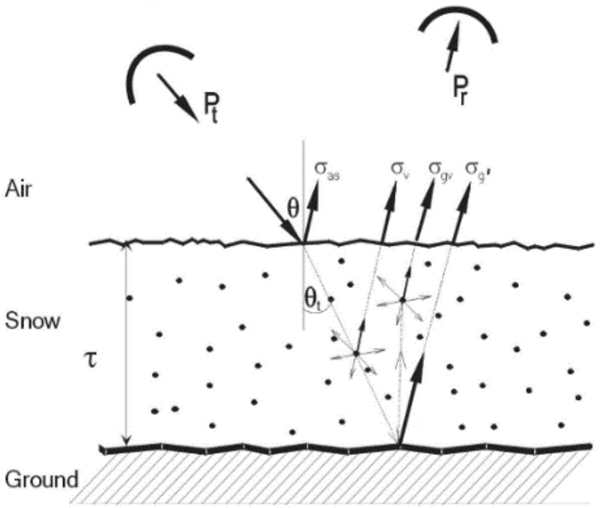
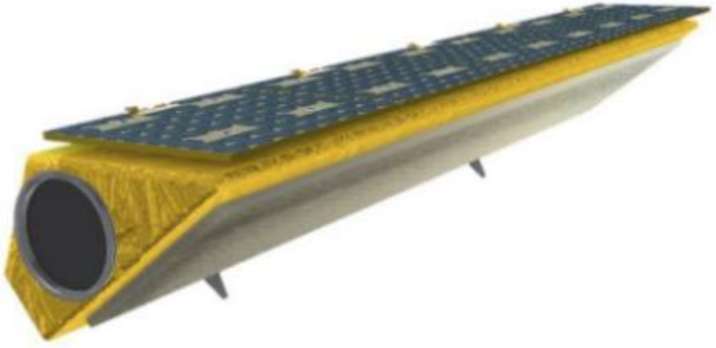
Ku-Band Radar Mission for Seasonal Snow





A partnership between Environment and Climate Change Canada and the Canadian Space Agency

Industrial consortium led by Airbus, with Magellan Aerospace, C-CORE, and H20 Geomatics

Environment and Climate Change Canada
Environnement et Changement climatique Canada
CSA ASC
Canada

Mission Objective: 500 m Ku-band radar measurements covering northern hemisphere snow covered areas every 5-7 days

PI: Chris Derksen (ECCC)

Science Team

Snow Retrievals

Lead: Josh King (ECCC)

Alex Langlois (U. Sherbrooke)
Juha Lemmetyinen (FMI)
Benoit Montpetit (ECCC)
David Small (U. Zurich)
Xiaolan Xu (JPL)

Data Assimilation

Lead and Mission Co-I:
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Sea Ice

Lead: Stephen Howell (ECCC)

Jean-Francois Lemieux (ECCC)
Randy Scharien (U. Victoria)
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Hydrology

Lead: Vincent Fortin (ECCC)

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Philip Marsh (WLU)

Other Applications

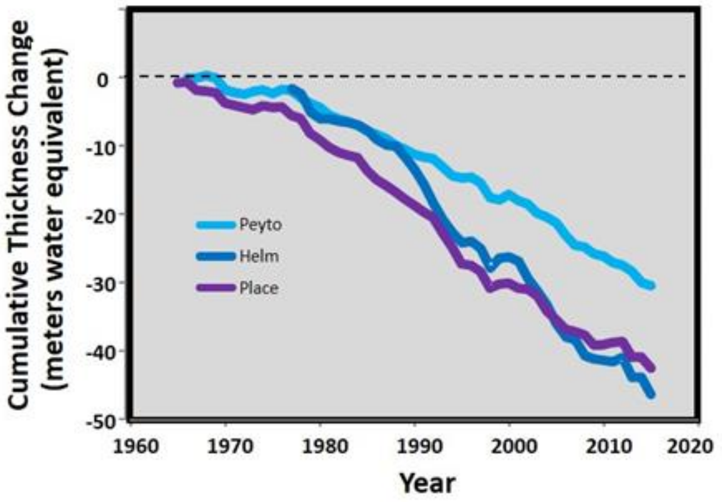
Laura Brown (U. Toronto; freshwater ice)
Christine Dow (U. Waterloo; land ice)
Wes van Wychen (U. Waterloo; land ice)
Simon Yueh (NASA JPL; ocean winds)
Richard Kelly (U. Waterloo; instruments)

