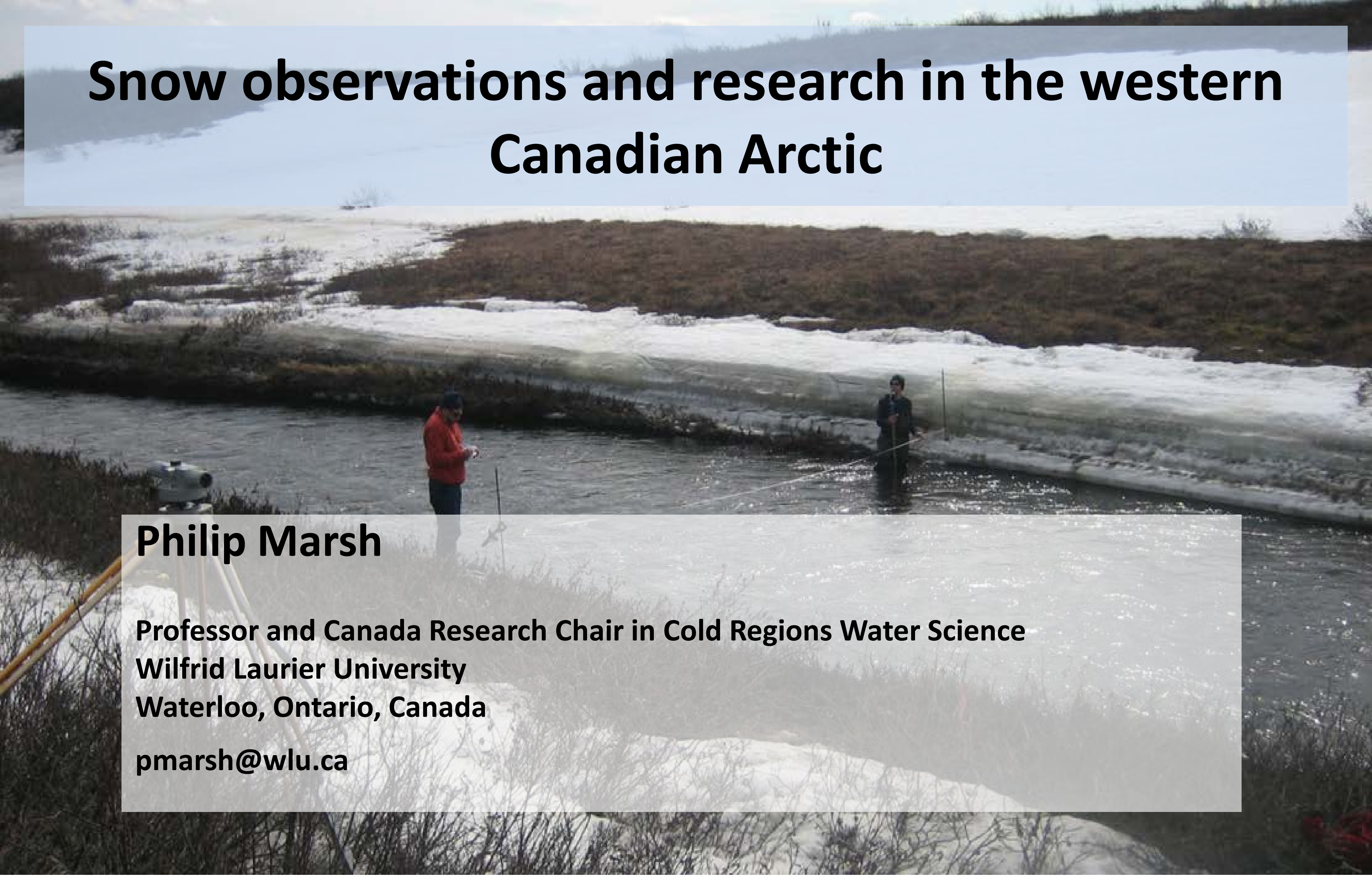
Snow observations and research in the western Canadian Arctic



Philip Marsh

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Wilfrid Laurier University

1987 - 2017 Cold Regions Research Centre
30 Years of Excellence

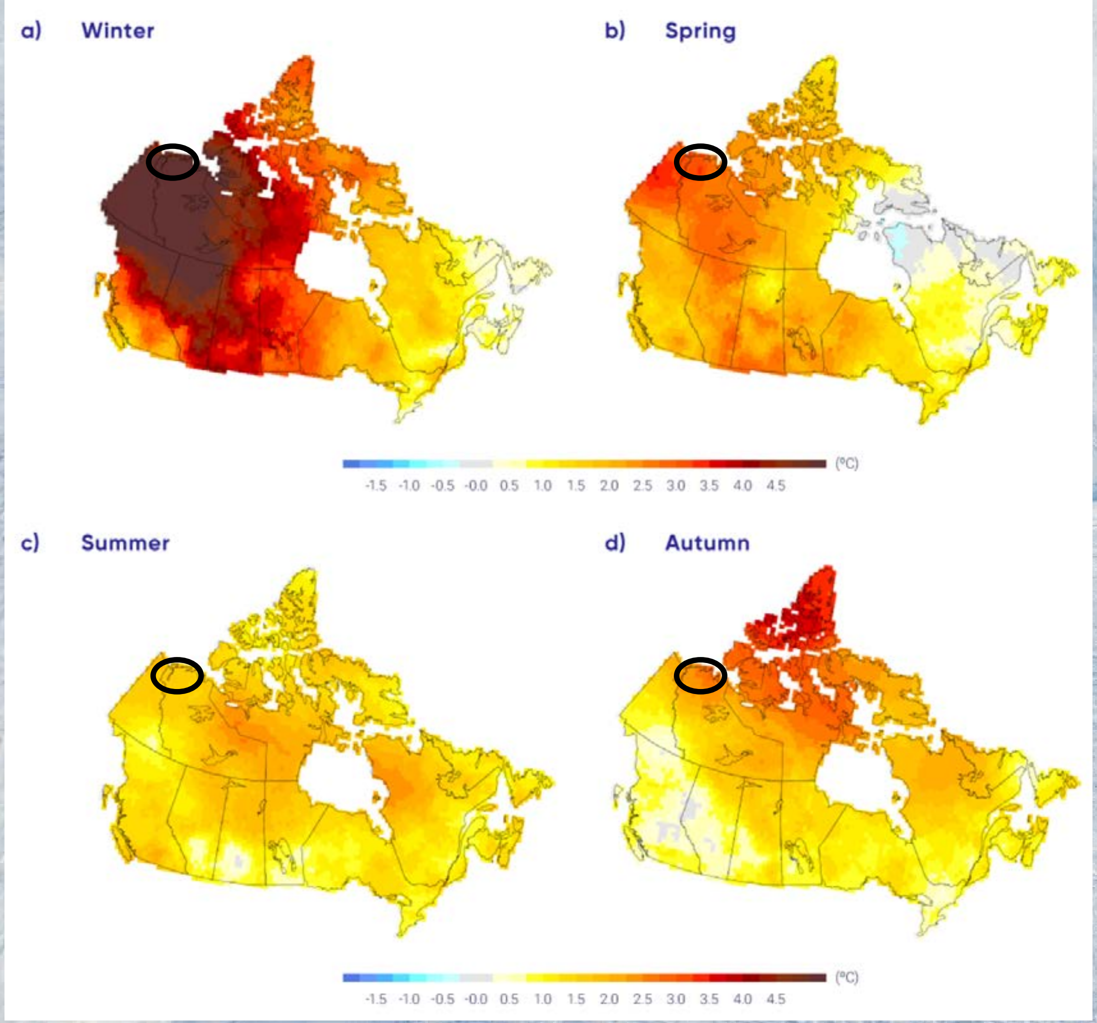
Make the case that:

1. Snow has *unique properties and spatial variability* and has important controls on Arctic ecosystems,
2. The *winter climate, and snow, is changing more rapidly* than the summer climate,
3. Snow is *poorly measured* during the Arctic winter, and *snow models have limited ability* to model Arctic snow,
4. Snow process studies over the entire winter in the Arctic have been *relatively ignored*.

Provide an example from the western Canadian Arctic where we studying winter snow processes, as well as summer hydrologic processes. This is an ABoVE transect.

