Terrestrial SNOW MASS Mission

Terrestrial Snow Mass Mission (TSMM)

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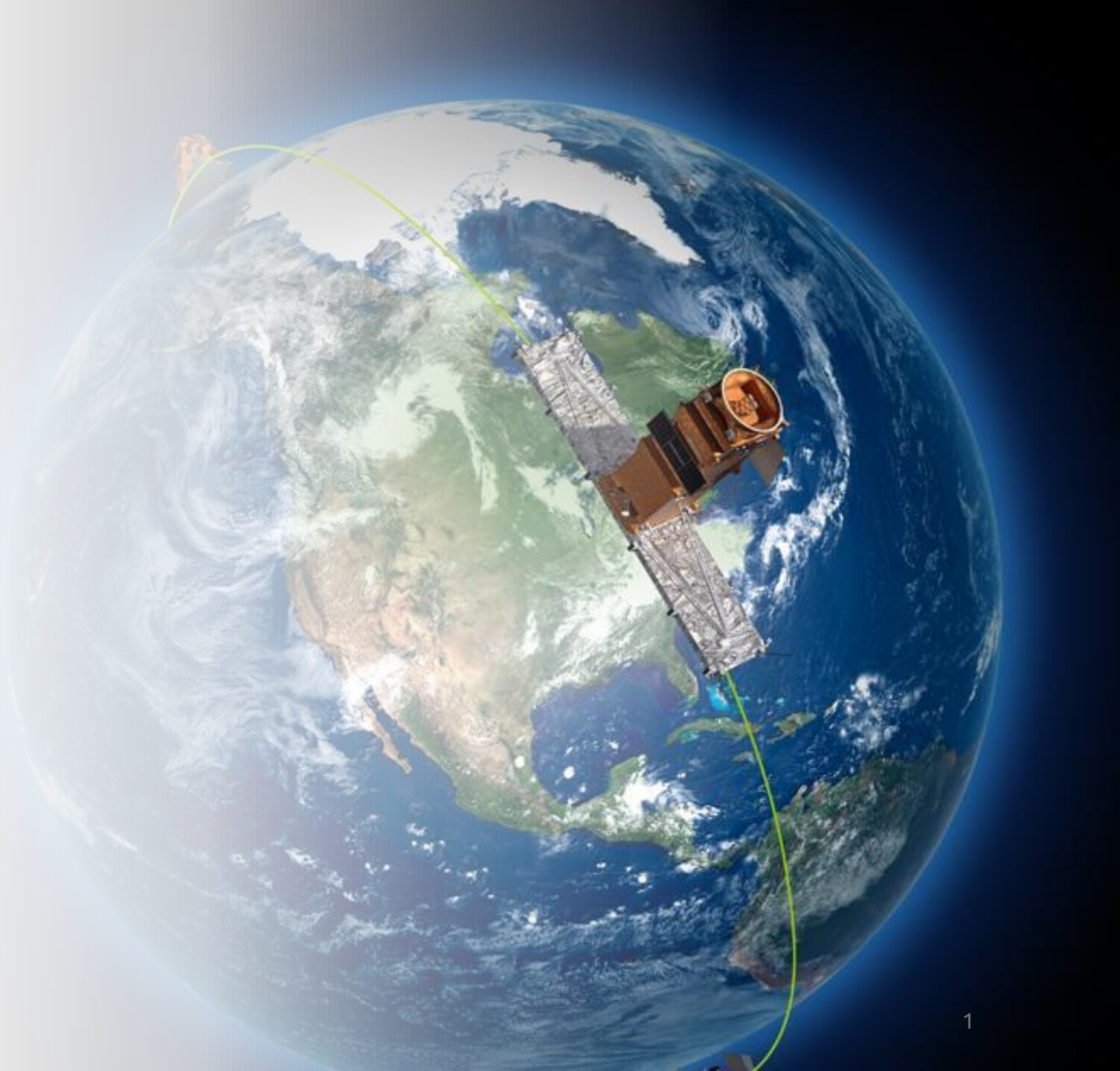
Environment and Climate Change Canada

On behalf of the TSMM team at ECCC, NRCan and CSA, a consortium of Canadian universities, and a broad network of collaborators and supporters



Incomplete Knowledge of Water Stored as Snow:

Carries increasing risks and implications for water and food security, hydroelectric power generation, protection of ecosystems, and the safeguarding of Canadians and their communities against floods and drought

Gathering environmental data & intelligence

- Canada's dynamic environment requires systematic monitoring, but its vastness precludes doing so entirely from the ground

Freshwater availability is changing across Canada

- Seasonal snow is a key component of the water cycle, so many sectors require accurate estimates of water stored in solid form as snow, expressed as the **'Snow Water Equivalent' (SWE)**

Streamflow predictions and flood forecasts lack skill and sufficient warning

- Incomplete knowledge of how much water is stored as snow limits the hydrological, climate, and weather services provided by the Government of Canada

Terrestrial Snow Mass Mission

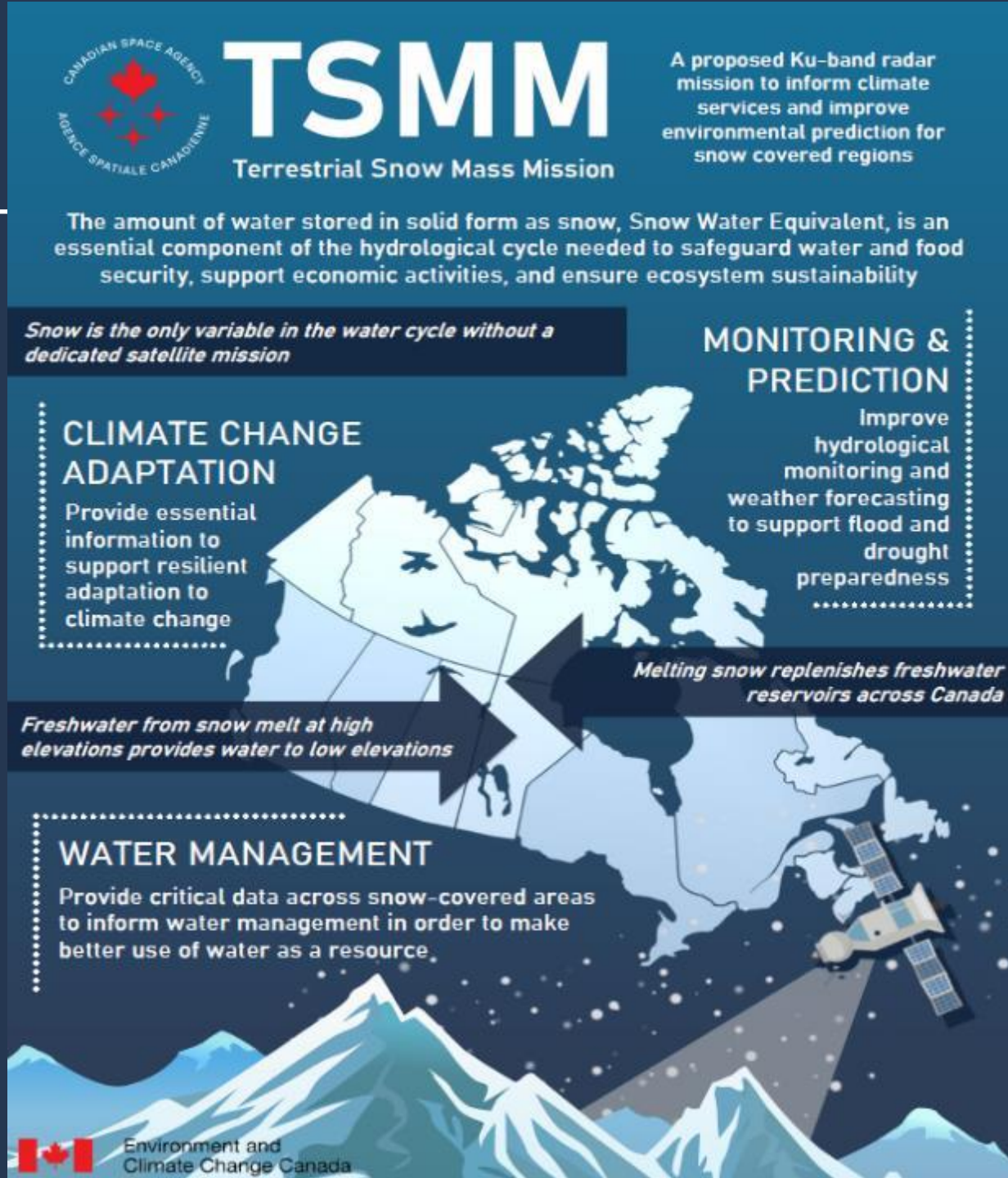
First satellite EO mission to *continuously* monitor snow nationally and globally … because water availability and security matters to Canadians everywhere

