Validating a snow surface radiative transfer model between 89 and 243 GHz using airborne observations over Arctic tundra

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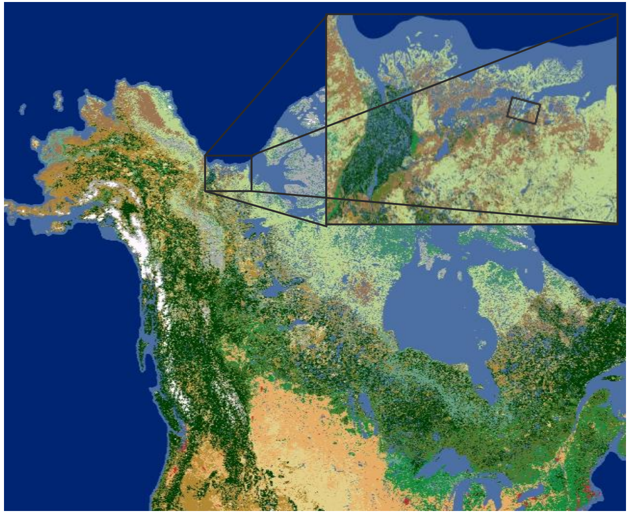

Location of the Trail Valley Creek site in Canada

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Motivation

- Microwave satellite radiance observations in polar regions have a **positive impact on NWP forecasts** both in the Arctic and at mid-latitudes but are often rejected as they are also **sensitive to the surface**
- **Snow microwave emissivity** is highly variable and **depends on snow microstructure**
- **Accurately predicting** snow surface emissivity would allow surface-affected microwave radiances to be **assimilated in the NWP system**
- A first step is to **validate the Snow Microwave Radiative Transfer (SMRT) model** at key atmospheric window and sounding frequencies from 89 to 243 GHz

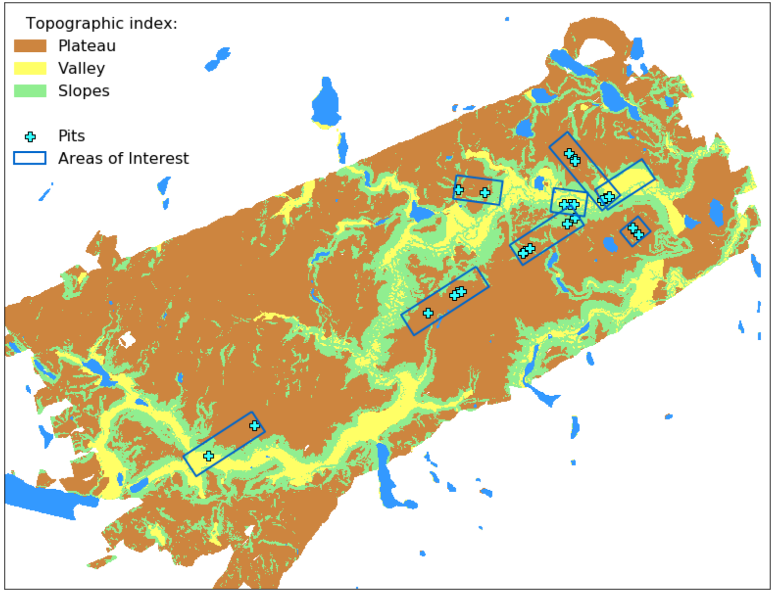

Figure: Topographic index of Trail Valley Creek, NWT, Canada with locations of 29 snow pits and 8 Areas of Interest (AOI)

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Data and methods

The **Facility for Airborne Atmospheric Measurements (FAAM) BAe 146 research aircraft** took part in a field campaign during the Year of Polar Prediction in March 2018, and collected **airborne microwave radiance observation**s over Trail Valley Creek in northern Canada.

Airborne observations were co-located with **ground-based radiometer observations** at 89 GHz and **in-situ vertical profile measurements of snow properties** across 29 snow pits.