Minimal requirements for satellite tasking for snow during summer means there is significant capacity to address secondary mission objectives

The Importance of Seasonal Snow

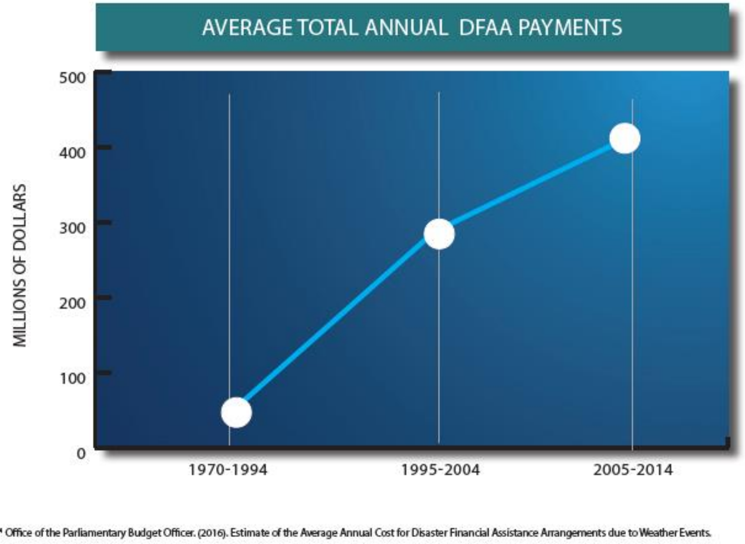
- Fundamental component of water, energy, and geochemical cycles (including carbon), and a vital freshwater resource which supports all economic sectors, human health and well-being, and ecosystems
- Contributing factor to costly natural hazards, particularly spring flood events
- Volatile natural resource, subject to variability and change in temperature and precipitation

Seasonal snow will emerge as an even more important freshwater supply as western Canadian glaciers disappear



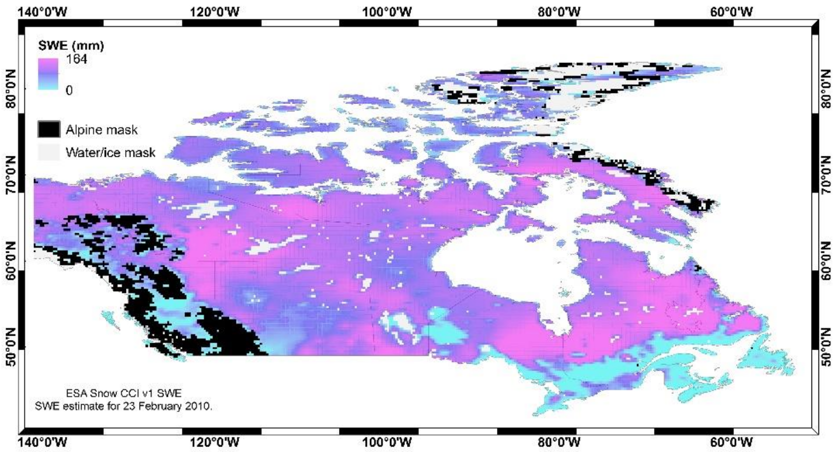
D. Burgess in Derksen et al., 2019

Exposure and costs related to natural hazards (including spring flood events) is increasing



Global Water Futures, 2019

Current satellite <u>snow water equivalent (SWE)</u> products are coarse (25 km) and mask out mountain areas



ESA Snow CCI SWE product

ECCC Requirements for Snow Monitoring

Quantifying Snow Mass Mission Concept Trade-Offs Using an Observing System Simulation Experiment