Mission Overview

- ✓ TSMM identified as a priority mission in Canada's Roadmap for Satellite Earth Observation to address an urgent knowledge gap for climate change adaptation
- ✓ TSMM radar measurements will deliver the first high resolution (500m) inventory of snow mass across Canada, updated daily, for more effective water resource management in a changing climate
- ✓ Assimilation of TSMM snow mass products in environmental prediction systems will improve hydrological forecasting for watersheds across Canada at longer lead times

Broader Impacts

- ✓ Ku-band SAR measurements have not been acquired from space before
- ✓ Fully open data policy to facilitate broad community uptake
- ✓ Radar data will support additional applications



Technical Concept

- TSMM will acquire two frequencies of Ku-band radar measurements (13.5/17.25 GHz), both of which are sensitive to snow mass
- These measurements have not been acquired from space before
- Canada has a rich heritage in radar remote sensing through the RADARSAT program
- Measurements at 500 m resolution will cover all of Canada every 5-7 days independent of cloud cover and darkness
- When and where needed, a 50 m mode will acquire measurements across a 30 km swath

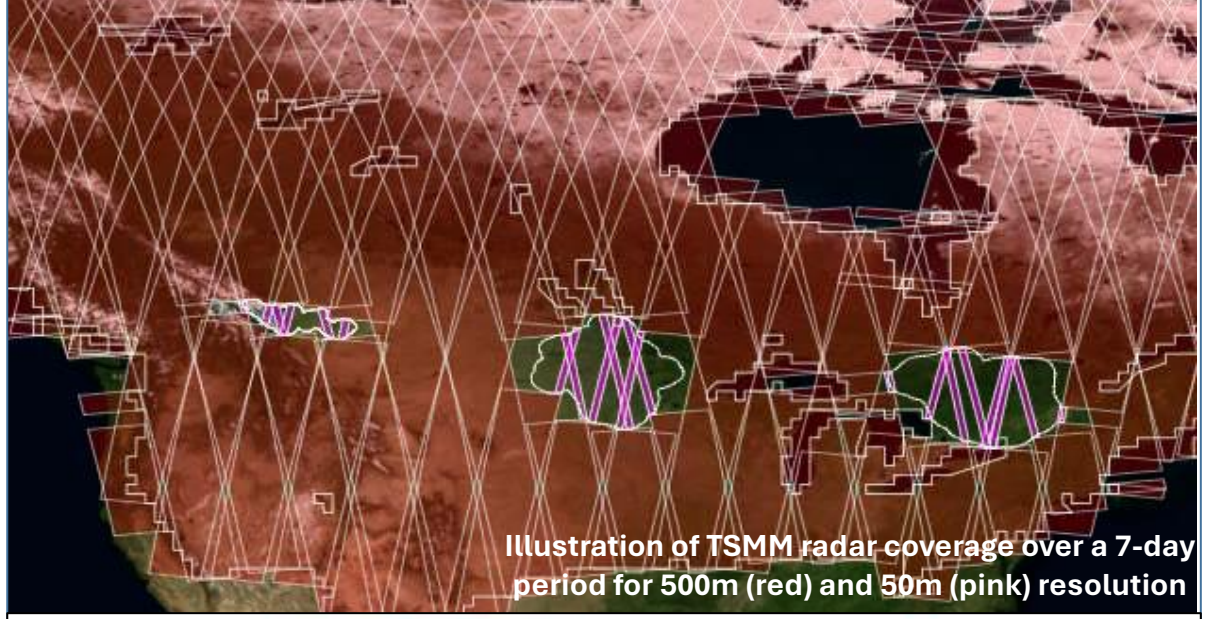
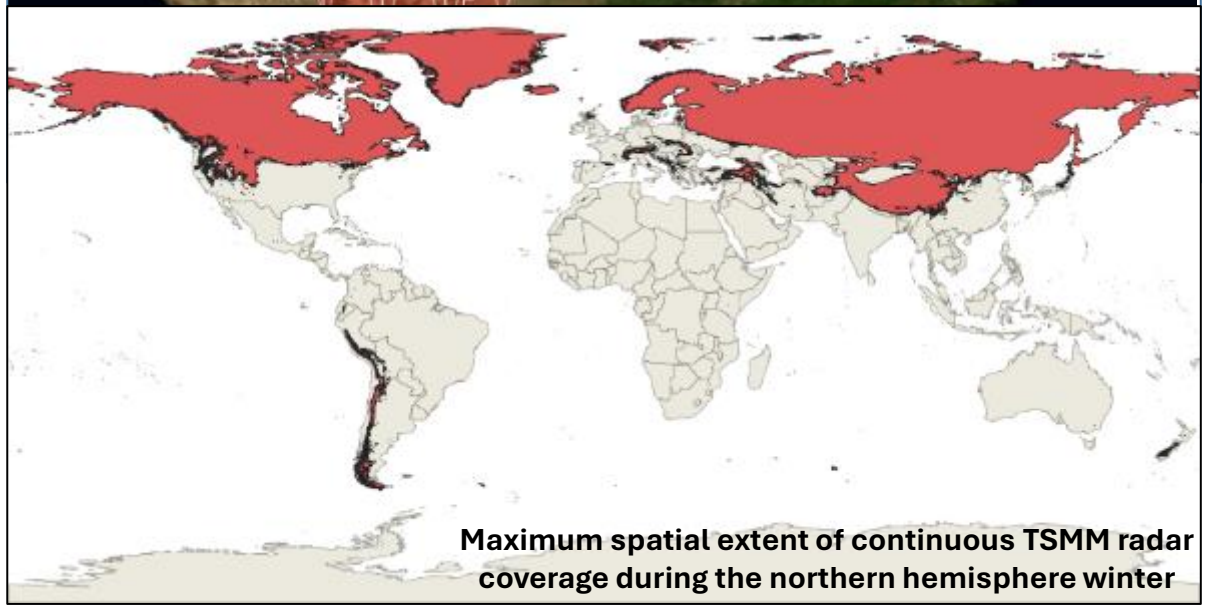
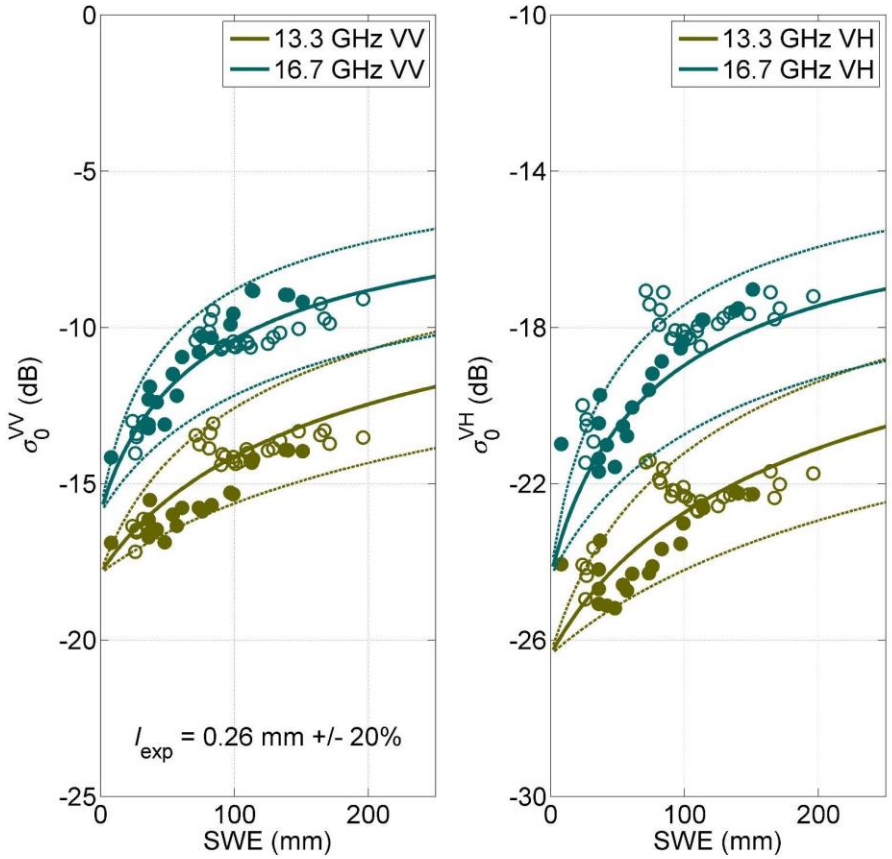


Illustration of TSMM radar coverage over a 7-day period for 500m (red) and 50m (pink) resolution



Maximum spatial extent of continuous TSMM radar coverage during the northern hemisphere winter

Why Ku-Band?

