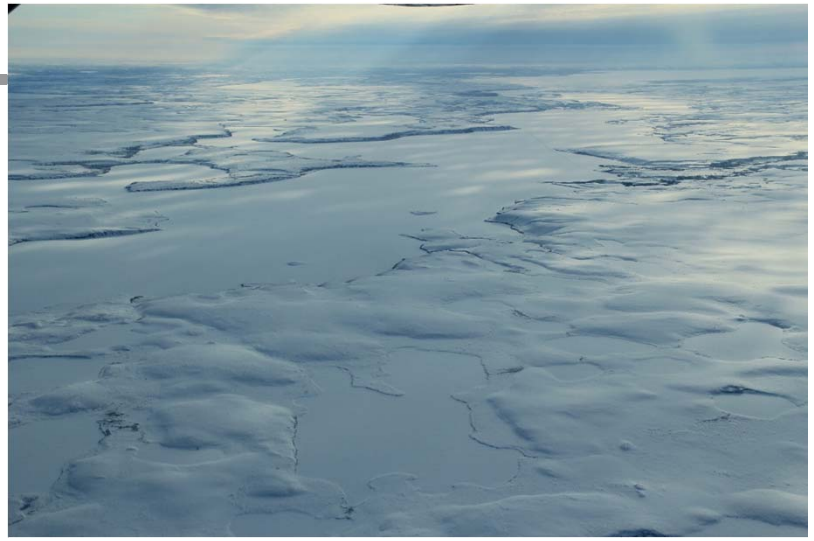
Environment and Climate Change Canada | Environnement et Changement climatique Canada

A Ku-band Radar Mission for Seasonal Snow Mass



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Dual-Frequency Ku-Band Radar Mission Concept for Snow Mass

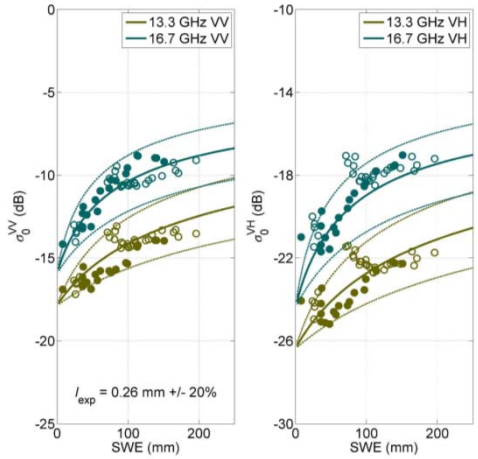
Improved remote sensing of snow mass is a priority at Environment and Climate Change Canada:

1. **Climate services and water availability** → Snow is a volatile freshwater resource, and the amount, distribution, and variability of terrestrial snow mass is poorly quantified (**requires snow mass estimates**) → How much water is stored as seasonal snow, how does it vary in space and time?

2. **Operational environmental prediction** → Improved initialization of snow mass will support more skilled hydrological prediction from land-atmosphere data assimilation systems (**requires backscatter**) → What is the contribution of snow to the water cycle and how well can we predict it?

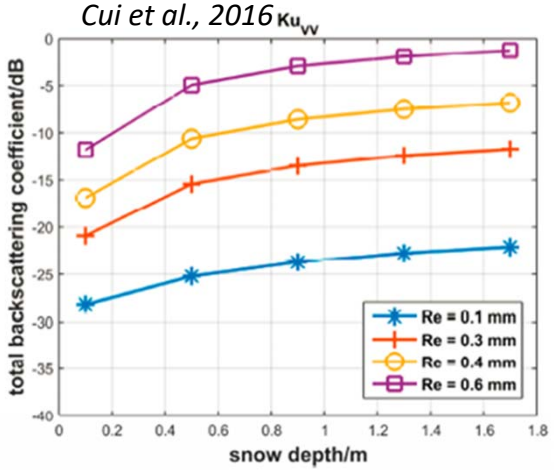
- Snow analysis from the Canadian Land Data Assimilation System is our starting point: provides snow mass and snow microstructure information