Measured snow properties included:

- Layer thickness
- Density
- Temperature
- Specific surface area (SSA)

Snow pit observations were used as **input to SMRT** for passive simulations of **microwave brightness temperatures** for **multi-layer snowpacks.**

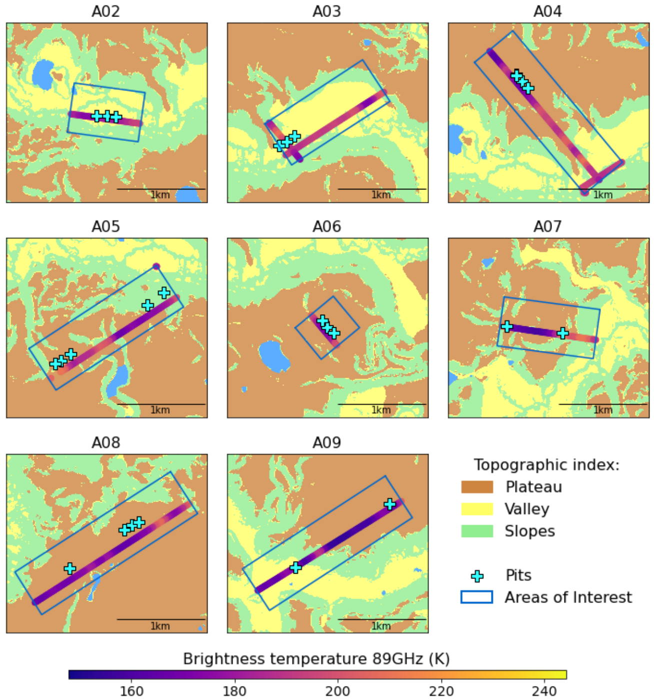

Figure: Topographic index for 8 Areas of Interest (AOI) with locations of snow pits and 89 GHz brightness temperature airborne observations. Snow pits were chosen to cover a range of topographies, aspects, and vegetation characteristics to be representative of the wider Arctic tundra.

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Comparison between SMRT simulations and ground-based radiometer observations at 89GHz

The **range of SMRT simulated brightness temperatures**, resulting from **variability in observed snow properties** (density and SSA), represent the ground-based radiometer observed brightness temperatures for all but two pits.

For these pits, underestimation of brightness temperatures could be attributed to snow properties such as low surface density (A03C1) and low SSA of the middle wind slab layer (A06S1).

These **simulations were improved** when such snow properties were replaced with median values for TVC data taken from Rutter *et al*. (2019).

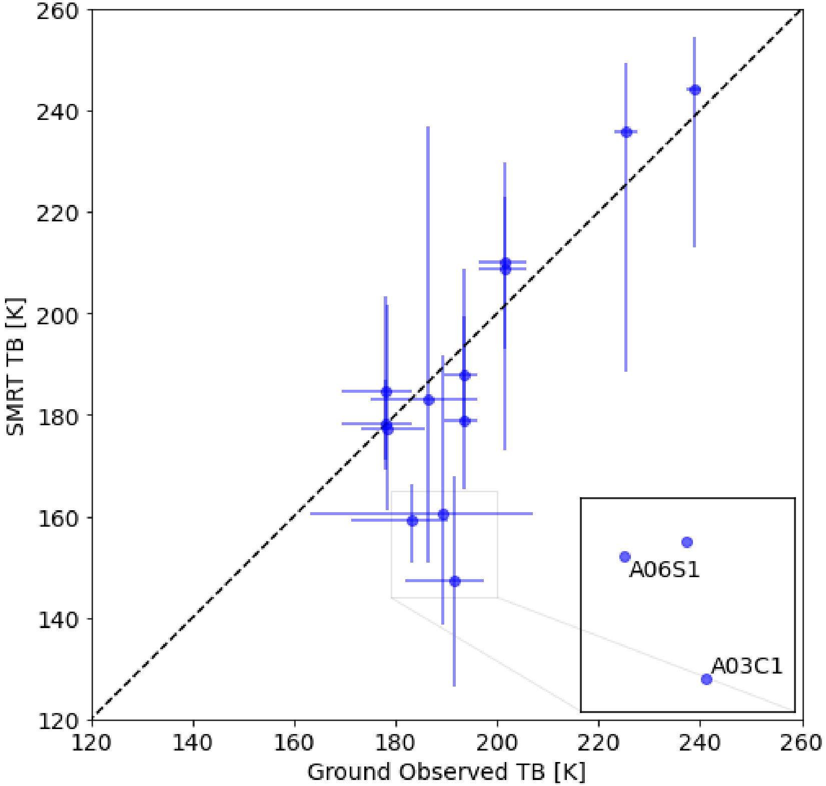

Figure: Simulated and ground observed brightness temperatures at 89 GHz. Error bars for SMRT show the range of simulations given the variability in observed microstructure.