1. Winter air temperature is warming faster than the other seasons across Canada

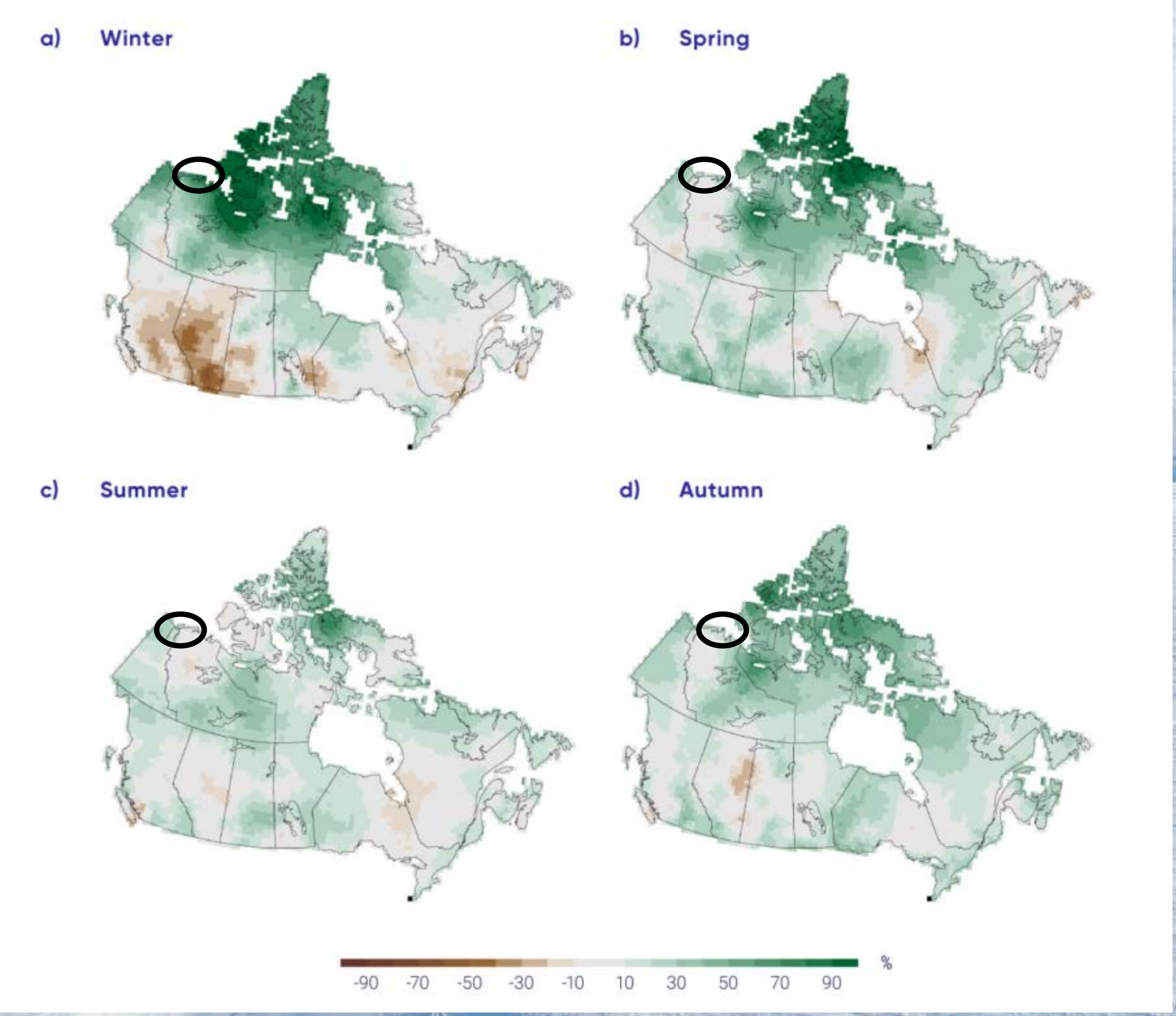
Observed changes in seasonal mean air temperature between 1948 and 2016



Zhang et al. 2019. Changes in temperature and precipitation across Canada. Chapter 4 in: Bush and Lemmen (eds). **Canada's Changing Climate Report.** Government of Canada, Ottawa, Ontario, pp 112-193.

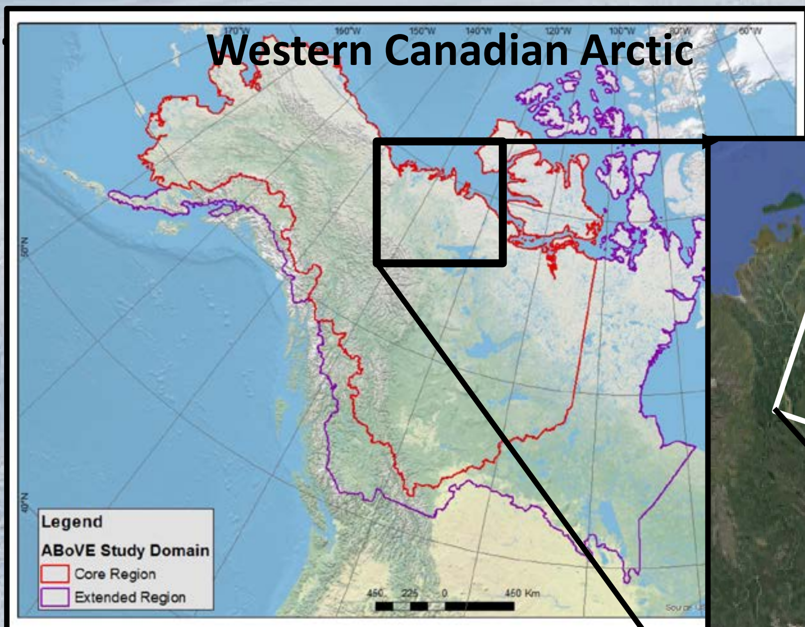
Precipitation change across all season has been variable, with both increases and decreases

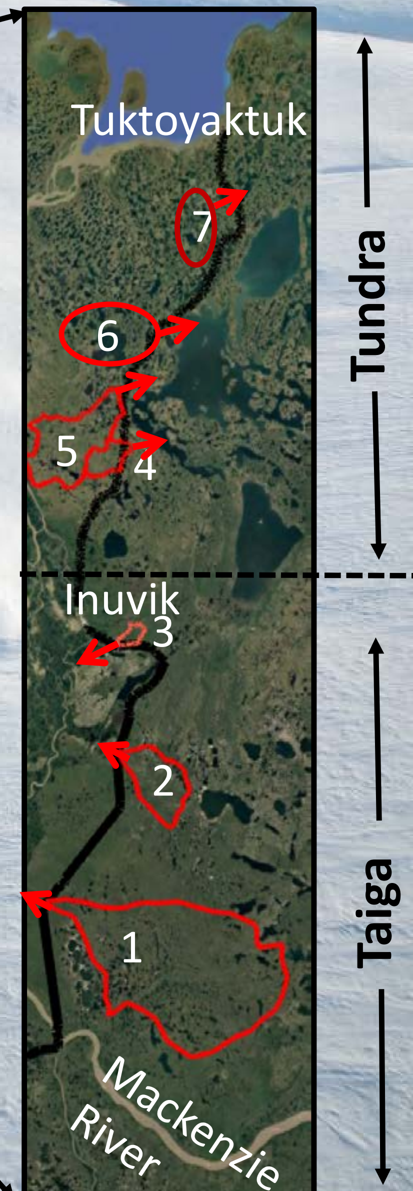
Observed changes in seasonal precipitation between 1948 and 2012



Zhang et al. 2019. Changes in temperature and precipitation across Canada. Chapter 4 in: Bush and Lemmen (eds). **Canada's Changing Climate Report.** Government of Canada, Ottawa, Ontario, pp 112-193.

2. A case study from the western Canadian Arctic: along strong environmental gradients in temperature, precipitation and vegetation



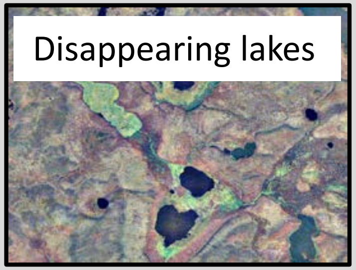


- Continuous permafrost
- Tundra – taiga ecotone
- Five Water Survey Canada streamflow stations
    1. Rengleng River. taiga
    2. Caribou Riever. taiga
    3. Havikpak Creek. taiga
    4. Trail Valley Creek. tundra
    5. Hans Creek. Tundra, large lake numbers and area
    6. + 2 new tundra stations this summer
- Four ECCC weather stations, + a number of research stations

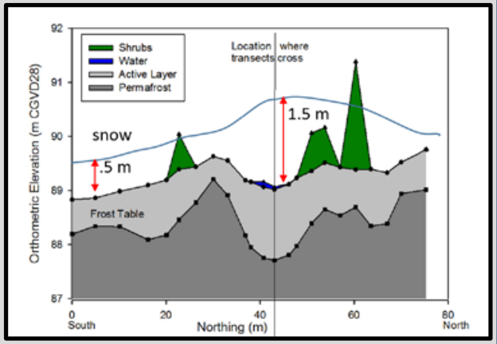
Combination of warming/drying is resulting in numerous ecosystem changes

Expanding shrubs

Changing lakes



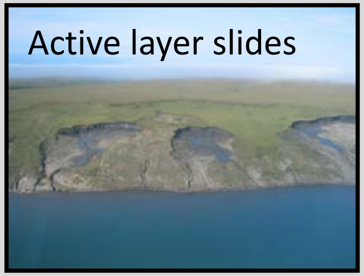
Resulting in changes in snow



Increasing snow in shrub patches

Increasing fires?