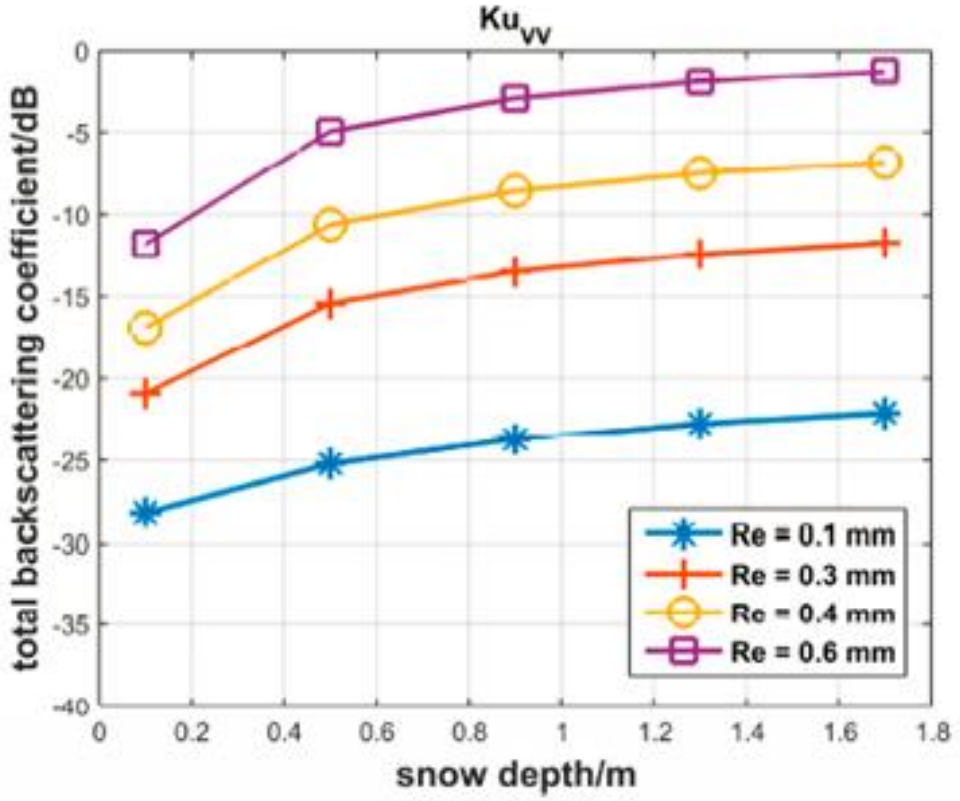


Sensitivity to **snow water equivalent (SWE)**
Circles: measurements; lines: model simulations

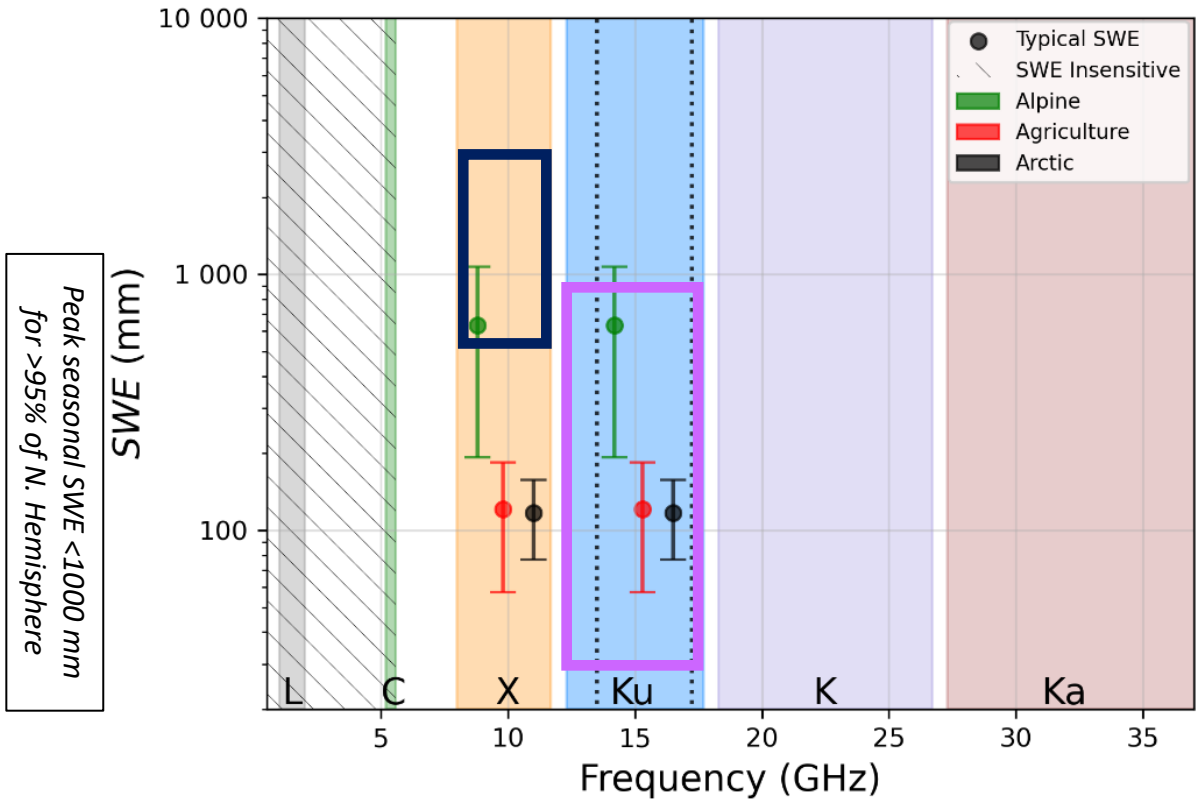
Why Dual-Frequency?

Dual-frequency SWE sensitivity for **TSMM**

Additional sensitivity at X-band



Sensitivity to **snow microstructure**



- ***Two frequencies*** of radar measurements sensitive to the snowpack volume are needed to skillfully retrieve snow water equivalent
- Dual Ku-band TSMM measurements are sensitive across a very wide range of snow water equivalent (up to 1000 mm)

Airborne Ku-band Radar Measurements

- ‘CryoSAR’ (L- and Ku-band radar) instrument consortium led by U. Waterloo, funded by CFI and NSERC

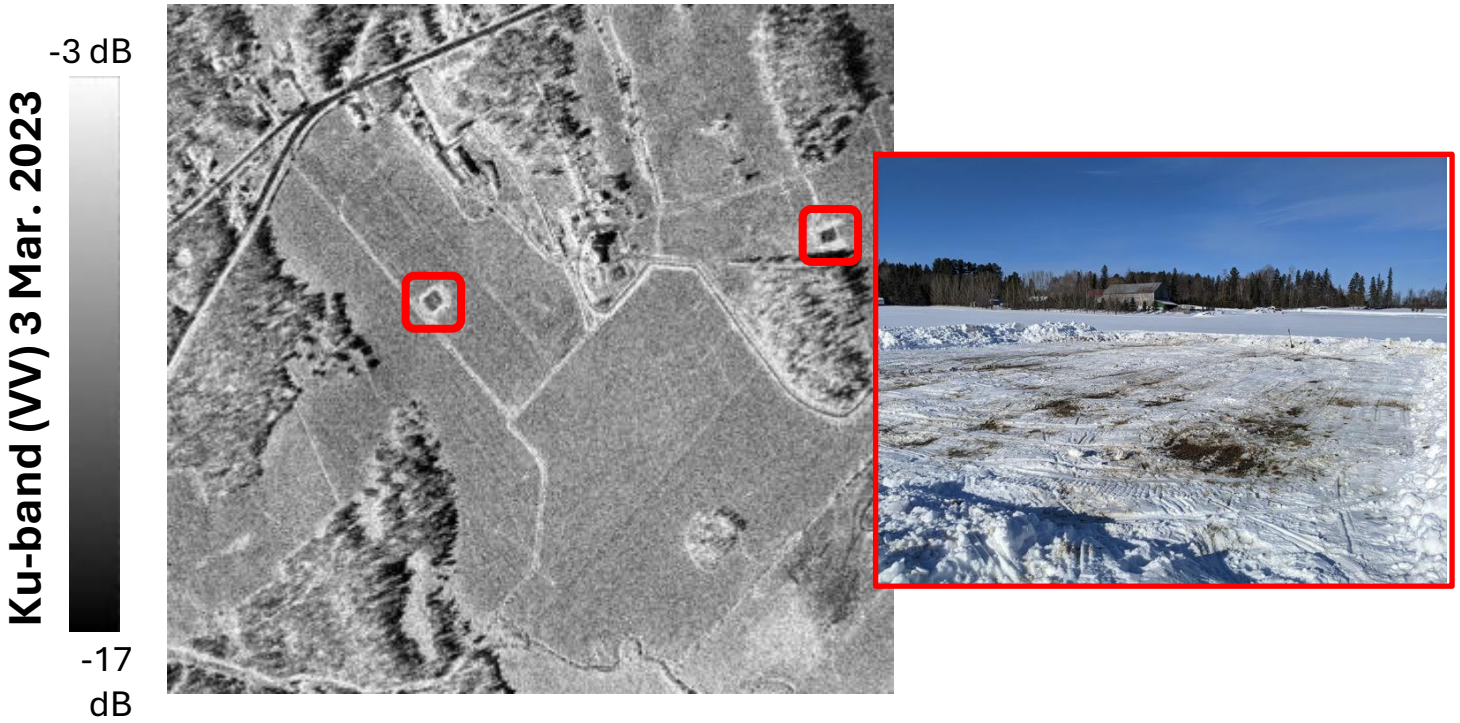
- Approval from Transport Canada for installation on any Cessna-208 allows for flexible low-cost deployment