Dual-Frequency Ku-Band Radar Mission Concept for Snow Mass



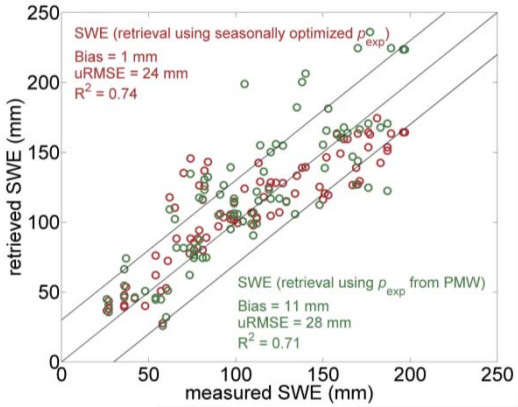
SnowScat backscatter at 13.3 and 16.7 GHz versus SWE, 2009/10 (blank symbols) and 2010/11 (filled symbols). Lines show MEMLS simulations using measured microstructure +/- 20 %.

Cui et al., 2016 Ku_{VV}



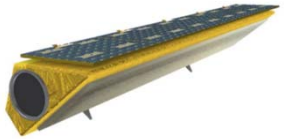
Influence of microstructure related to wavelength, hence two Ku-band frequencies (comparable sensitivity to SWE; different sensitivity to microstructure) are necessary.

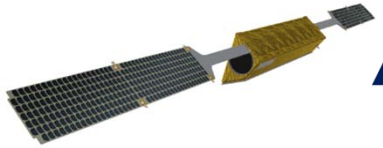
Lemmetyinen et al., 2018



SWE retrieved from dual-Ku band radar backscatter using seasonally optimized effective correlation length(red=radar derived; green=passive microwave derived).