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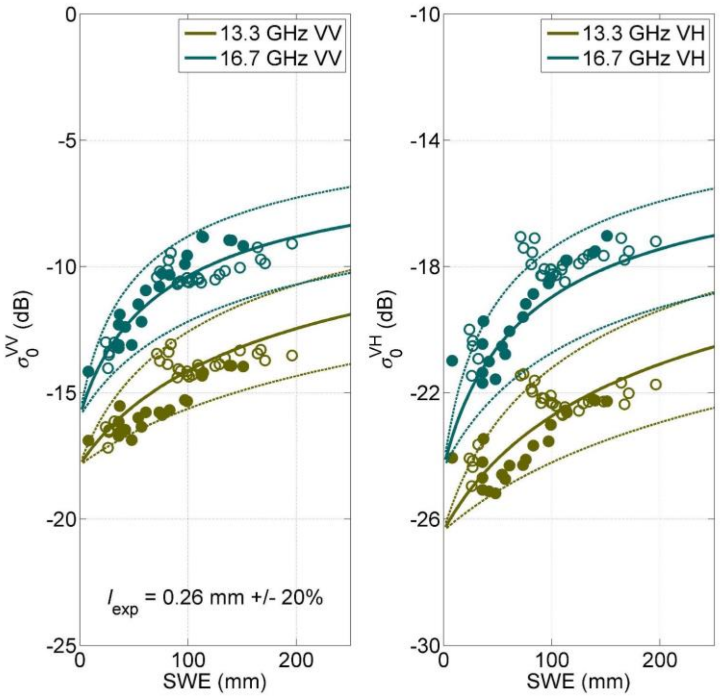
Current satellite-derived SWE products do not meet ECCC requirements for spatial resolution, accuracy, and latency: a new space-based approach is necessary

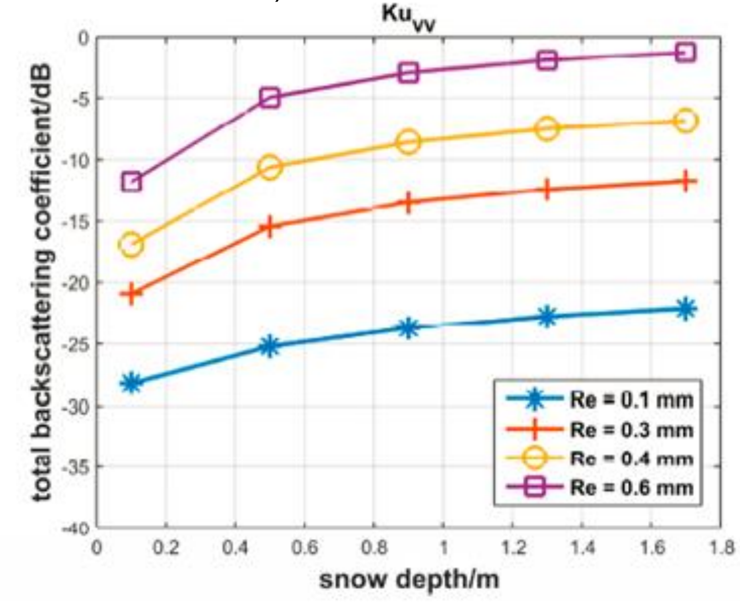
Quantitative analysis of impacts on ECCC prediction systems completed using an Observing System Simulator Experiment

Theme	**1. Climate services and water availability**	**2. Operational environmental prediction**
Need	The amount, distribution, and variability of terrestrial snow mass is poorly quantified	ECCC prediction systems (NWP; hydrology) require improved snow mass estimates
Science	How much water is stored as seasonal snow, how does it vary in space and time?	What is the contribution of snow to the water cycle and how well can we predict it?

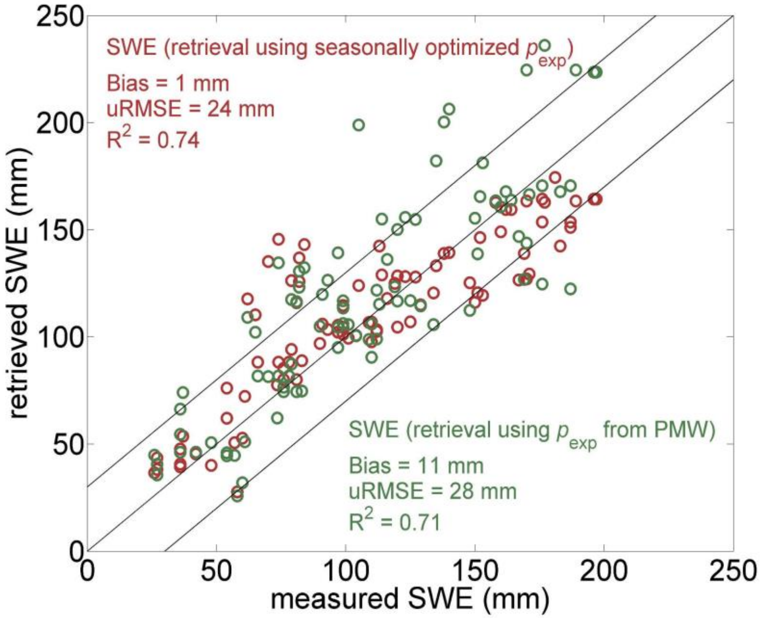
Dual-Frequency Ku-Band Radar for Snow Mass