Rutter, N., Sandells, M. J., Derksen, C., King, J., Toose, P., Wake, L., Watts, T., Essery, R., Roy, A., Royer, A., Marsh, P., Larsen, C., Sturm, M. (2019). Effect of snow microstructure variability on Ku-band radar snow water equivalent retrievals. The Cryosphere, 13(11), 3045–3059. https://doi.org/10.5194/tc-13-3045-2019

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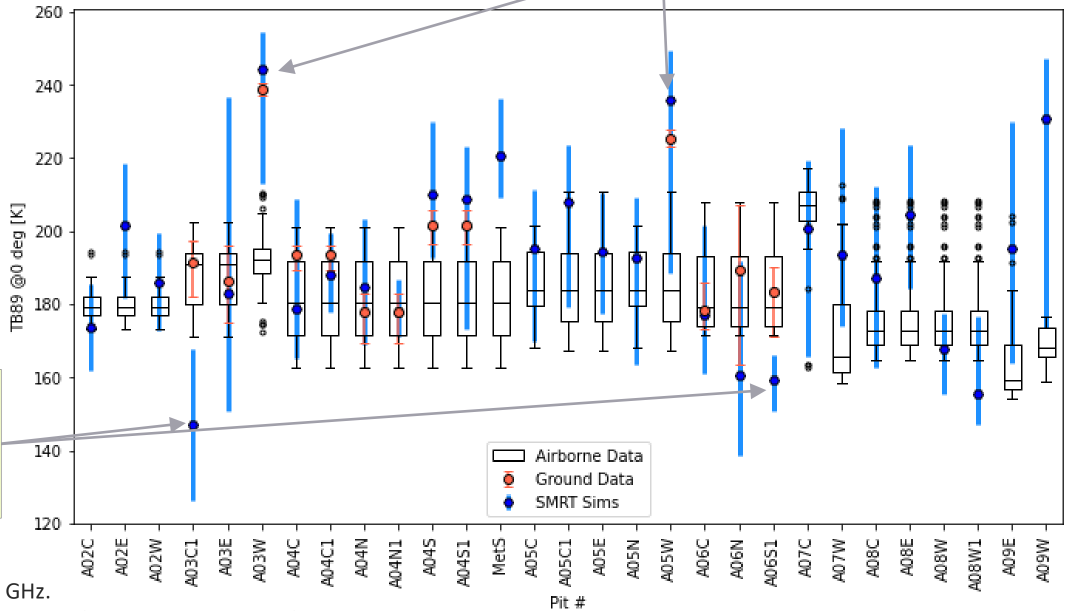
Comparison between SMRT simulations and ground-based and airborne observations at 89 GHz

Of the 29 snow pits, only 4 had no overlap between the range of SMRT brightness temperatures and the range in airborne observations.

The range in SMRT simulated brightness temperatures given the variability in observed snow pit properties suggest that **SMRT can represent airborne observed brightness temperatures** at 89 GHz in most cases.

A03W and A05W were the deepest pits and were associated with surface features e.g. snow drifts not captured by the aircraft footprint, hence there was reasonable agreement with the ground observations but not the airborne.



A03C1 and A06S1 simulations underestimated brightness temperatures compared with airborne observations as well as the ground-based observations as seen on the previous slide.

Figure: Observed and simulated brightness temperatures for each snow pit at 89 GHz.

- Box-and-whiskers show all airborne observations over a particular topographic index (plateau, valley, slope), corresponding to the pit topographic index, within the AOI.
- Blue points show SMRT simulations with error bars representing the range of simulations given the variability in observed microstructure.
- Orange points and error bars show surface-based radiometer observations where they were available.