Technical Concept

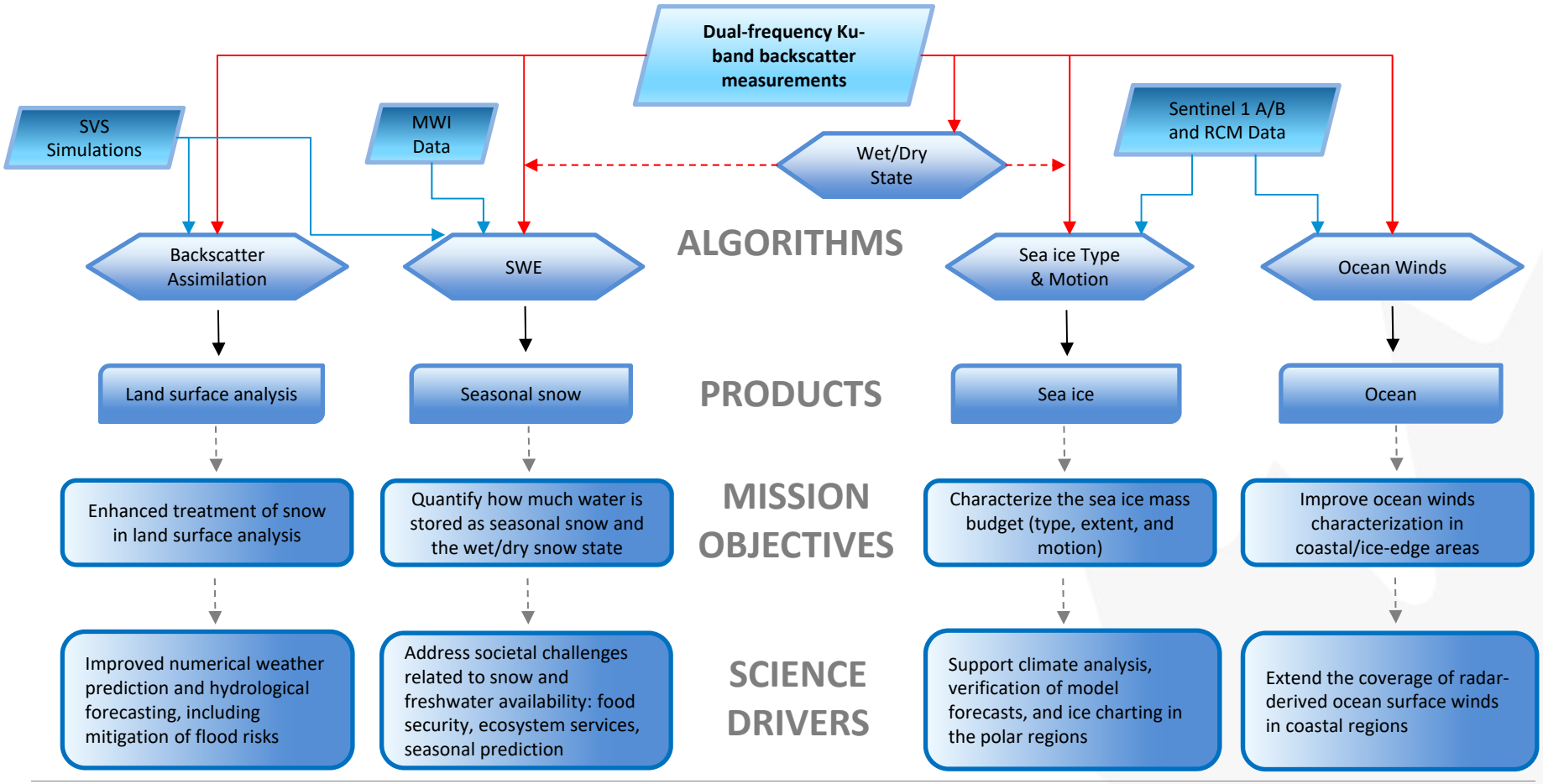




AIRBUS

- Single-aperture dual-frequency Ku-band antenna (13.5/17.2 GHz); sequential frequency operation
- 500 km swath (18 x 30 km)
- 250 m resolution (>4 looks)
- Stripmap mode: 10 m (single look)
- Mass, power, and heat dissipation budgets show a SAR-on duty cycle of 20-30% is achievable
- Multiple orbits still under consideration; complete swath overlap with the Microwave Imager (MWI) and C-band Scatterometer (SCA) (Met-Op-SG Sat B) is possible
- **Pre-cursor mission options are a high priority**

Characteristic	Threshold	Goal	Comments
Frequencies	Dual-band operation, 13.5 and 17.2 GHz		Maximises SWE retrieval capability and snow microstructure characterisation
Polarizations	VV; VH		Dual-pol negates effects of horizontal layering in the snowpack; cross-polarized backscatter benefits the detection of extreme high ocean winds
Ground Resolution	500 x 500m	250 x 250m	
Number of Looks	>4		Provides multi-looking to enhance radiometric quality
Acceptable Incidence Angle Range	23° - 55°	23° - 50	
NESZ – 13.5 GHz	<-26 dB (VV & VH)		Low NESZ ensures high sensitivity measurement of strong backscatter for dry snow, and detection of wet snow cover with weak backscatter.
NESZ – 17.2 GHz	<-25 dB (VV & VH)		
Azimuth and Range DTAR	<-20 dB		Typical DTAR to adequately control ambiguities
Radiometric stability	<0.5 dB		Required temporal consistency of observations
Radiometric absolute accuracy	1 dB	0.5 dB	Enables accurate retrieval of SWE


Dual-frequency Ku-band backscatter measurements
SVS Simulations
MWI Data
Wet/Dry State
Sentinel 1 A/B and RCM Data
ALGORITHMS
Backscatter Assimilation
SWE
Sea ice Type & Motion
Ocean Winds
PRODUCTS
Land surface analysis
Seasonal snow
Sea ice
Ocean
MISSION OBJECTIVES
Enhanced treatment of snow in land surface analysis
Quantify how much water is stored as seasonal snow and the wet/dry snow state
Characterize the sea ice mass budget (type, extent, and motion)
Improve ocean winds characterization in coastal/ice-edge areas
SCIENCE DRIVERS
Improved numerical weather prediction and hydrological forecasting, including mitigation of flood risks
Address societal challenges related to snow and freshwater availability: food security, ecosystem services, seasonal prediction
Support climate analysis, verification of model forecasts, and ice charting in the polar regions
Extend the coverage of radar-derived ocean surface winds in coastal regions

Trail Valley Creek Airborne 13.5 GHz radar

Trail Valley Creek Snow Experiment (TVCSnow)

Tundra environment ~50 km North of Inuvik, Northwest Territories.

