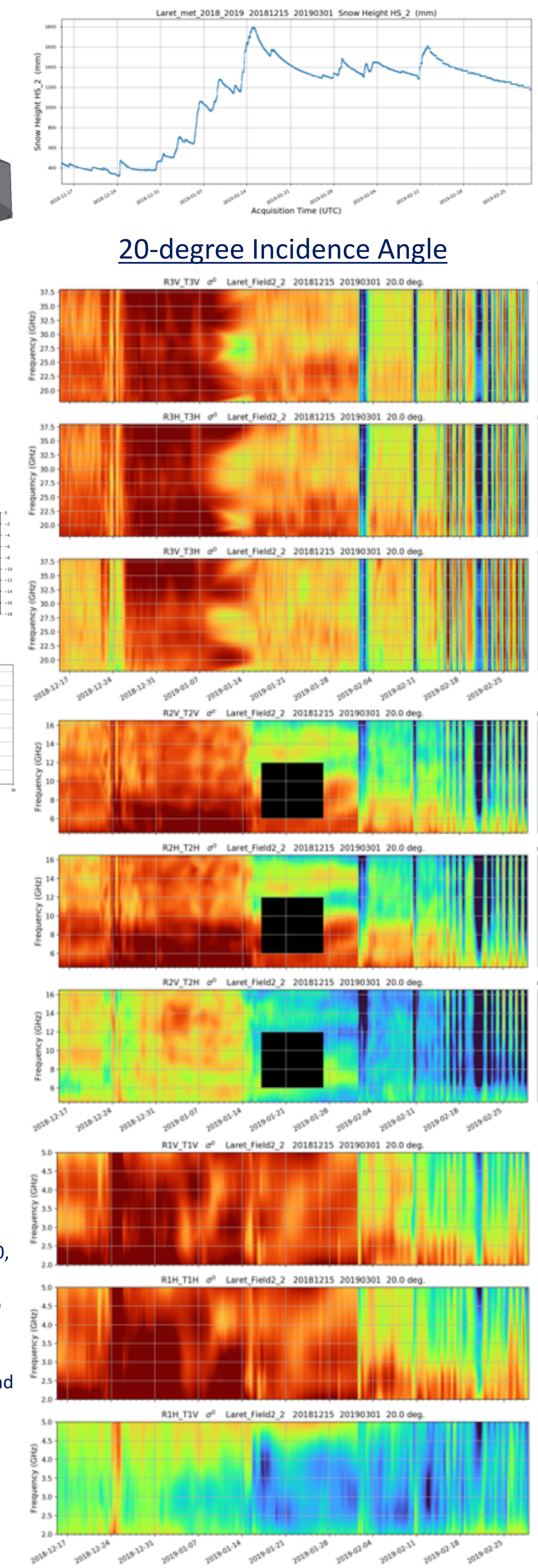
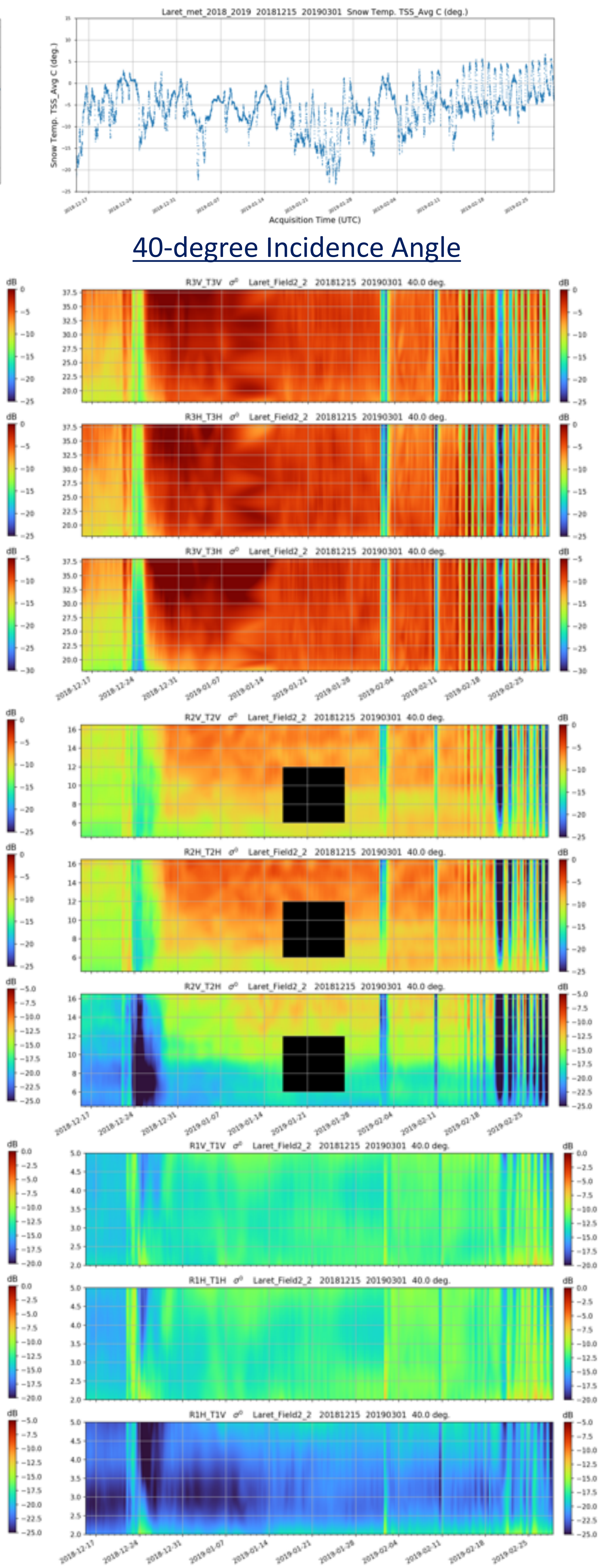


20-degree Incidence Angle



40-degree Incidence Angle

Conclusions

- WBSCAT has been calibrated over the full frequency range using reference targets: Sphere, Corner-Reflector, Polarization Grid data acquired August, 2020 at the ESTEC HERTZ test facility
- The entire 2018-2019 data series has been processed to σ_0 using calibration data from the ESTEC calibration data set
- Large changes in the angular dependence of σ_0 with incidence angle at 2,2.5,3,4,5 GHz
- There is a strong decrease in backscatter above 9 GHz related to the heavy snowfall on 14-Jan-2019
- Backscatter variations between 20 and 37.5 GHz during the snowfall period suggests layered or resonant structures in the snowpack
- Freeze-thaw cycles are strongly visible at above 5-6 GHz during late February into March