Changing topography



But …. There area also difficult to explain changes

Dramatically changing climate, but – <u>unexpected hydrological changes</u>, that currently are unpredictable by our models

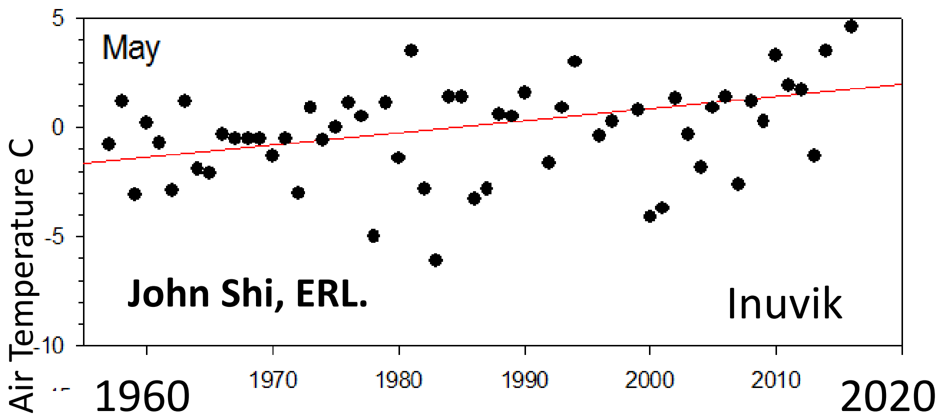
1. **Spring melt is starting earlier, but time of Q5 to Q50 either not changing or occurring later (John Shi, ERL)**

2. **Precipitation is decreasing, ET must be increasing, but**
   - **upland lakes don’t appear to be changing**

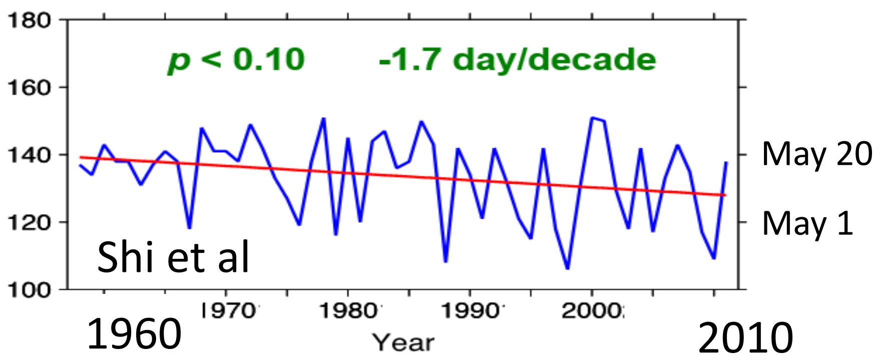
3. **Rate of rapidly draining lakes**
   - declining

Earlier snowmelt, but spring melt discharge is not changing

Much warmer air temperature during the melt period

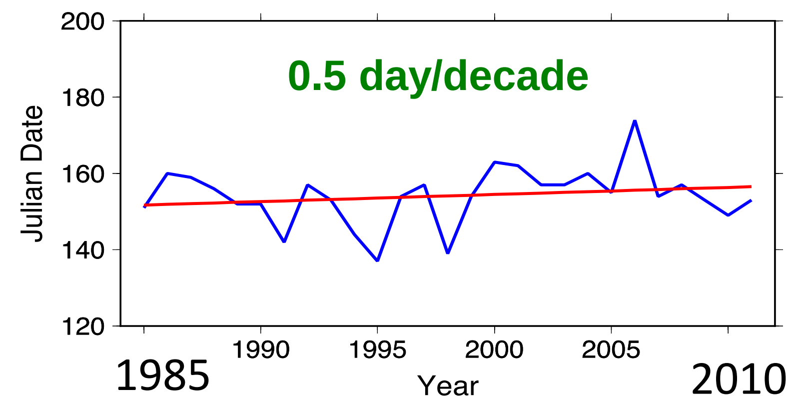


Start of snowmelt

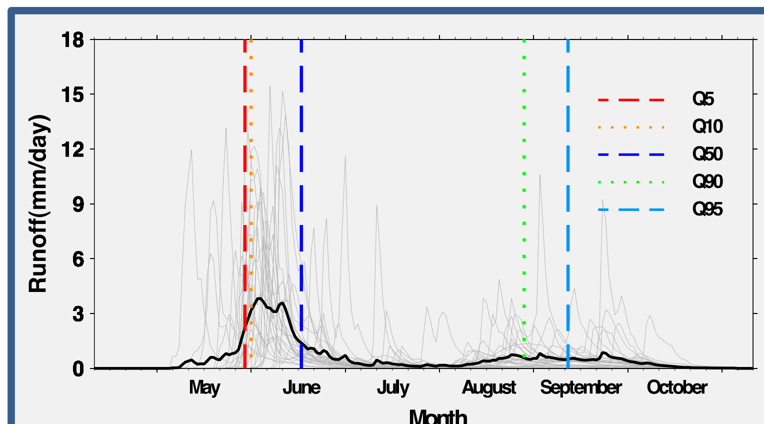


Defined as first 5 days, mean temp > 0°C

Date of Q50. i.e. 50% of runoff



Trail Valley Creek



<u>Possible reason</u>: increasing shrub patch size and density, deeper snow in shrub patches, changes in snow melt energy balance, delayed percolation of meltwater & delayed runoff

But …. There area also difficult to explain changes

Dramatically changing climate, but – <u>unexpected hydrological changes,</u> that currently are unpredictable by our models

1. **John Shi ERL paper earlier start of spring melt, but time of Q5 to Q50 either not changing or occurring later**

2. **Precipitation is decreasing, open water season is increasing, and ET is likely increasing, but upland lakes don't appear to be changing**

3. **Rate of rapidly draining lakes - declining**

Upland lakes, with small contributing area area not decreasing. Why?

<u>Possible reason</u>: increased shrubs around lake edge, resulting in increased snow accumulation and runoff to the lakes

But …. There area also difficult to explain changes

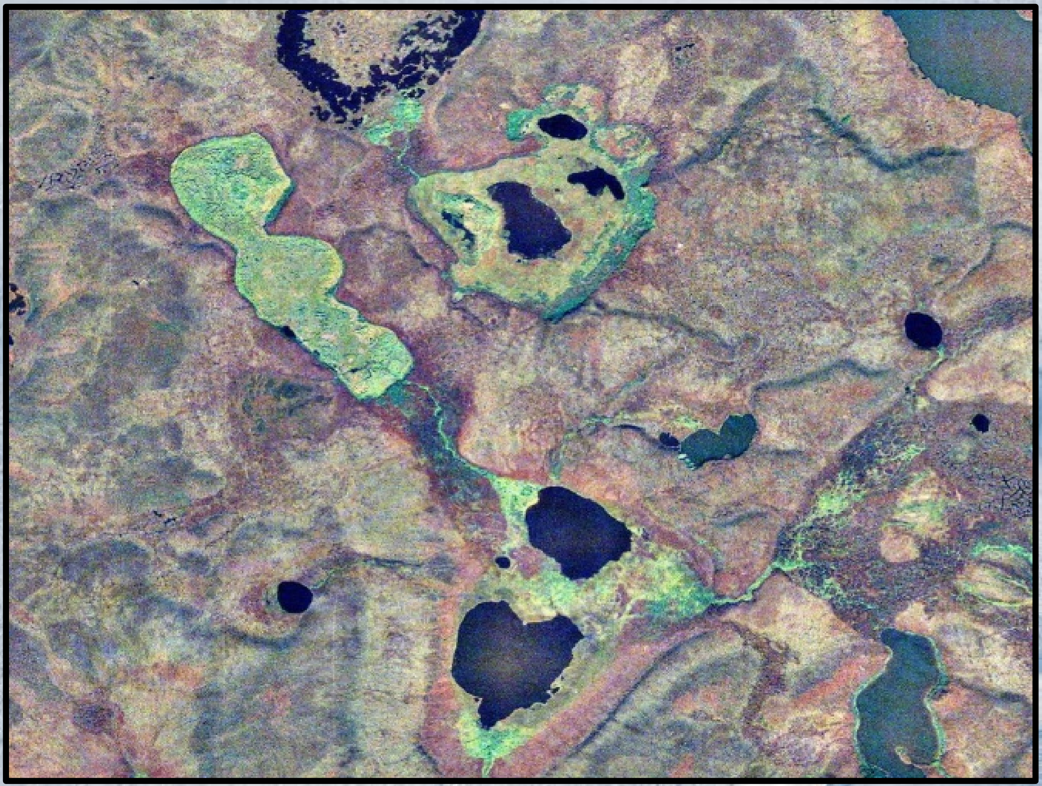
1. **Dramatically changing climate, but – <u>unexpected hydrological changes</u>, that currently are unpredictable by our models**