- November 9-23, 2018
  -Early season snow; soil freeze-up
- January 7-23, 2019
  -Accumulation period
- March 17-31, 2019
  -End of season microstructure
  (+ unexpected surface melt/refreeze)

UMass 13.5 GHz Radar

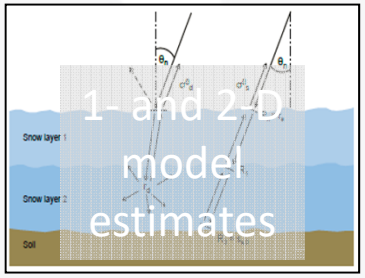
- Airborne 13.5 GHz (Ku)
- Single-polarization (VV)
- 2 x 2 m, 1000 m swath

TVC field campaign

- Snow transect measurements
- SnowMicroPen, IceCube
- Microstructure measurements

SMRT (Picard et. al, 2017, GMD)

- Active-passive microwave radiative transfer model for snow
- Can use field estimated microstructure in the scattering coefficient



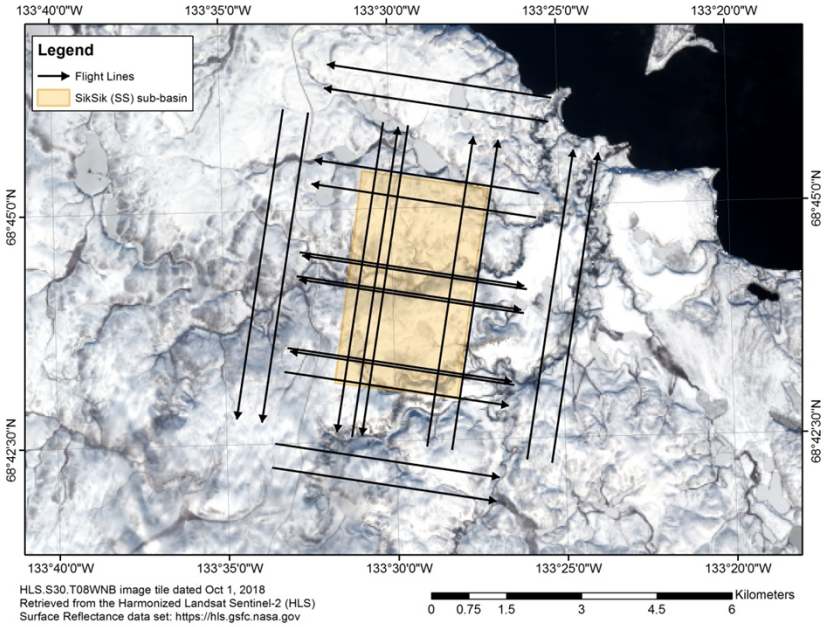
Airborne Radar System

- University of Massachusetts 13.25 GHz
  -Slotted waveguide (2 Rx / 1 Tx)
  -InSAR capable