Cui et al., 2016



Lemmetyinen et al., 2018

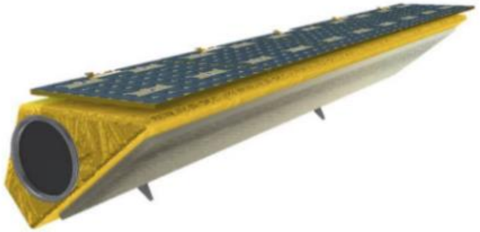


Sensitivity to **snow water equivalent (SWE)**

Sensitivity to **snow microstructure**

Constraints required to estimate SWE

Technical Concept



AIRBUS

- Single-aperture dual-frequency Ku-band antenna (13.5/17.2 GHz)
- 250 km swath = complete coverage of Canada every 5 days
- 500 m resolution (>4 radar looks)
- Higher resolution (50 m) strip map mode
- Mass, power, and heat dissipation budgets show a SAR-on duty cycle of 20-30% is achievable
- Different orbit scenarios are under analysis

Characteristic	Mission Design	Comments
Frequencies	Dual-band operation, 13.5 and 17.2 GHz	Maximize SWE retrieval capability and snow microstructure characterisation
Polarizations	VV; VH	Dual-pol negates effects of horizontal layering in the snowpack; cross-polarized backscatter allows the detection of extreme high ocean winds
Ground Resolution	500 x 500 m	Significant improvement over current 25 km SWE products
Number of Looks	>4	Multi-looking to enhance radiometric quality
Incidence Angle Range	23° - 55°	SWE retrieval performance likely to be poorer at shallow and steep incidence angles
NESZ – 13.5 GHz	<-26 dB (VV & VH)	Low NESZ ensures sensitivity to SWE (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 accuracy	1 dB	Enables accurate retrieval of SWE