   1. **John Shi ERL paper earlier start of spring melt, but time of Q5 to Q50 either not changing or occurring later**

   2. **Precipitation is decreasing, ET must be increasing, but**
      - **upland lakes don't appear to be changing**

   3. **Rate of rapidly draining lakes**
      - has been declining for decades

Rapidly draining lakes

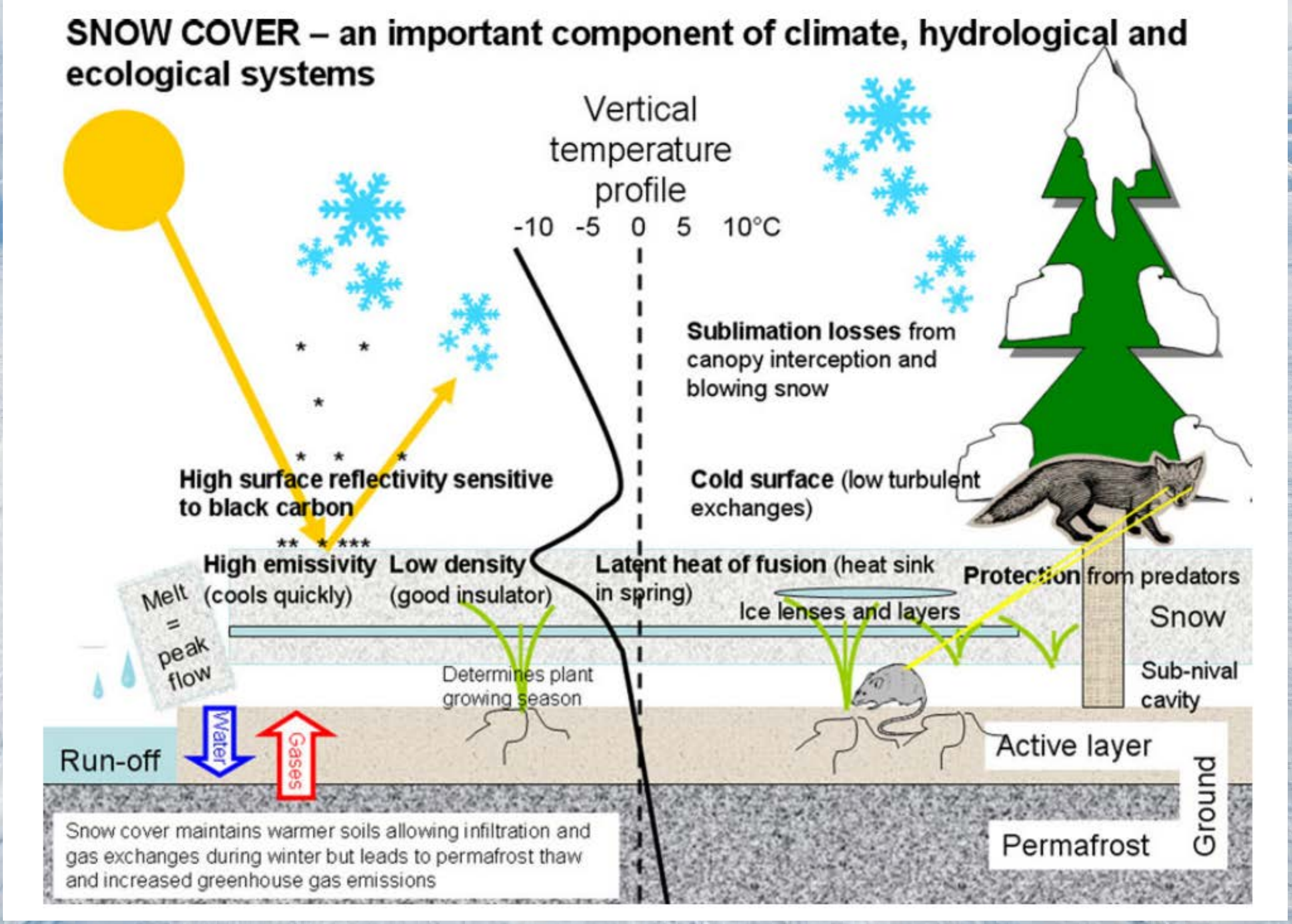


J.R. Mackay showed that lakes in the area have drained at a rate of 1 per year over the last few thousand years.

Marsh et al., showed that since 1950, the rate of lake drainage has been decreasing, and has reduced to about 0.5 per year

Possible reason: decreased ice wedge cracking in the winter, as a result of warming winter temperature, but decreasing snow fall and average depth (but deeper snow in shrub patches)

Understanding these, and other ecosystem changes, requires improved understanding of snow and links to other key aspects of the Arctic and Boreal systems



Johansson, M., et al. 2011. ***4 . Changing Snow Cover and its Impacts. SWIPA*****.**

3. But – there is a lack of the required snow measurements

Due to extreme winter conditions, limited electrical power, and field crews focussed on summer conditions, there is a significant lack in winter snow measurements across the Arctic.

Point measurements of the following are prone to large errors and are extremely unreliable:

- *Snowfall*: extreme under catch is normal
- *Sublimation*: eddy covariance difficult to operate in winter
- *Snow depth*: continuous measurements in deep snow drifts have not been possible
- *Snow density*: no methods for continuous observations
- *Snow water equivalent*: limited options for continuous measurement

Very few methods available to map spatial variability in snow & measure discharge

Mapping the extreme spatial variability in snow is difficult as it has traditionally relied on manual snow surveys of depth and density. Difficult / impossible to properly account for spatial variability across terrain/vegetation type.

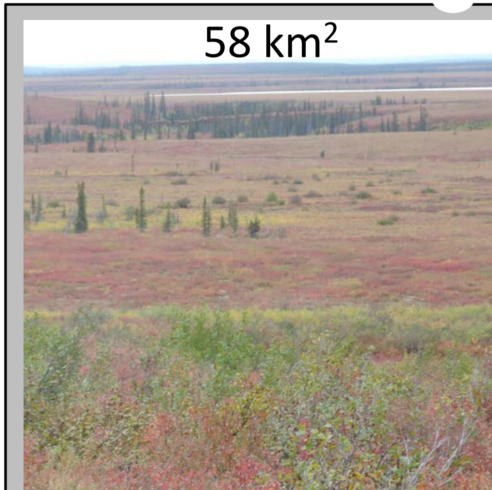
<u>Recent advances:</u>

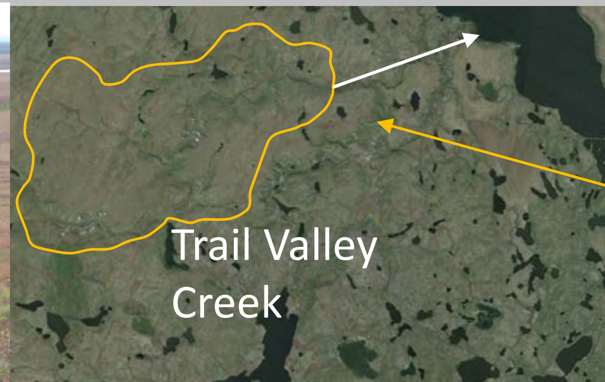
- *Snow depth*: photogrammetry and lidar
- *SWE*: airborne gamma – lines, not mapping

Streamflow during melt: prone to huge errors

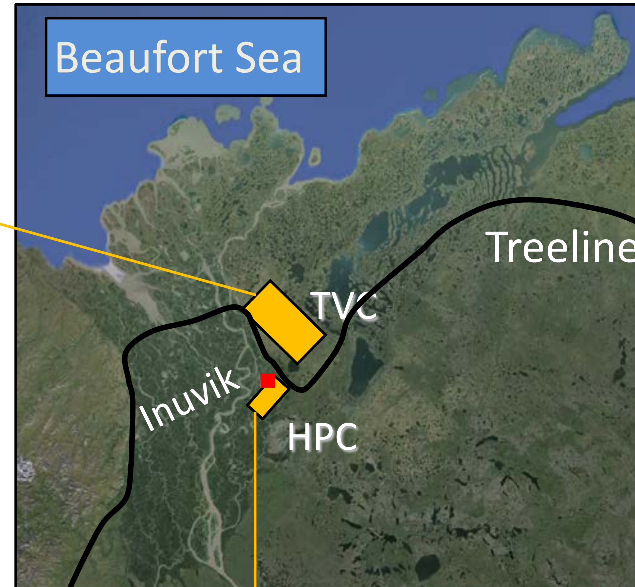
These limitations make understanding the role of snow and the development and testing of snow models extremely difficult.