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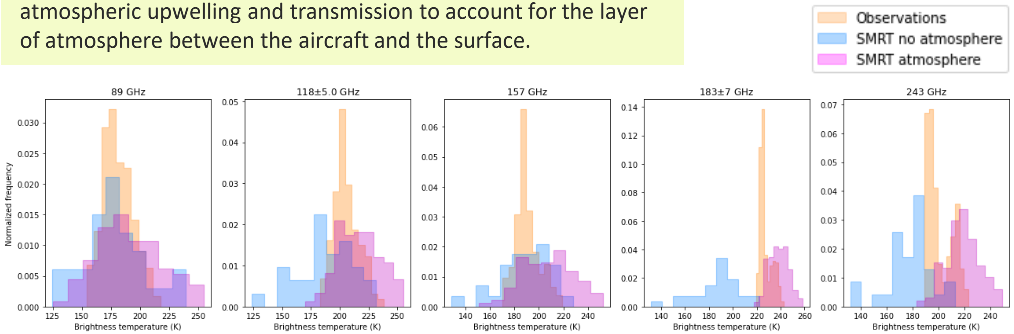
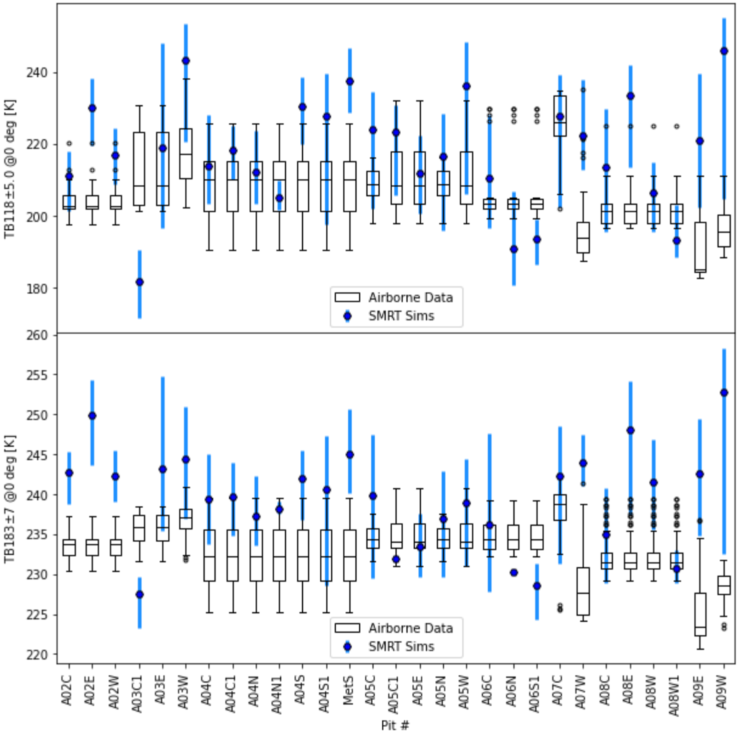
Comparison between SMRT simulations and airborne observations at higher frequencies

Despite greater uncertainty in simulations at higher frequencies due to limitations of the Improved Born Approximation electromagnetic model, and a general warm bias in many of the simulations, many pits do see an overlap between the range in SMRT simulated brightness temperatures and airborne observations at the higher frequencies.

A **key feature** of this analysis is **the inclusion of an anisotropic atmosphere** in the SMRT simulations, the impact of which is particularly apparent at higher frequencies and atmospheric sounding channels (118 and 183 GHz).

The atmosphere accounts for atmospheric downwelling (radiation transmitted into the snowpack and reflected by the surface) and atmospheric upwelling and transmission to account for the layer of atmosphere between the aircraft and the surface.





Above: Observed and simulated brightness temperatures for each snow pit at 118±5.0 GHz (temperature sounding) and 183±7 GHz (humidity sounding).
Left: Histogram of brightness temperatures from 89-243 GHz showing the impact of neglecting atmospheric contribution in SMRT simulations.

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Summary

- Improved prediction of snow microwave emissivity would **allow surface sensitive satellite radiances to be assimilated in NWP systems**
- The **Snow Microwave Radiative Transfer (SMRT) model** produces **realistic simulations** of ground and airborne observed surface brightness temperatures at 89 GHz when accounting for observed variability in snow microstructure
- Simulations at higher frequencies and atmospheric sounding channels can be improved by accounting for the atmosphere

Next steps and long-term goals

- Further validation of SMRT:
  - Understanding simulation-observation differences at different frequencies
  - Accounting for Mie scattering at higher frequencies
  - Simulating surface emissivity using SMRT output
  - Assessing the performance of SMRT at satellite scale
- Coupling SMRT with a land surface model such as JULES to represent the snow structure
- Coupling SMRT to the RTTOV radiative transfer model used for operational satellite data assimilation

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