Environment and Climate Change Canada | Environnement et Changement climatique Canada

Canada

Example CryoSAR Imagery: 2022/23 Flights near North Bay, ON

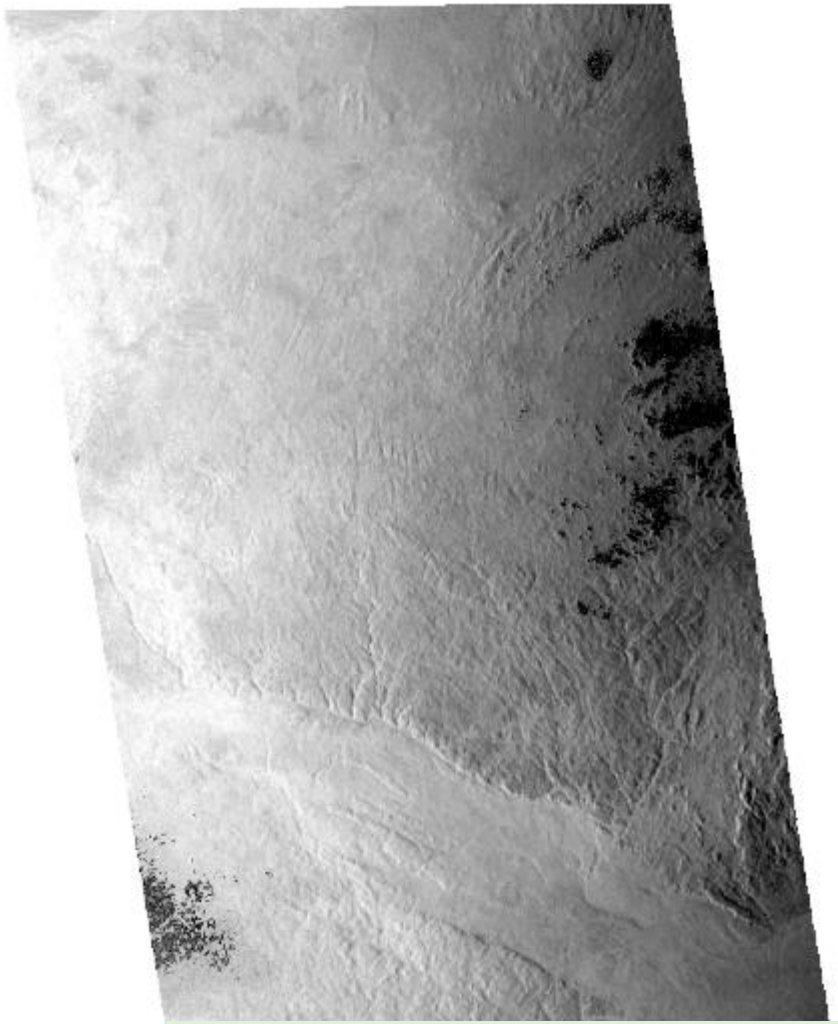
- At L-band, soil surface roughness features in agricultural fields are clearly evident because the snow is ‘invisible’ to radar



- At Ku-band, soil surface features disappear because the radar signal is scattered by the overlying snowpack
- Note clear response to areas with snow removed

TSMM Implementation

- TSMM technical concept **leverages Canadian industrial expertise** in radar remote sensing
- Uses **existing NRCan ground segment infrastructure**
- Science expertise is in-place to deliver **Canadian leadership** to a critical observation gap
- TSMM can support additional science objectives related to sea ice (prediction), glaciers, ocean surface winds, and forest fire risk (NRCan)
- Updated costing analysis, science and technical advancement in progress to ensure readiness to respond to opportunities



Simulated TSMM radar image in the Ottawa River watershed 3 February 2023

Mission Engagement with Broad Support from Partners

Within ECCC:

- Atmospheric Science and Technology Directorate
- Canadian Centre for Meteorological and Environmental Prediction
- Canadian Ice Service
- Canada Water Agency
- Wildlife and Landscape Science Directorate

Other Federal Departments:

- AAFC – Drought Watch program
- NRCan
  - CCMEO (Canada Centre for Mapping and Earth Observations)
  - CFS (Canadian Forest Service)
  - GSC (Geological Survey of Canada)
  - Renewable and Electricity Policy
- Public Safety Canada – GOC (Government Operations Centre)

Canadian Universities:

- Consortium of 14 universities working on TSMM-related science (coordinated by U. de Sherbrooke)

Provincial and Territorial:

- National Administrators Table (administration of hydrometric monitoring agreements)
- Mackenzie River Basin Board
- Prairie Provinces Water Board
- Hydro Quebec

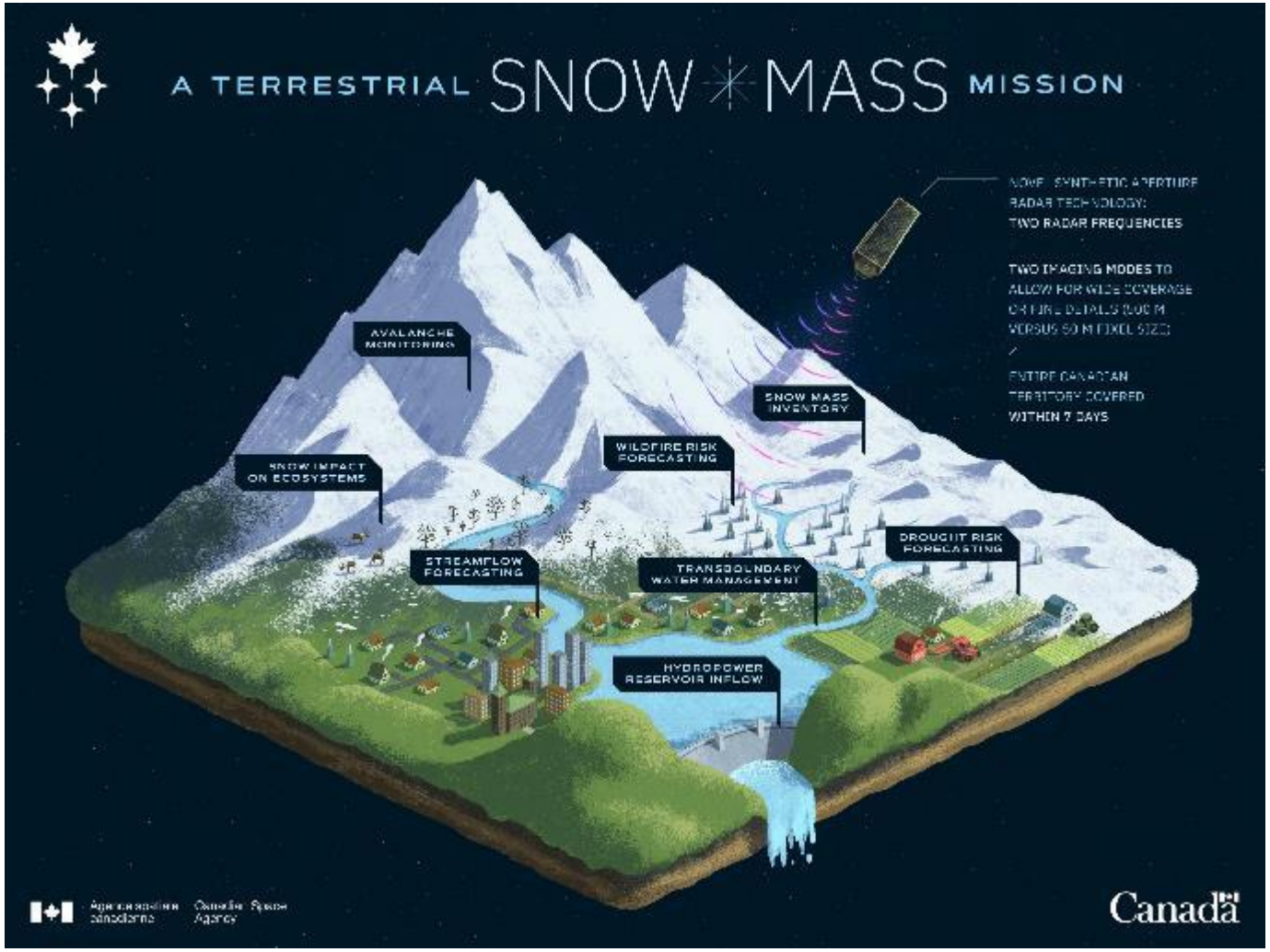
International:

- IJC (International Joint Commission)
- NASA – Terrestrial Hydrology Program
- NOAA – National Water Center
- USGS (United States Geological Service)
- FMI (Finnish Meteorological Institute)
- EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites)
- ECMWF (European Centre for Mid-range Weather Forecasting)

TSMM positions Canada as a leader in snow mass observations, with data and products highly anticipated by domestic and international partners

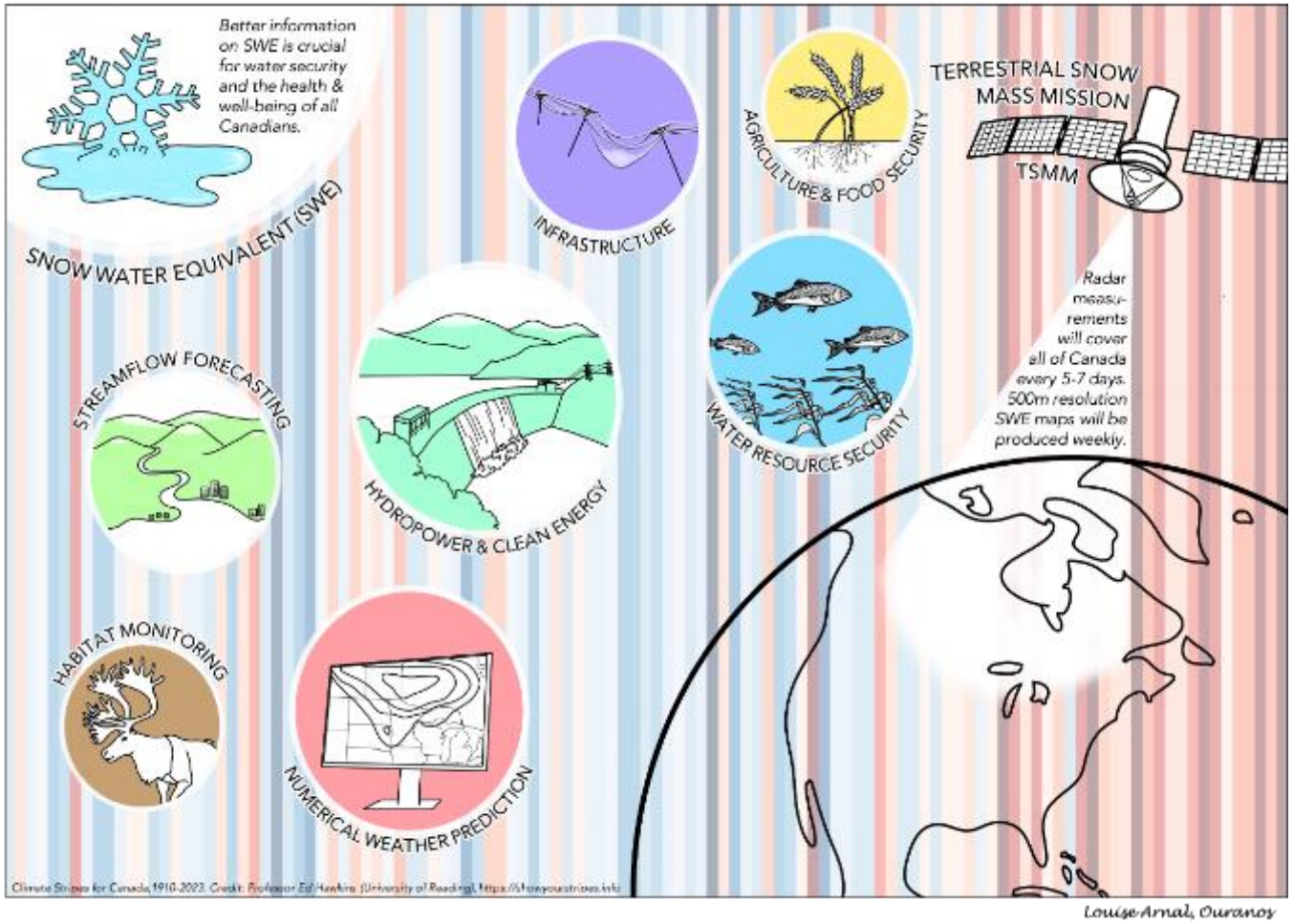
Summary

- TSMM is currently in a formulation phase, with detailed analysis (including costing) completed for the space (CSA), ground (NRCan), and science (ECCC) segments; aim is to launch the mission by 2032
- Radar measurements will cover global snow-covered areas, with snow mass product development focused on Canada and trans-boundary watersheds
- Algorithms, data, and products will be open
- Ku-band radar measurements will support additional applications outside of the snow season (e.g. Fire Weather Index System; Canadian Drought Monitor)
- TSMM team is fully open to partnerships and collaborations



Alignment with Government Priorities to Address Pressing Challenges

Climate Change Action	***ECCC Science Strategy 2024 to 2029*** ***Canada's National Adaptation Strategy***
Environmental Monitoring and Prediction	***ECCC Core Responsibilities:*** • ***Taking Action on Clean Growth and Climate Change*** • ***Predicting Weather and Environmental Conditions***
Emergency Preparedness	***Emergency Management Strategy for Canada***
Clean Energy	***Clean Energy Regulations*** *(upcoming)* ***Clean Electricity Strategy*** *(upcoming)*
Earth Observation	***Canada's Space Strategy*** ***Canada's Strategy for Satellite Earth Observation***



Primary Policy Drivers

TSMM socio-economic benefits

Environment Canada Environnement Canada

Agriculture and Agri-Food Canada Agriculture et Agroalimentaire Canada

Canada

SNOSWAB – an online model for daily estimation of snowpack processes, soil water content and soil water budget

Serban Danielescu

Environment and Climate Change Canada &
Agriculture and Agri-Food Canada

NDGW meeting (virtual)
November 2024

SNOSWAB

https://snoswab.hydrotools.tech

(Snow, Soil Water and Water Balance Model)

- Novel conceptual model
- Estimates daily dynamics of snowpack processes (snow accumulation, snowmelt), soil water content and water balance components (infiltration, drainage, surface runoff)
- Requires air temperature, precipitation, rainfall and evapotranspiration and (basic) soil properties.
- Includes import/export functions, data visualization (tables and graphs)
- Integrates calibration and error checking routines
- Free, no user registration required

Hydrology Tool Set (HTS)

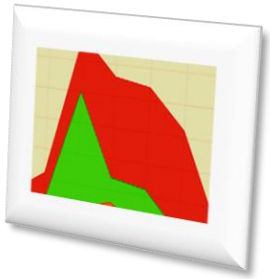
https://www.hydrotools.tech

ETCalc

8 methods for ET

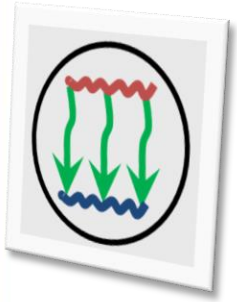
SepHydro

12 algorithms for baseflow separation



SWIB

Crop water stress, soil water balance, irrigation requirements, impact of irrigation on aquifer storage