4. Integrated observing program in the Western Canadian Arctic

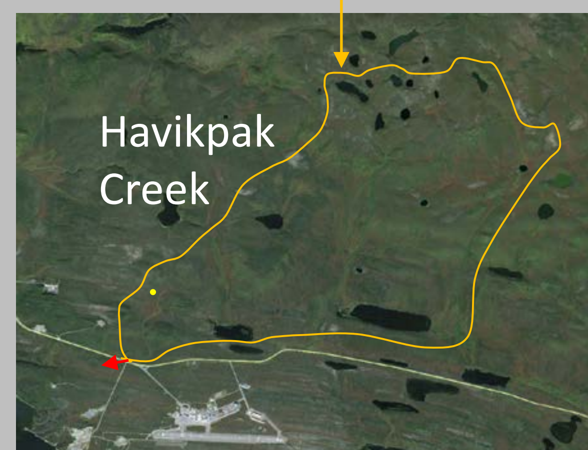




Eskimo Lakes



50 km apart

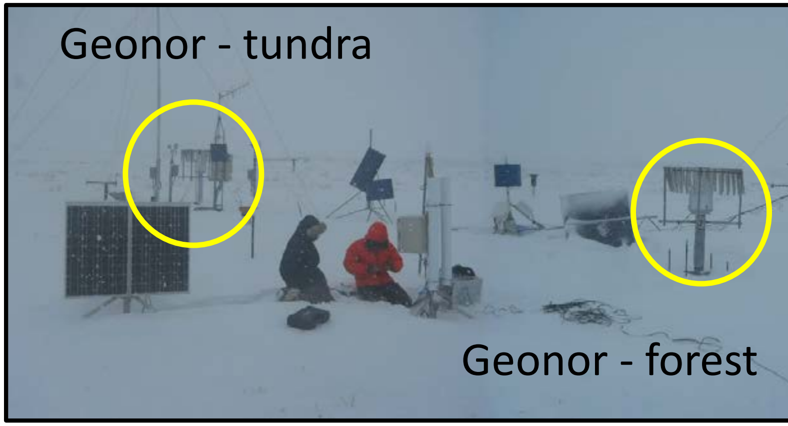


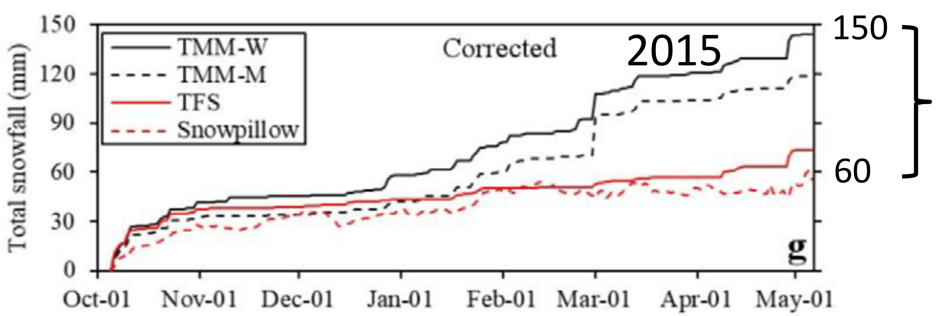
Both are continuous permafrost.

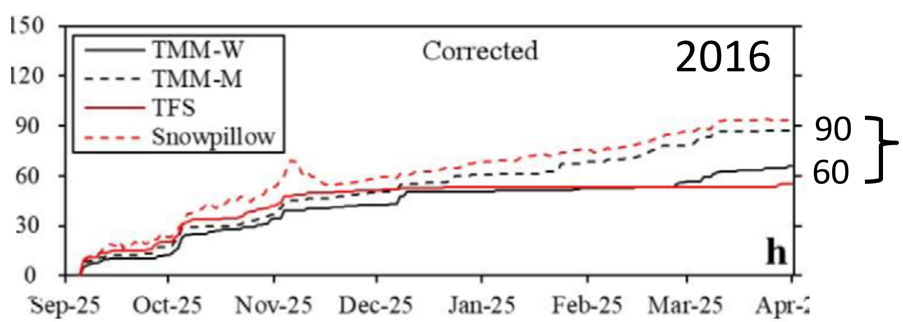
Climate very similar

Improving snow measurements

Improving snowfall measurements







Phil Mann. 2017

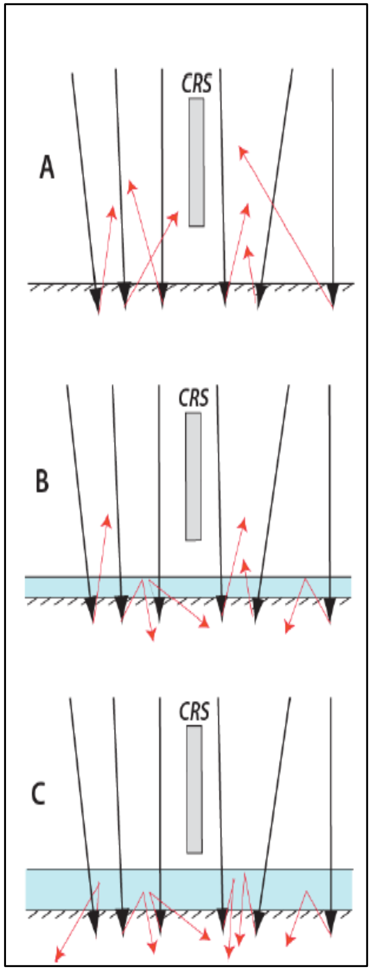
Problem

- Unacceptable errors using multiple Geonor Weighing snow gauges

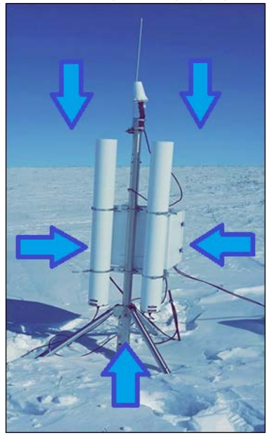
Solution

- New power system to allow heating of gauges to overcome snow capping issues
- **Installation of a Micro Rain Radar (MRR) and Disdrometer to measure snowfall**

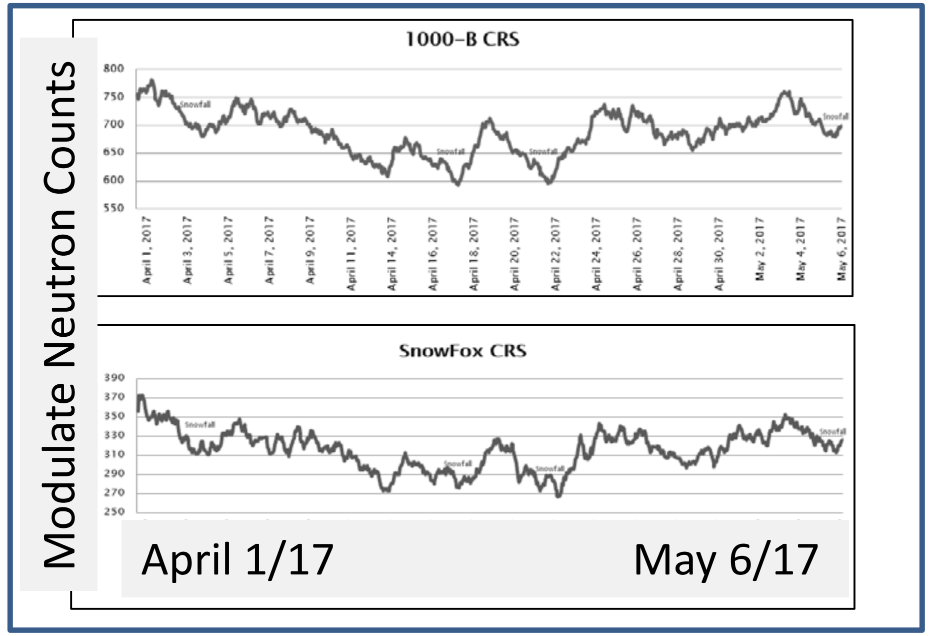
Improving snow water equivalent accumulation measurements