- 16 flight lines samples 3 times during each campaign

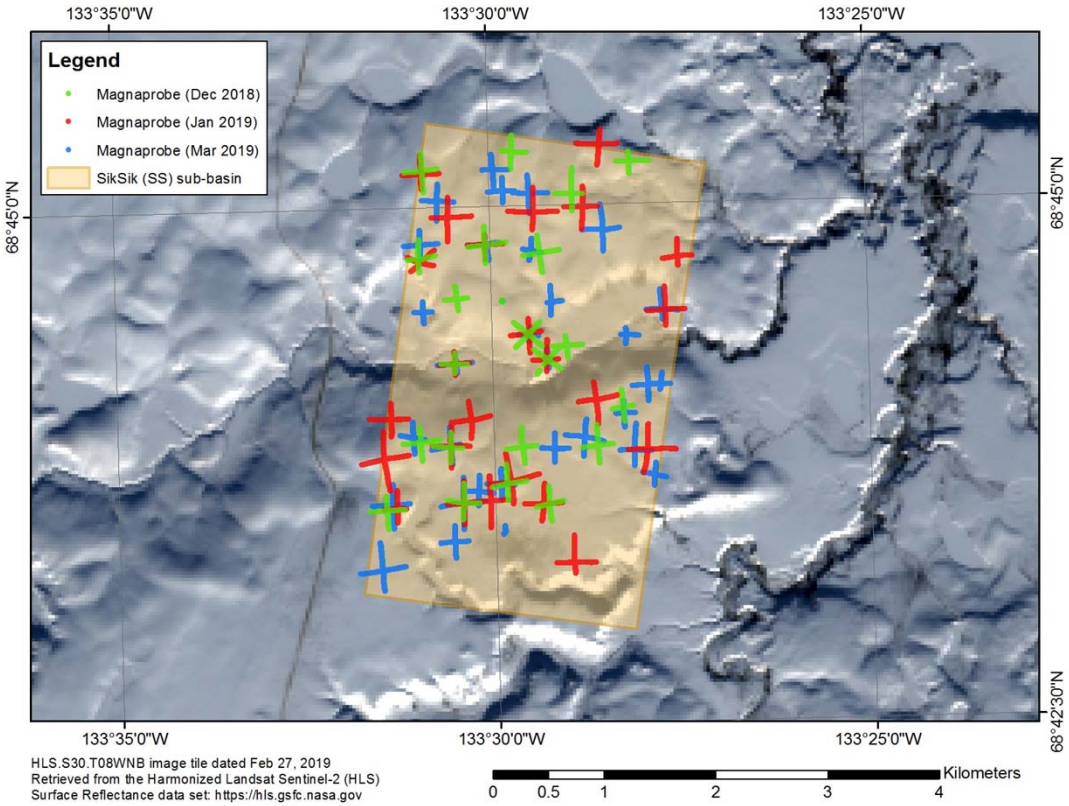
- Flight plan allowed 75% overlap

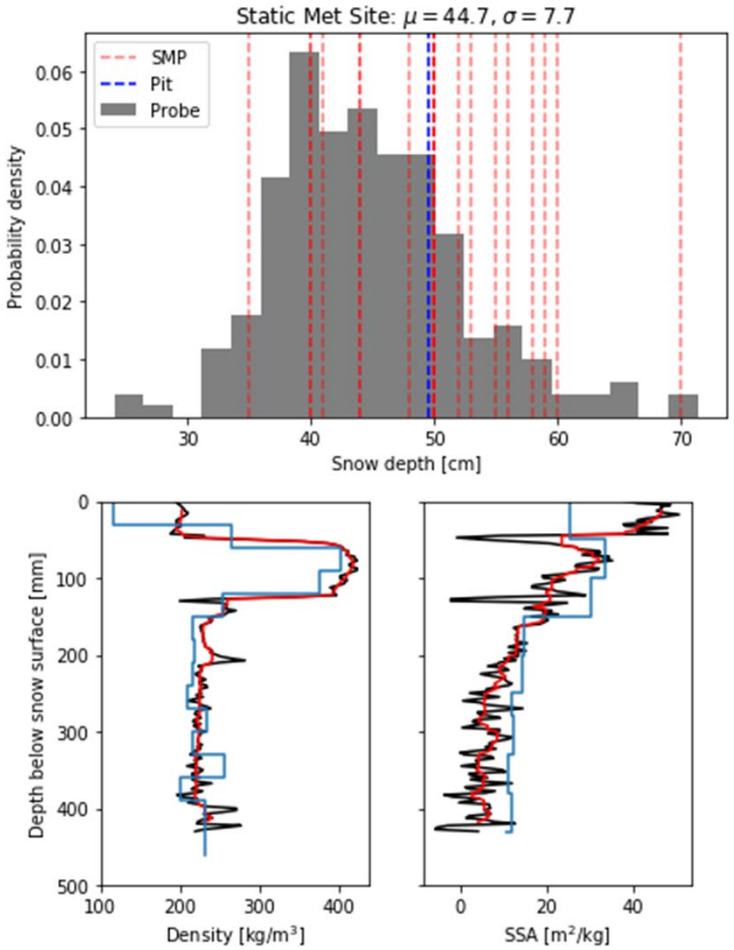
- Corner reflectors within study area for calibration and focusing