RBUDDY

Groundwater recharge

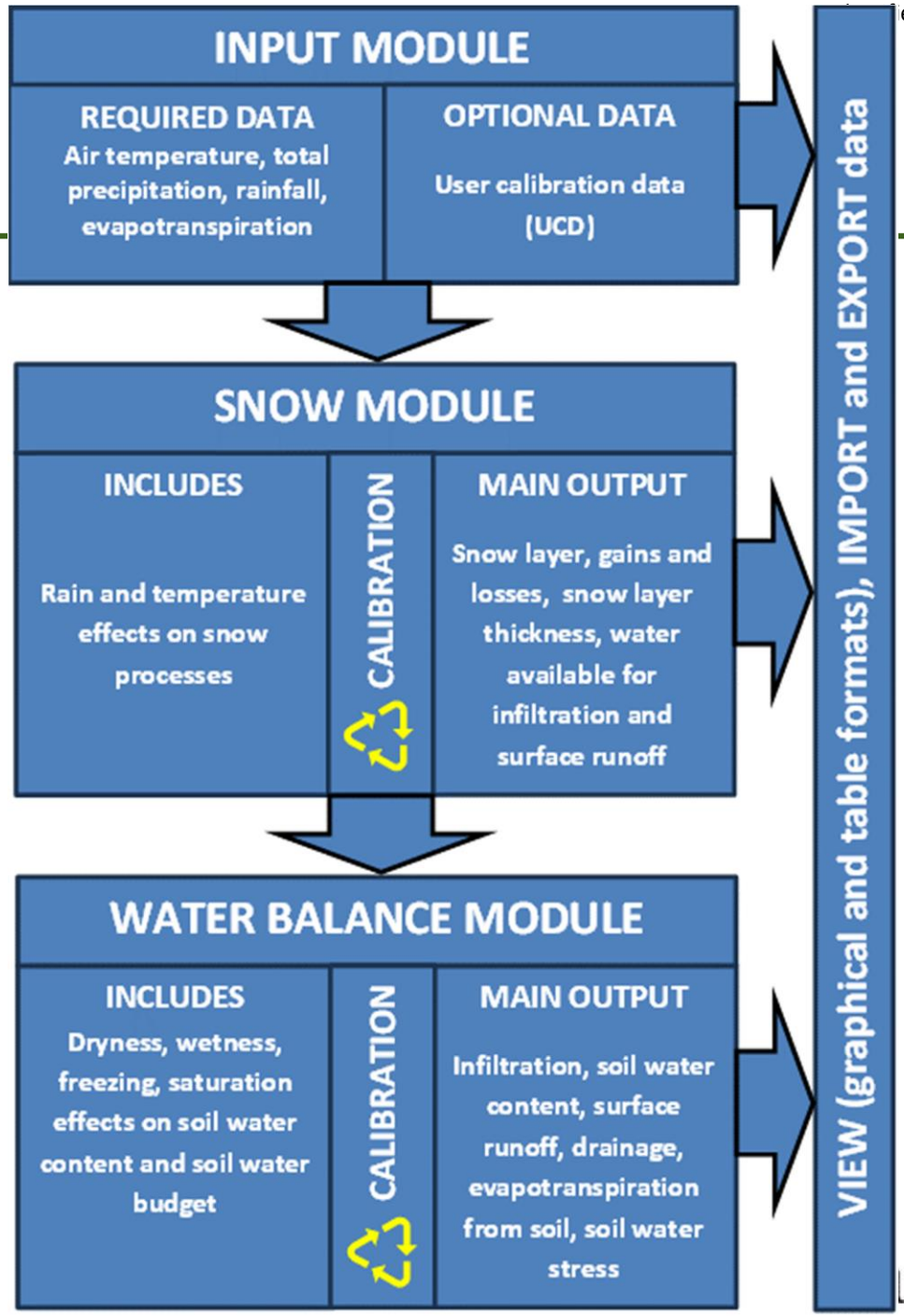
SBUDDY

Snowfall and rainfall fractions

SNOSWAB development context

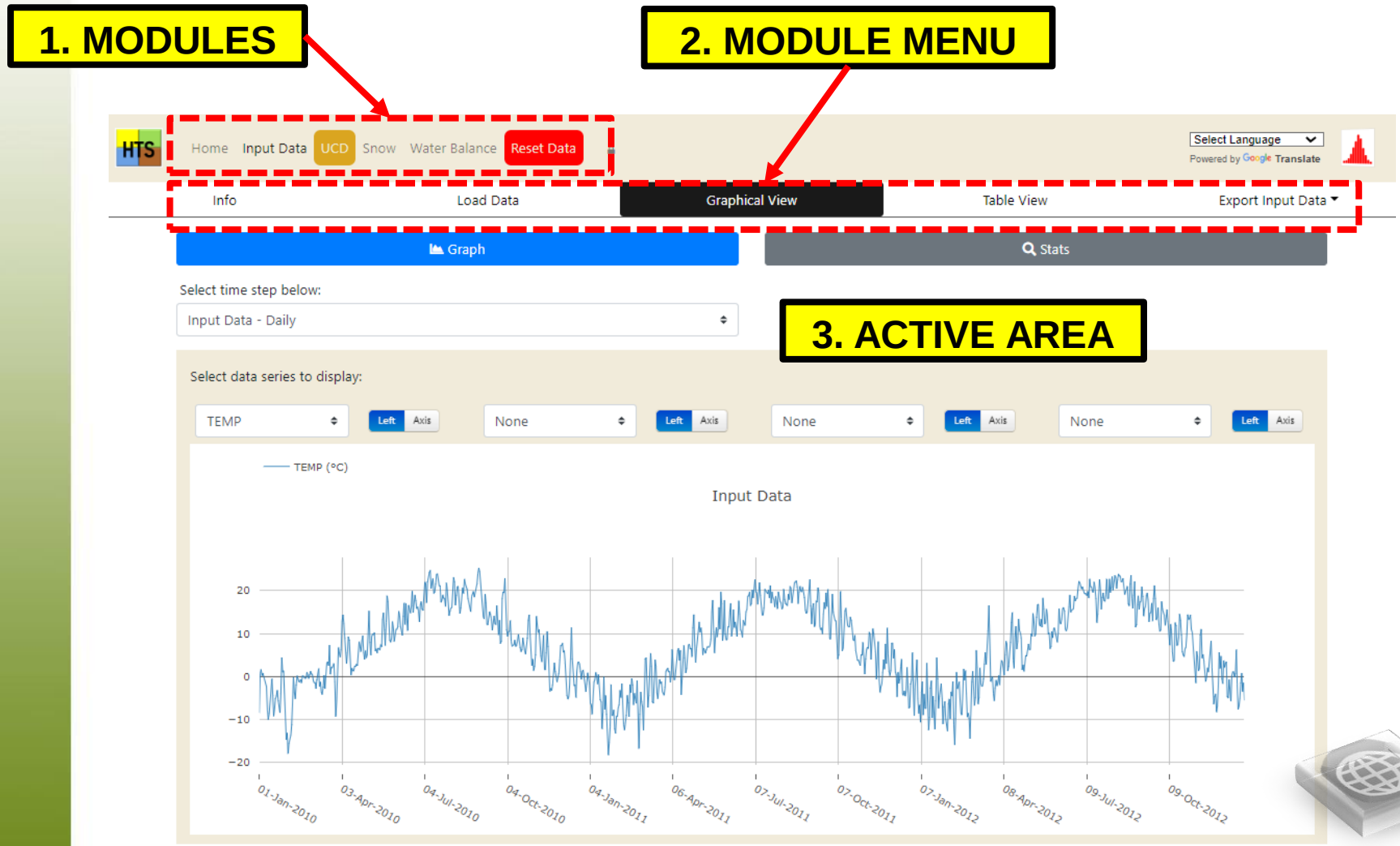
- Water in soil is important for hydrological, biological and biochemical processes
- Snow processes are critical for baseflow and runoff formation & transport of contaminants
- Numerous standalone (offline) models, with various degrees of complexity available for various processes integrated in SNOSWAB
- No online models similar to SNOSWAB have been identified

SNOSWAB WORKFLOW



(Danielescu, 2024)

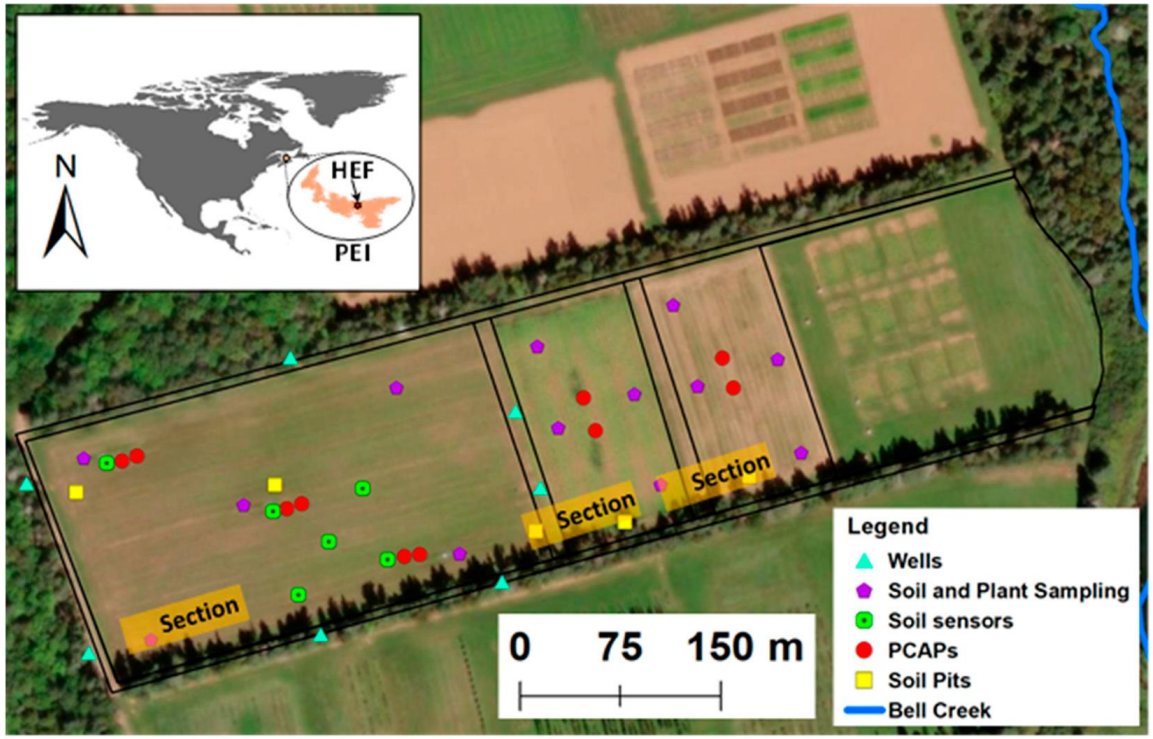
SNOSWAB interface



SNOSWAB application

- 12-year (2008–2019) data set [calibration 2009-2014; validation 2015-2019]