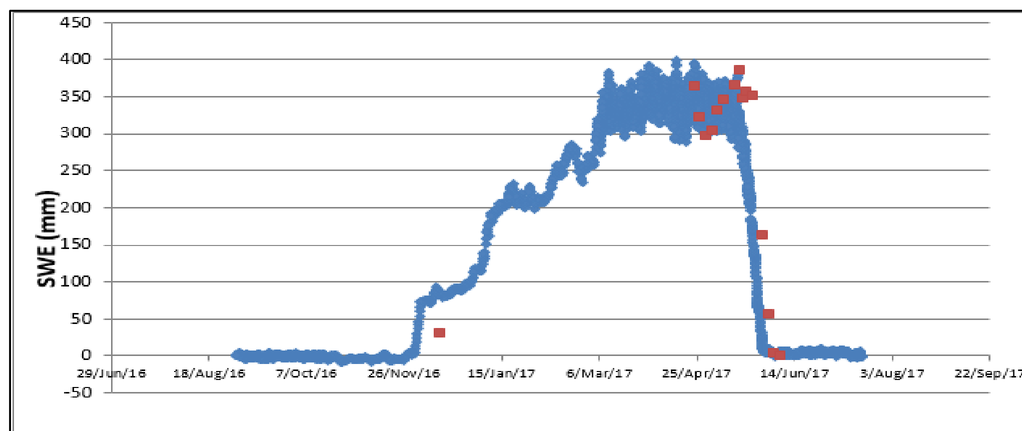


CRS-1000



SnowFox





Anton Jitnikovitch. 2018

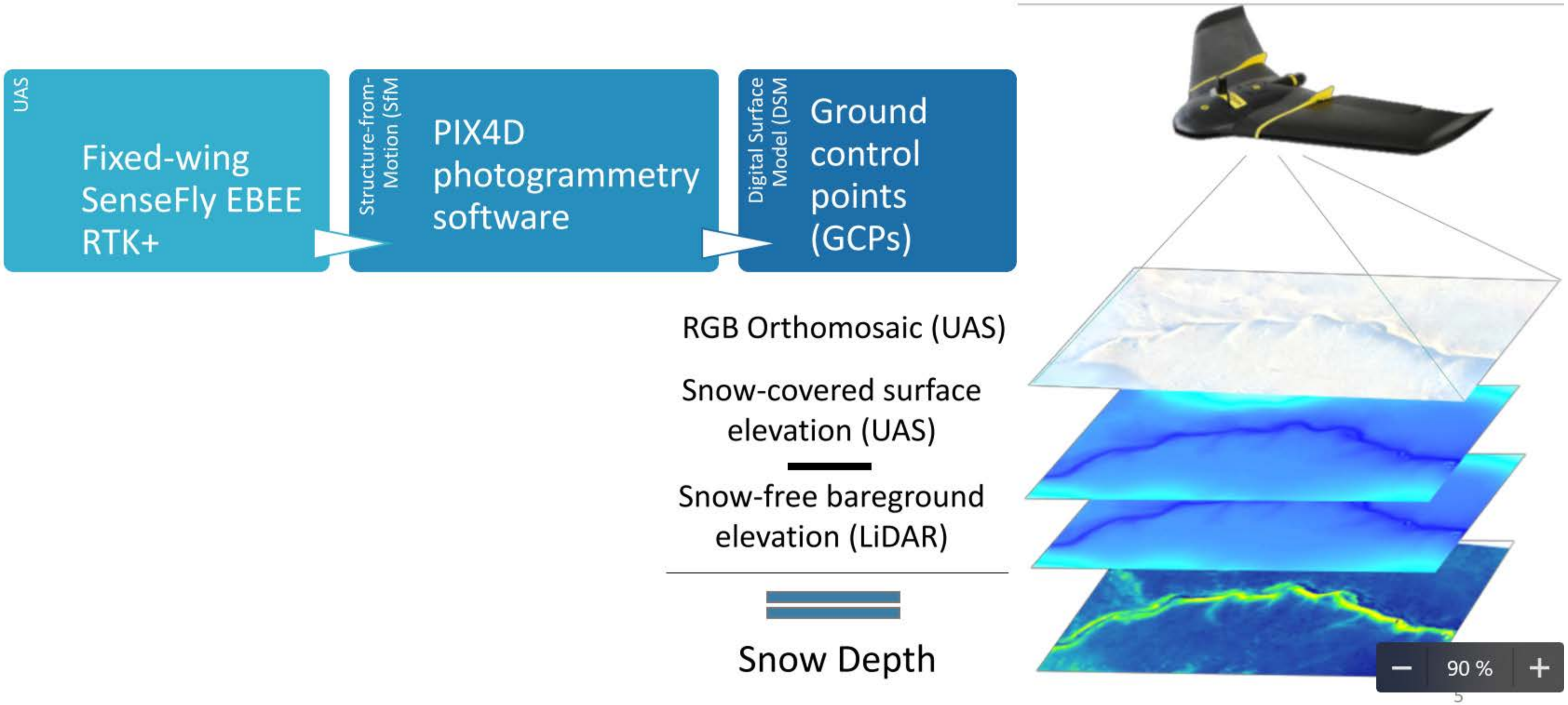
Improving winter sensible & latent Heat Fluxes

Eddy covariance

- Nested towers
- Tundra and shrub tundra
- Lake tower
- Forest tower

Improving snow remote sensing

Structure-from-motion snow depth mapping



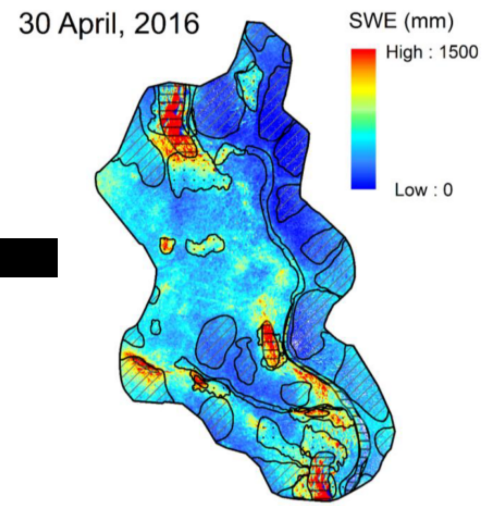
Branden Walker, 2019

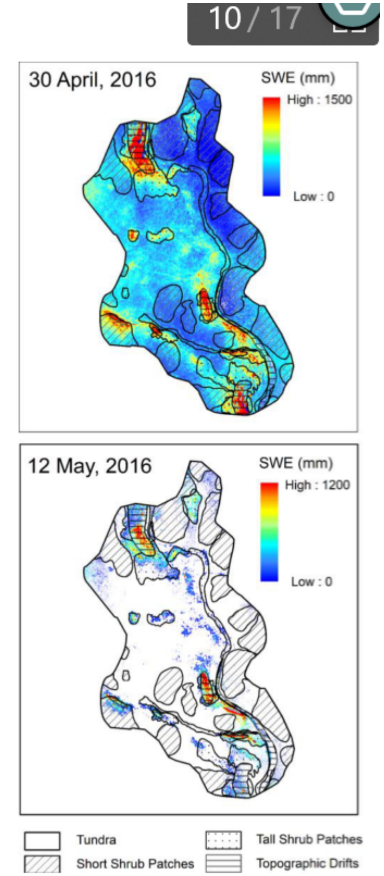
Mapping end of winter snow water equivalent by vegetation type

Snow Water Equivalent (SWE)