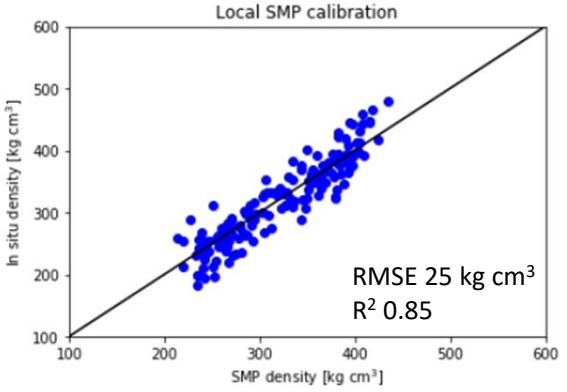
Snow Measurements

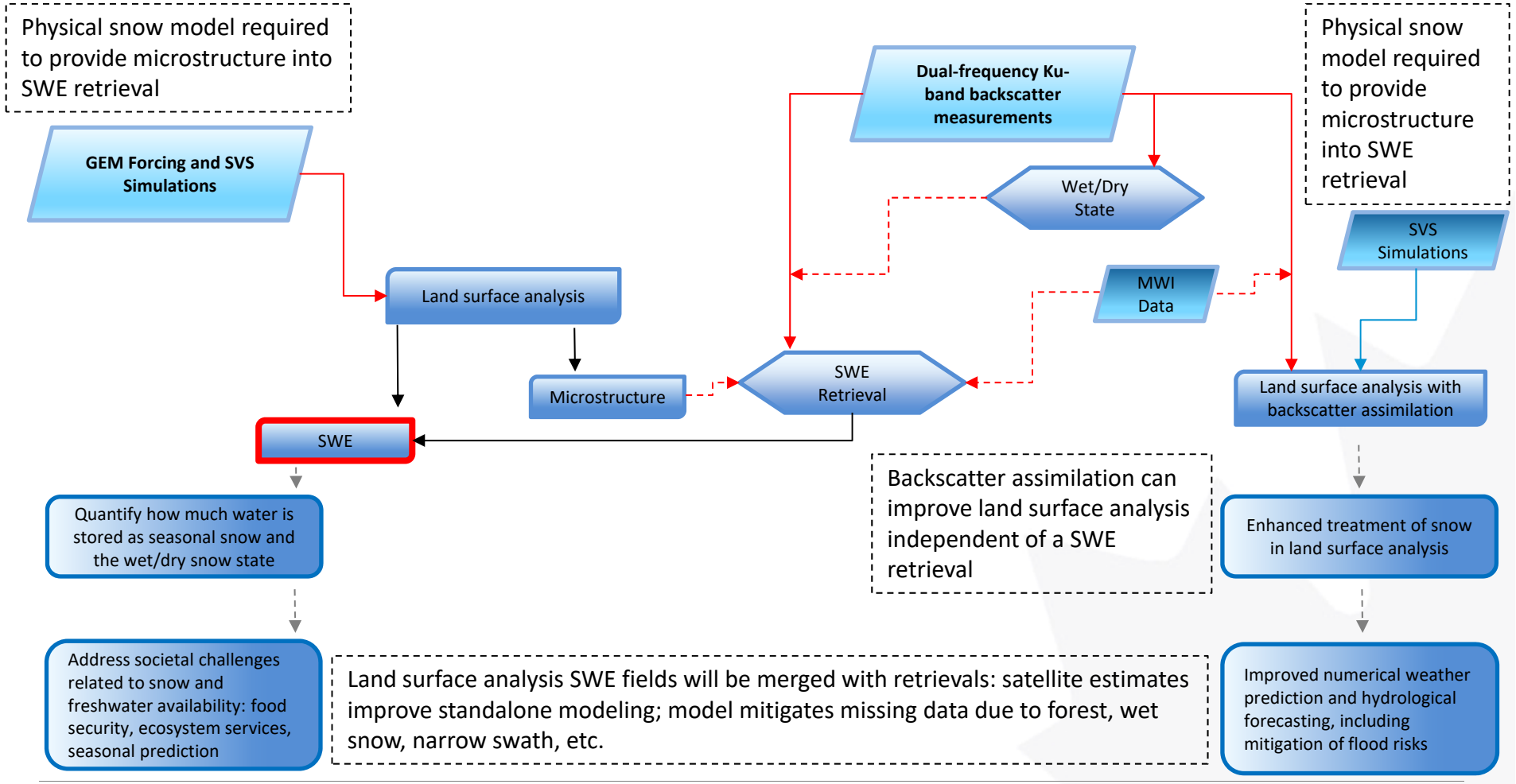
December 2018:	22 sites
January 2019:	25 sites
March 2019:	31 sites
Snow depths:	21946
SMP profiles:	1444
Snow pits:	76