- AAFC's Harrington Experimental Farm (HEF) (PEI)



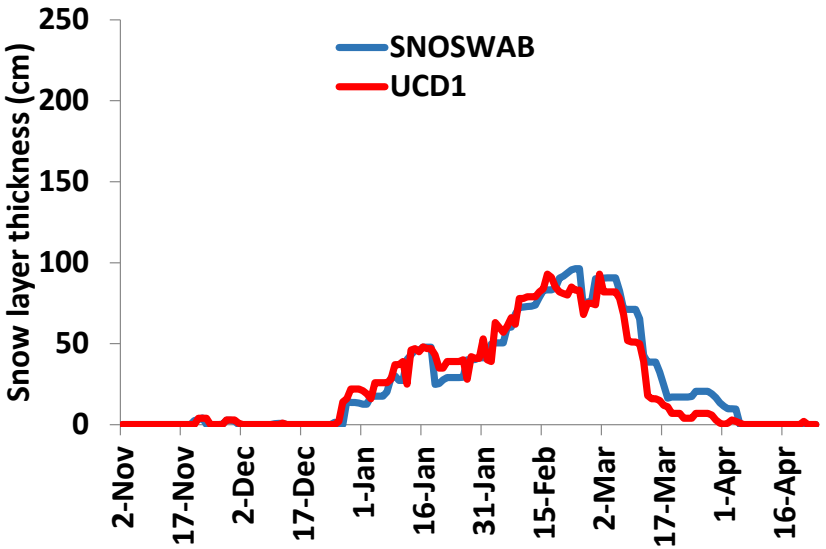
(Danielescu et al., 2024)

- Research aimed at understanding the impact of potato cropping systems on the quantity and quality of surface water and groundwater.

- Calibration/Validation data: snowpack thickness, soil water content, surface runoff, drainage

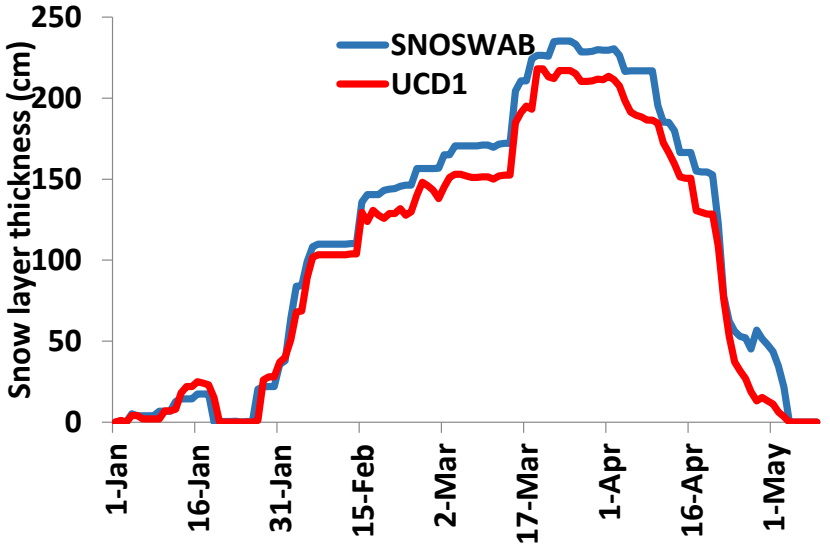
SNOSWAB – snow layer thickness

CALIBRATION



- R^2: 0.84
- NRMSE (%): 7.7%
- PBIAS (%): 14.8%

VALIDATION

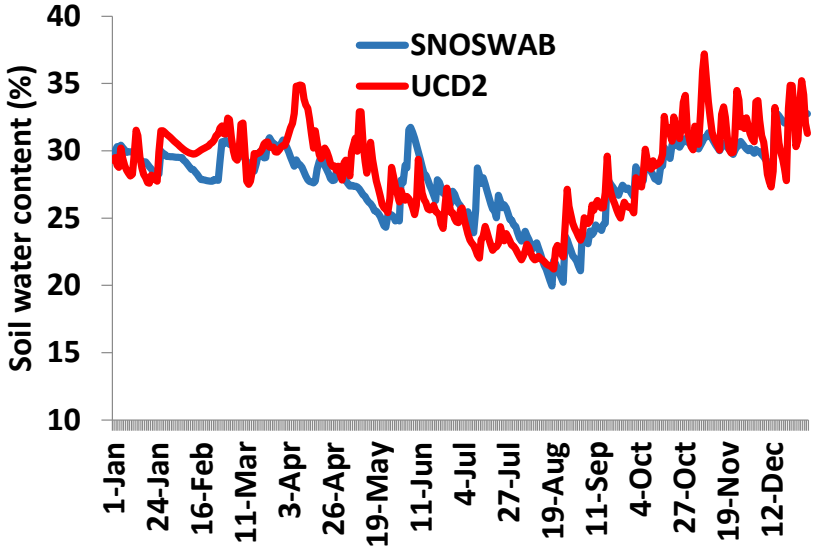


(Danielescu, 2024)

- R^2: 0.98
- NRMSE (%): 2.8%
- PBIAS (%): -6.1%

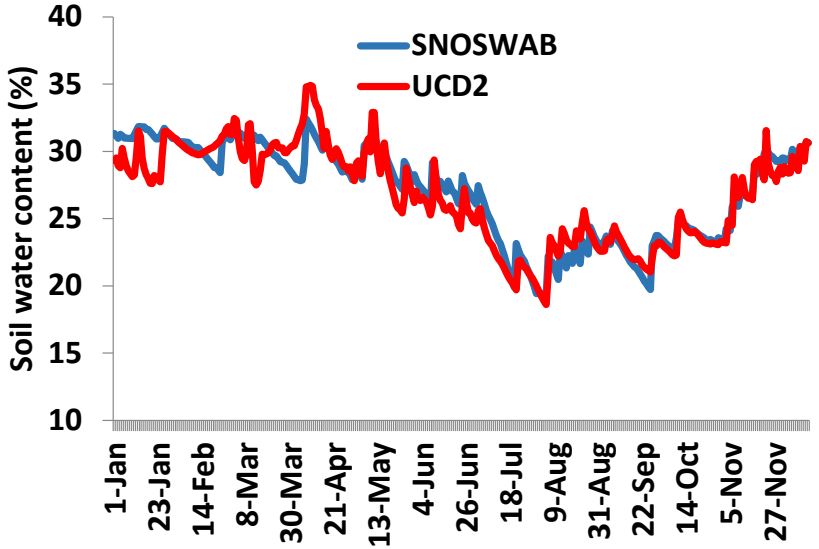
SNOSWAB – soil water content

CALIBRATION



- R^2: 0.64
- NRMSE (%): 12.1%
- PBIAS (%): -4.0%

VALIDATION

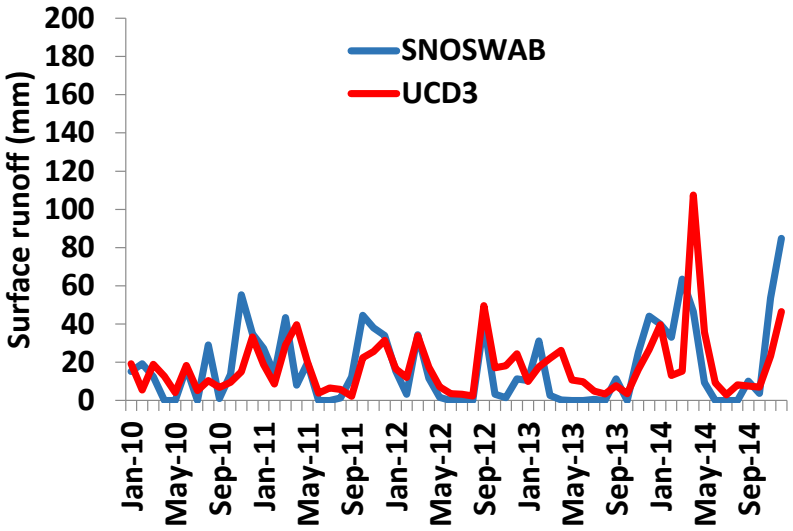


(Danielescu, 2024)