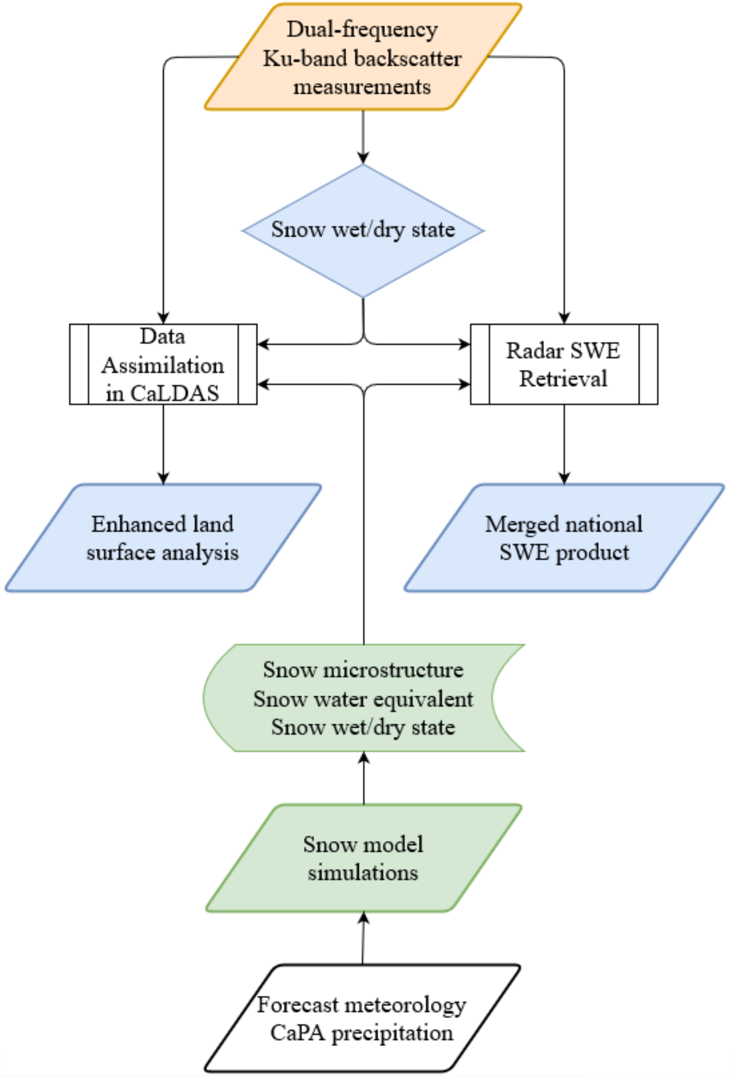
Current Status: Technical Readiness

- Radar remote sensing is the only technological solution which meets the SWE requirements of ECCC
- Because this is the first spaceborne Ku-band SAR mission of its type, an ‘explorer’ mission to meet a specific cost cap was developed in Phase 0 by industrial partners in order to ***advance technological innovation*** and ***prove the scientific viability*** with ***reduced overall risk***
- This ***‘design-to-cost’**** explorer concept meets ECCC science requirements through dual frequency (17.2/13.5 GHz) Ku-band radar measurements at 500 m spatial resolution; 50 m spatial resolution mode is available for specific regions (e.g. mountains areas) and events (e.g. periods of high flood risk)
- Imaging swath of 250 km combined with a duty cycle of approximately 25% meets the requirement to cover all of Canada every 5 days
- This technological solution is facilitated by recent development of relatively low-cost but robust spaceborne radar systems, such as the NovaSAR-1 mission developed by Airbus
- Under the CSA Space Technology Development Program (STDP) contracts were issued to Canadian industry in the spring of 2020 to advance two independent technical designs of the Ku-band radar antenna

*Design-to-cost: maximize payload capability within a fixed programmatic budget to facilitate the deployment of a demonstrator mission within a defined cost and schedule envelope

Current Status: Science Readiness

- Snow water equivalent and snow wet/dry state retrievals under development, supported by recent field campaigns
- Retrieval approaches will be fed information from the Soil Vegetation and Snow (SVS) land surface model
- In areas without radar coverage (e.g. due to swath gaps) SWE will be derived solely from land surface model output so that the remote sensing information is combined with modeling to create seamless coverage in space and time
- Ku-band backscatter will also be directly assimilated within the Canadian Land Data Assimilation System (CaLDAS) to enhance initialization of weather and environmental prediction systems (e.g. streamflow) to address operational components of the ECCC mandate
- CSA-FAST funded Ku-band airborne radar measurements planned within 2021-2023 time frame



Community-Wide Collaborations

- *NASA Terrestrial Hydrology Program* supported UMass Ku-band radar flights in Canada during 2018/19
- *NASA JPL* Ku-band TomoSAR deployed in the U.S. over the past three winters; potential to relocate to Canada?
- *Global Institute for Water Security/Global Water Futures* programs represent key mission stakeholders with potential role in field programs, use of mission products, model support, connections to hydrological users etc.
- *NASA SnowEx*: new data and analysis opportunities, particularly SWESARR data
- *U. Michigan* group is significantly advancing radar modeling and retrieval analysis
- *Finnish Meteorological Institute*: science support via ongoing field measurements and algorithm development
- Companion mission ideas are welcome, but require discussion due to performance limitations of the Explorer-scale radar
- Scientific readiness for the mission continues to be enhanced by community-wide progress in field techniques (e.g. quantitative microstructure measurements), physical snow modeling, data assimilation, multi-frequency radar analysis, etc.

Paths Forward

- '**Explorer**' scale radar mission is aligned with Canadian science and industrial expertise developed through the RADARSAT missions, but allows technical innovation to a new spaceborne radar frequency
- Given the mission cost envelope, no formal partnerships with other agencies are required at this time, but consideration of new opportunities always welcome
- Schedule developed as part of Phase 0: **launch in 2027 is potentially feasible**, followed by a nominal **3 year operating phase**
- Discussion ongoing regarding the mission name: Canadian Radar Explorer Mission?

Activity 1

- *'Whole of Government' Earth Observation prioritization exercise* currently underway (proposal submitted last week)

Activity 2

- Completion of TSMM industrial Phase 0 in September 2020
- Preparation of mission materials for internal review at CSA (early 2021)
- Potential for approval to Phase A at that point

Activity 3

- Completion of first round of STDP industrial contracts in early 2021
- Planning underway for second round of STDP contracts during FY 2020/21
- CSA-FAST funded airborne measurements and analysis, 2021-2023 (PI: Richard Kelly)