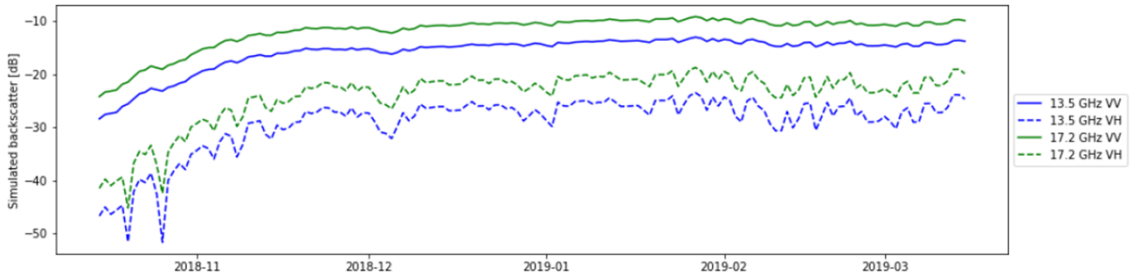
- Central snow pit used to calibrate co-located SMP and derive high vertical resolution estimates of density and SSA
- Based on SMP methods described in Proksch et. al. 2015, re-calibrated using TVC snow pit density measurements
- Nearly impossible to characterize radar integrated area with a single snow pit, multiple SMP measurements improve this

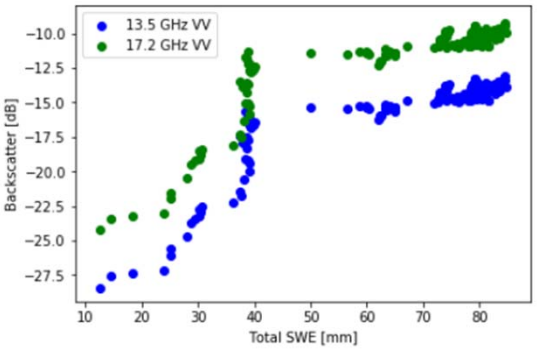


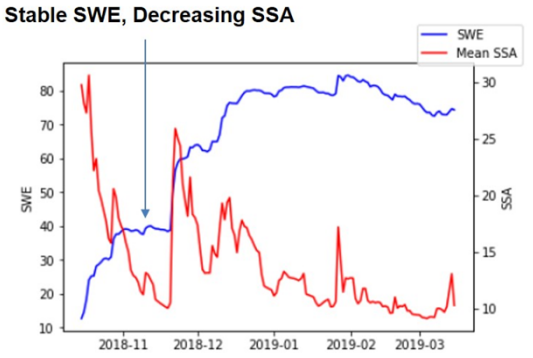

Physical snow model required to provide microstructure into SWE retrieval
GEM Forcing and SVS Simulations
Land surface analysis
Microstructure
SWE
Quantify how much water is stored as seasonal snow and the wet/dry snow state
Address societal challenges related to snow and freshwater availability: food security, ecosystem services, seasonal prediction
Dual-frequency Ku-band backscatter measurements
Wet/Dry State
SWE Retrieval
MWI Data
Backscatter assimilation can improve land surface analysis independent of a SWE retrieval
Land surface analysis SWE fields will be merged with retrievals: satellite estimates improve standalone modeling; model mitigates missing data due to forest, wet snow, narrow swath, etc.
Physical snow model required to provide microstructure into SWE retrieval
SVS Simulations
Land surface analysis with backscatter assimilation
Enhanced treatment of snow in land surface analysis
Improved numerical weather prediction and hydrological forecasting, including mitigation of flood risks