- R^2: 0.75
- NRMSE (%): 10.9%
- PBIAS (%): -0.5%

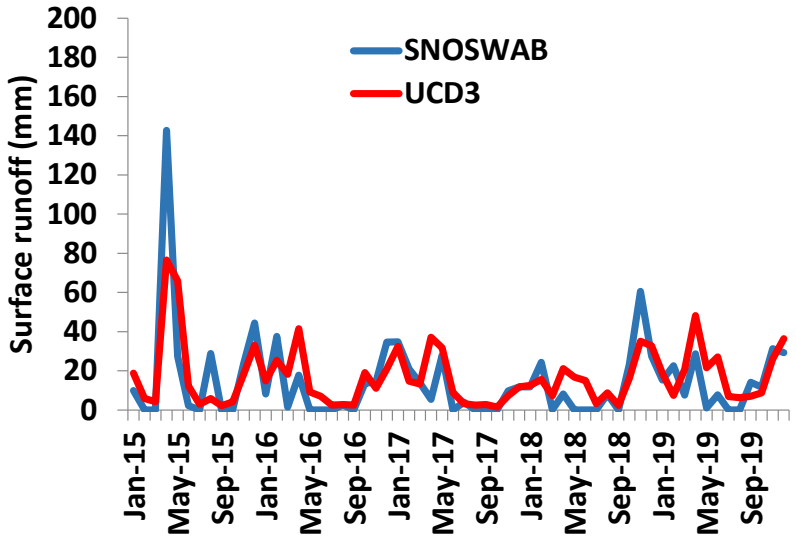
SNOSWAB – surface runoff

CALIBRATION



- R^2: 0.33
- NRMSE (%): 16.0%
- PBIAS (%): 1.9%

VALIDATION

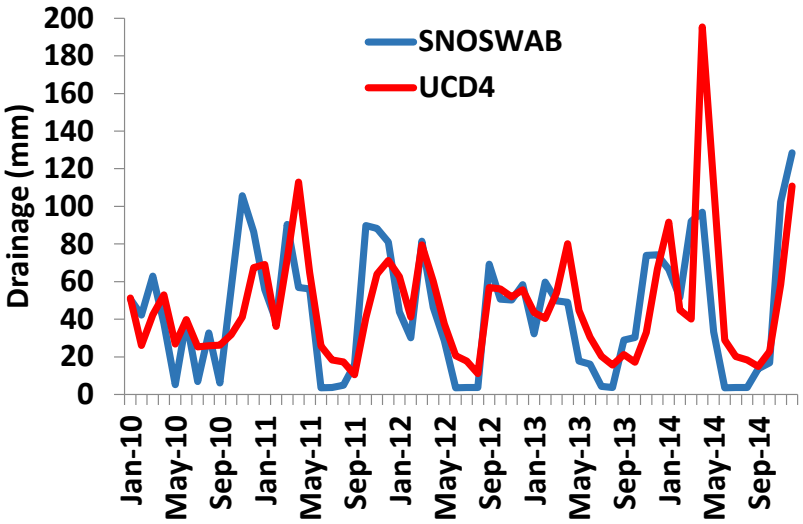


(Danielescu, 2024)

- R^2: 0.56
- NRMSE (%): 19.4%
- PBIAS (%): 14.0%

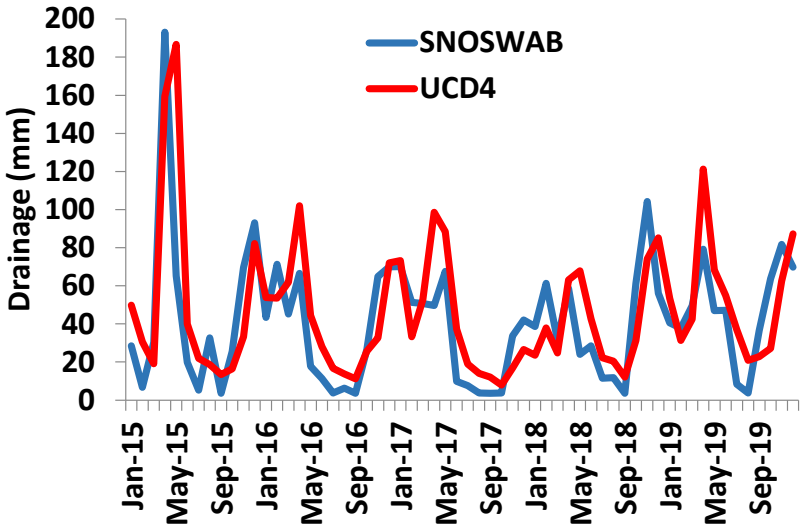
SNOSWAB – drainage

CALIBRATION



- R^2: 0.42
- NRMSE (%): 14.6%
- PBIAS (%): 6.9%

VALIDATION



(Danielescu, 2024)

- R^2: 0.53
- NRMSE (%): 14.5%
- PBIAS (%): 12.5%

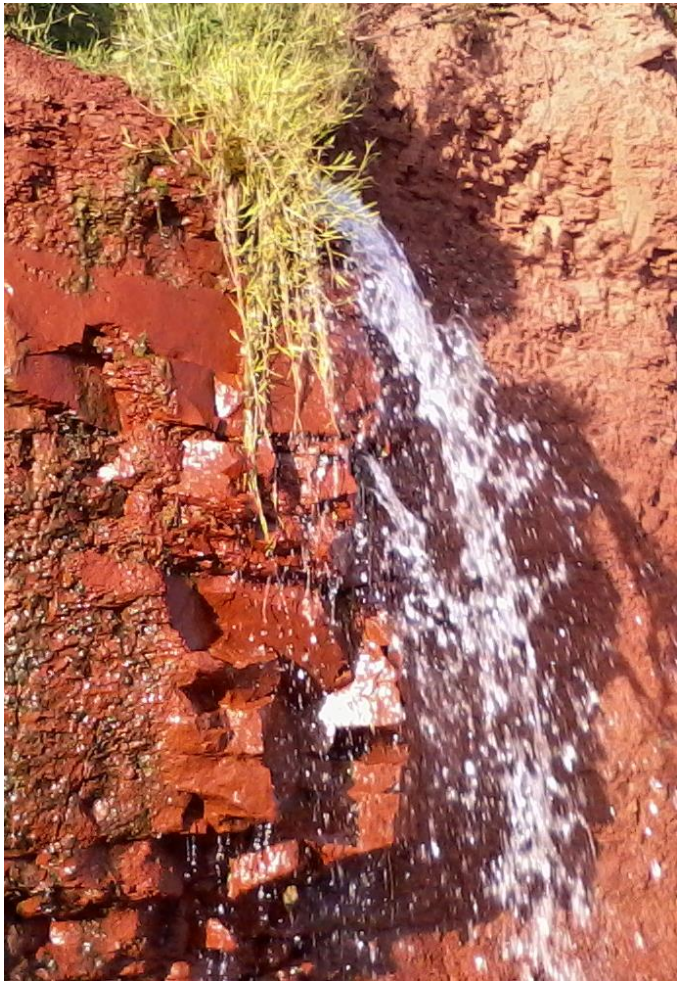
References

- *Danielescu S (2024) Development and Application of the Snow, Soil Water and Water Balance Model (SNOSWAB), an Online Model for Daily Estimation of Snowpack Processes, Soil Water Content and Soil Water Balance. Water 16: 1503. DOI: https://doi.org/10.3390/w16111503*

- *Danielescu S, MacQuarrie KTB, Nyiraneza J, Zebarth B, Sharifi-Mood N, Grimmett M, Main T, Levesque M (2024) Development and Validation of a Crop and Nitrate Leaching Model for Potato Cropping Systems in a Temperate–Humid Region. Water 16: 475. DOI: https://doi.org/10.3390/w16030475*

Future development plans

- routines for water additions and losses
- multiple soil layers
- autocalibration routines
- connect to monitoring stations



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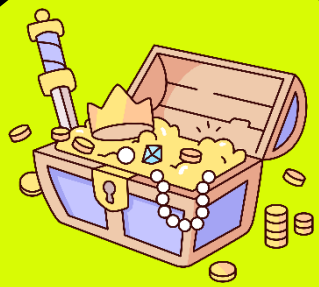

- AAFC: GF2, LL
- ECCC: LWBI