= 50 mm SWE

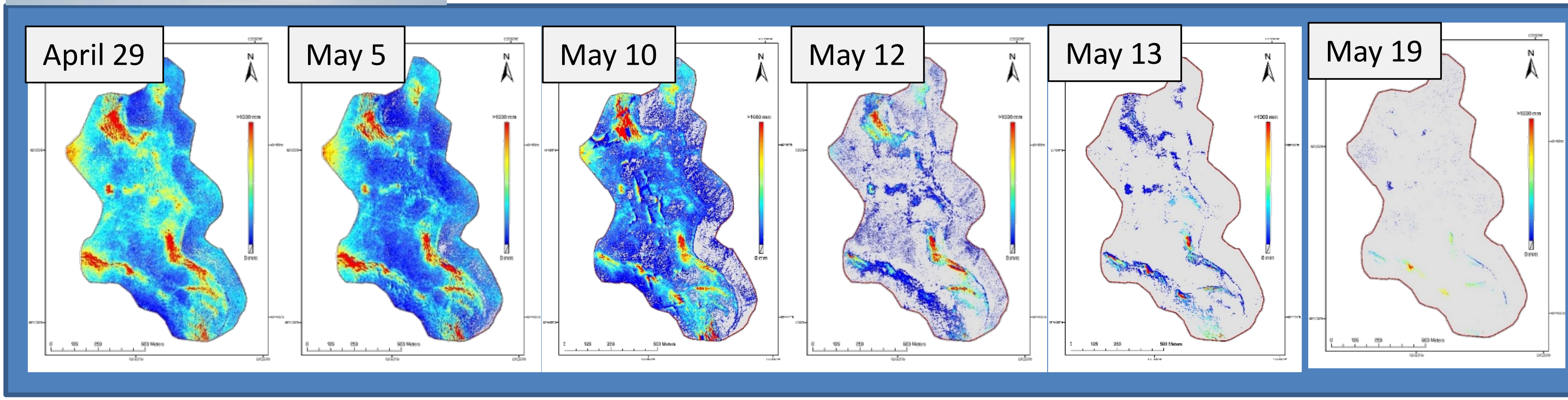
End of winter Snow Water Equivalent		
	Fraction of basin (%)	SWE (mm)
Tundra	54	
Short Shrub	28	
Tall Shrub	12	
Drift	6	

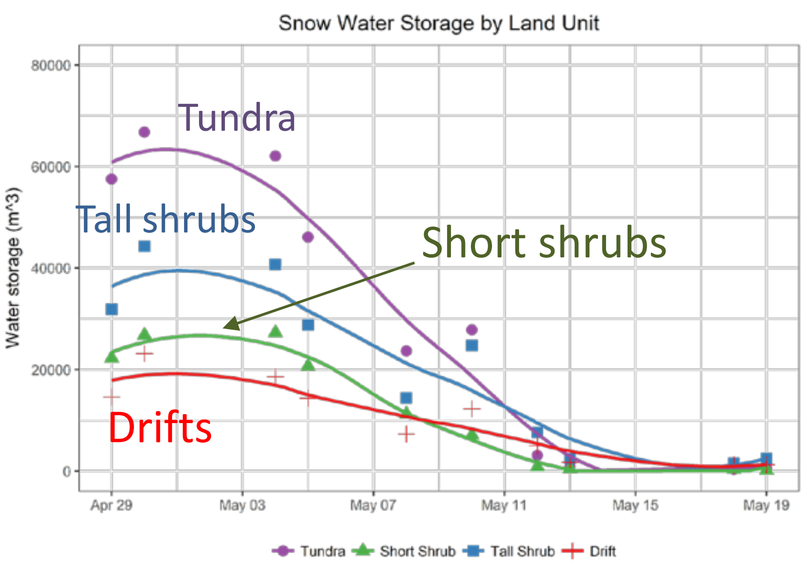


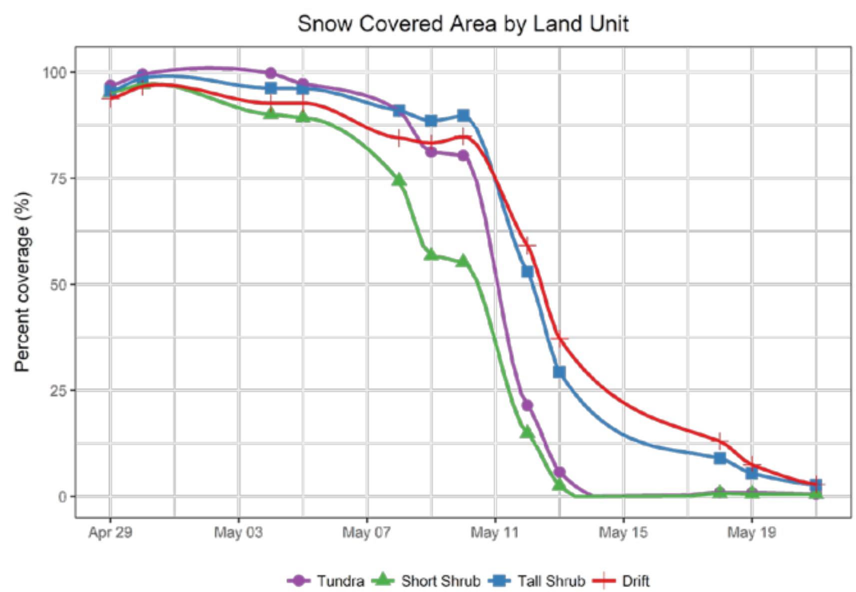


Branden Walker, 2019

Improved mapping of snow depth through melt period



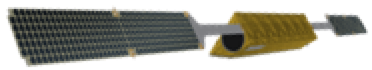




Branden Walker

Using snow-radar to map snow across Arctic tundra

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



- Climate Research Division, ECCC
- Meteorological Research Division, ECCC
- Canadian Space Agency
- Airbus Defence and Space
- Science Steering Group

TVCSnow Project

- Climate Research Division, ECCC
- Canadian Space Agency
- University of Massachusetts
- Wilfred Laurier University

Chris Derksen and Josh King, ECCCC

Radar Mission Drivers

1. The amount, distribution, and variability of terrestrial snow mass is poorly quantified (**requires snow water equivalent retrieval**)

2. The performance of land-atmosphere data assimilation systems is limited by inadequate treatment of snow mass (**requires backscatter**)

3. Improved initialization of snow mass will allow more skilled hydrological prediction

4. Spring snow mass can represent a significant hazard

How much water is **stored as seasonal snow** and 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?

Trail Valley Creek is an important test-bed for determining snow/radar interactions

Chris Derksen and Josh King, ECCCC

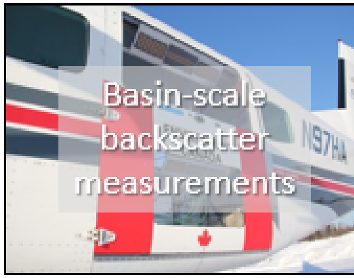
Trail Valley Creek Snow Experiment: TVCSnow

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

- November 9-23, 2018
  - Early season snow, soil freeze-up
- January 7-23, 2019
  - First large storms
- March 17-31, 2019
  - End of season microstructure
- April to May, 2019
  - Snowmelt period