Ku-band Radar Assimilation

- Snow simulated with SVS-2 (driven by HRDPS at 2.5-km grid spacing): 'optimistic' snow only simulation (assumes we're able to decouple unwanted vegetation and background signals)
- Model configuration better represents the effects of blowing snow on wind slab formation (but snow redistribution by wind not simulated; no modification to improve the simulation of decreasing basal snow density related to depth hoar formation)
- Outputs: daily total snow depth and SWE, density, mass, temperature, SSA per snow layer, soil temperature, and humidity of the upper soil layer
- Backscatter simulated using the Snow Microwave Radiative Transfer (SMRT) backscatter model with inputs from the SVS-2 simulation







First Radar Results

Next steps:

- Motion compensation
- Calibration using corner reflectors
- SAR processing to gain full resolution (currently it is 5m, can achieve 2m)

Paul Siqueira and Max Adam, UMass

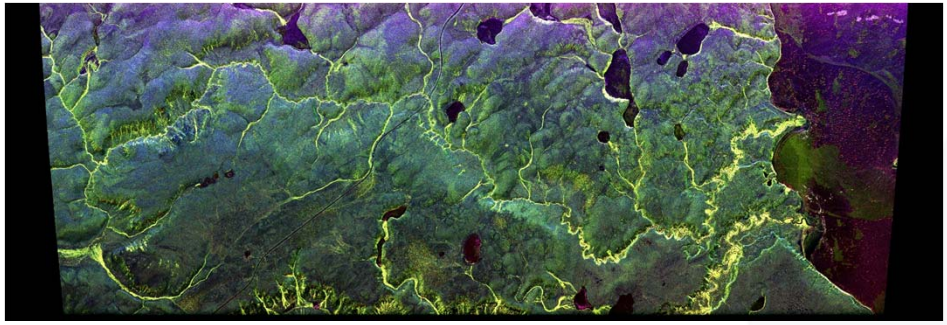
Supporting Measurements

AWI Polar 6 (Airborne)
- High resolution lidar
- Wideband FMCW 2-18 GHz SnowRadar

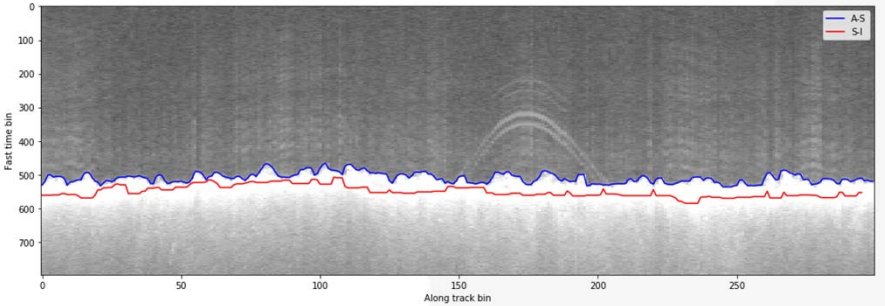
DLR F-SAR (Airborne)
- Multi-frequency InSAR

RADARSAT-2 (ECCC) and TerraSAR-X (DLR)
- Bi-monthly dual-pol acquisitions

Structure from Motion (WLU)
- Drone flight each deployment
- Snow depth maps at 2 cm resolution



L-band backscatter from DLR F-SAR



Snow depth from AWI SnowRadar

A Ku-band Radar Mission for Seasonal Snow Mass

- Technical concepts under development as part of Phase 0 industrial contract funded by CSA
- SWE retrieval frameworks under development at ECCC, U. Michigan, and the Finnish Meteorological Institute
- Preparation of CaLDAS for assimilation of Ku-band radar backscatter in progress at ECCC (Stephane.Belair@canada.ca)
- Snow microstructure estimates provided by SVS-2 (which are required for forward modeling and inversion); CaLDAS provides SWE analyses (so spaceborne radar doesn't have to retrieve SWE everywhere)
- Secondary mission objectives identified; further experimental work is required to develop these further
- Science Team in place to steer Phase 0 activities
- Future field campaign options not finalized (Joshua.King@canada.ca)