UMass 13.5 GHz Radar

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

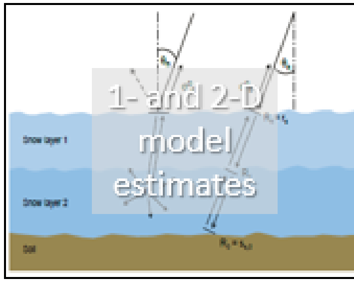


TVC field campaign

- 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



Chris Derksen and Josh King, ECCCC

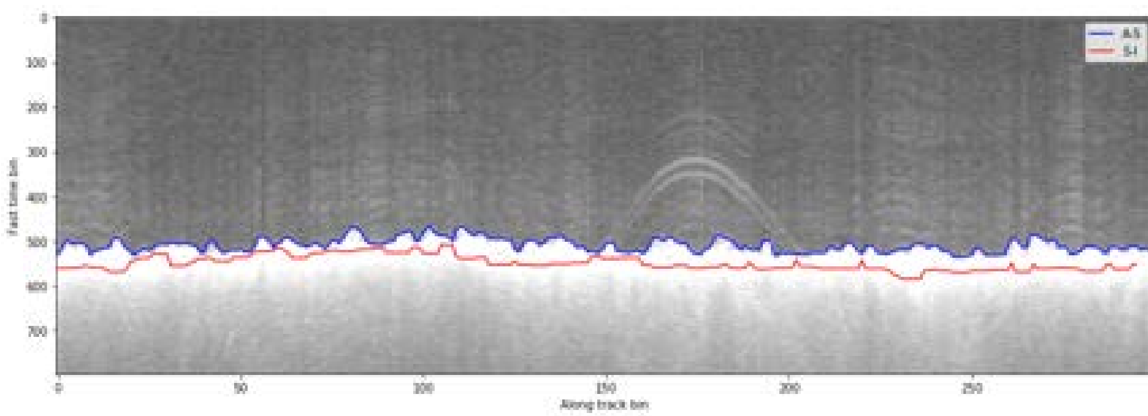
TVCSnow: supporting measurements

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

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

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

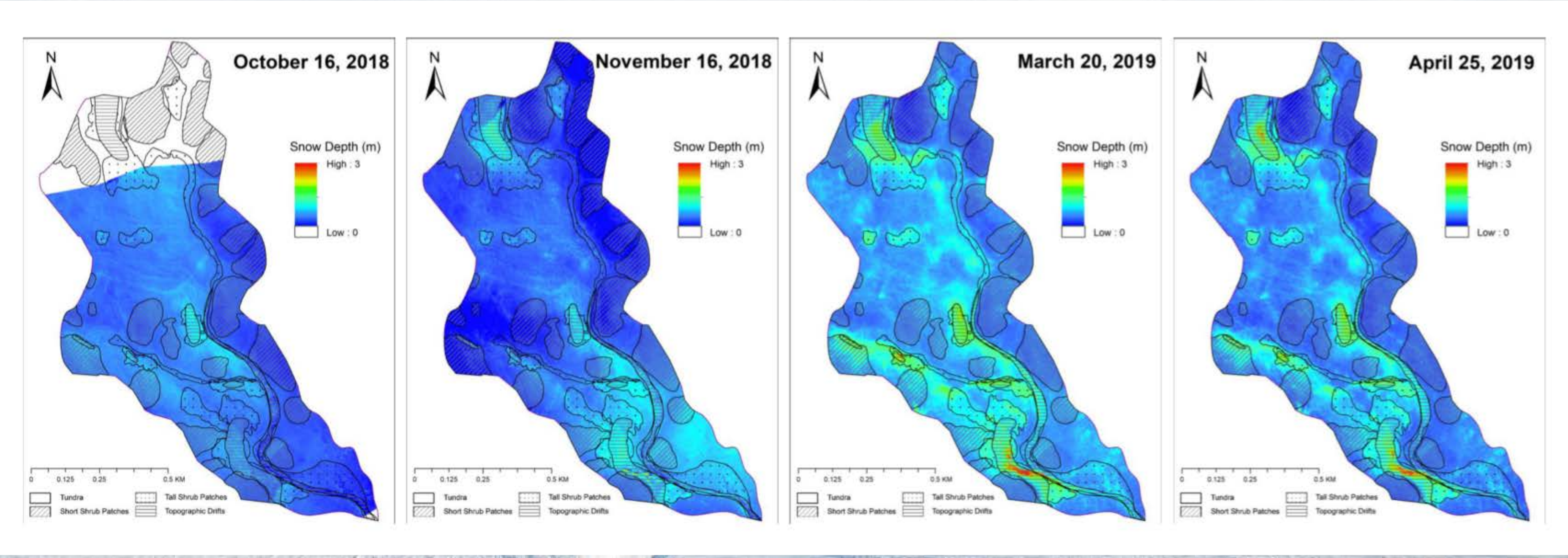
Structure from Motion (WLU)
- Drone flight each deployment
- Snow depth maps at 2 cm resolution



Snow depth from AWI SnowRadar

Chris Derksen and Josh King, ECCCC
Philip Marsh and Branden Walker, WLU

Mapping snow depth over the winter SfM



January – weather conditions too severe for UAS flights
- Low temperature, high winds, low light

Branden Walker, 2019

Snow modelling

- **Snow accumulation modelling**:
  - John Pomeroy’s Prairie Blowing snow model. Barun Majumder

- **Permafrost modelling:**
  – AWI CryoGrid. Evan Wilcox

- **Lake modelling:**
  - Canadian Small Lake Model. Murray Mackay, ECCC

- **Integrated modelling**:
  - Canadian Hydrological Model, Global water Futures

Canadian Hydrological Model

GWF Next Generation Modelling

Computers and Geosciences 119 (2018) 49–67

Contents lists available at ScienceDirect

Computers and Geosciences

journal homepage: www.elsevier.com/locate/cageo

ELSEVIER

Research paper

Multi-objective unstructured triangular mesh generation for use in hydrological and land surface models

Christopher B. Marsh[a,b,*], Raymond J. Spiteri[a,c], John W. Pomeroy[a,b], Howard S. Wheater[a,b]

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[b] Global Institute for Water Security (GIWS), University of Saskatchewan, Canada
[c] Numerical Simulation Lab, Dept. Computer Science, University of Saskatchewan, Canada

CHM – variable size triangular network

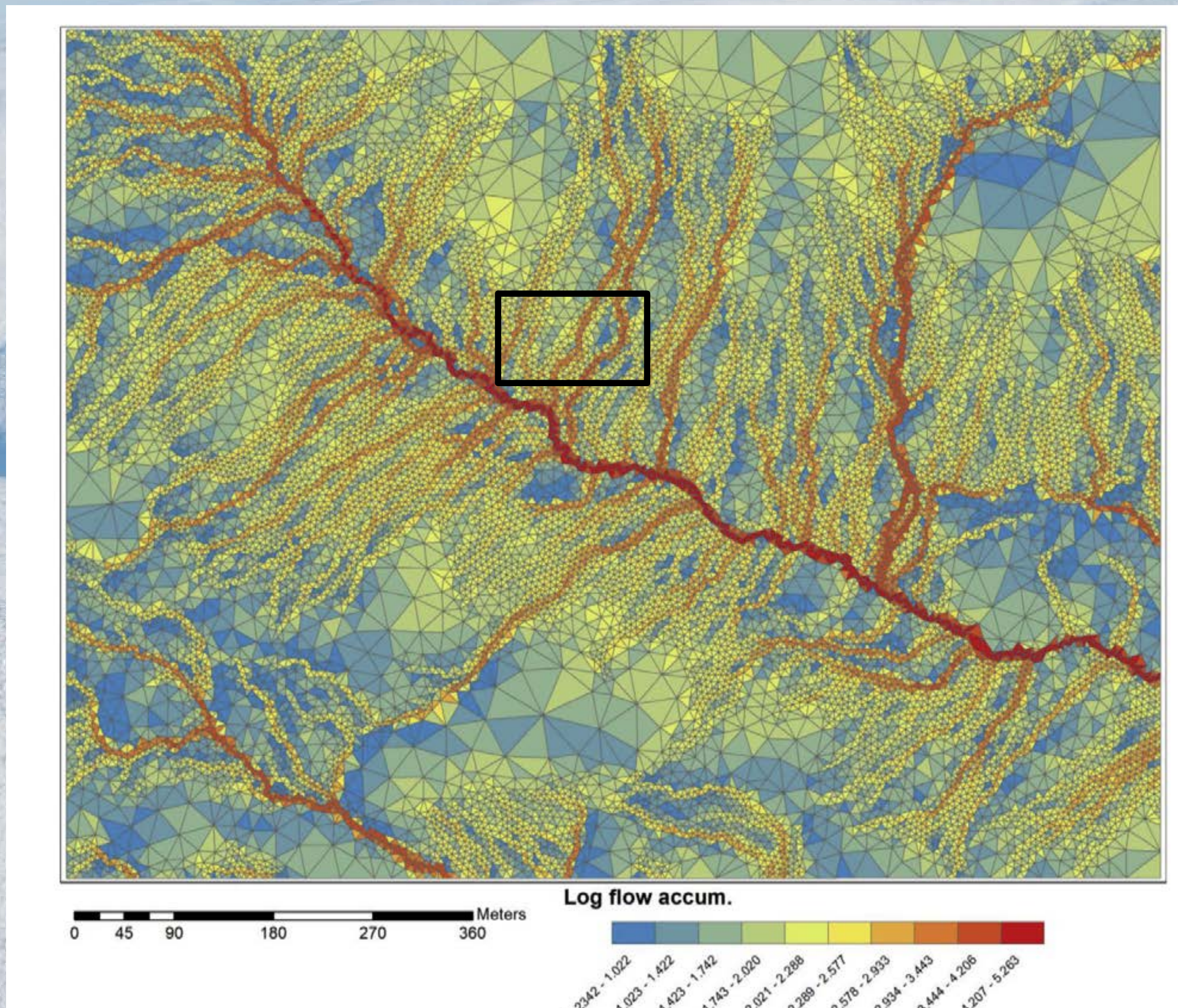
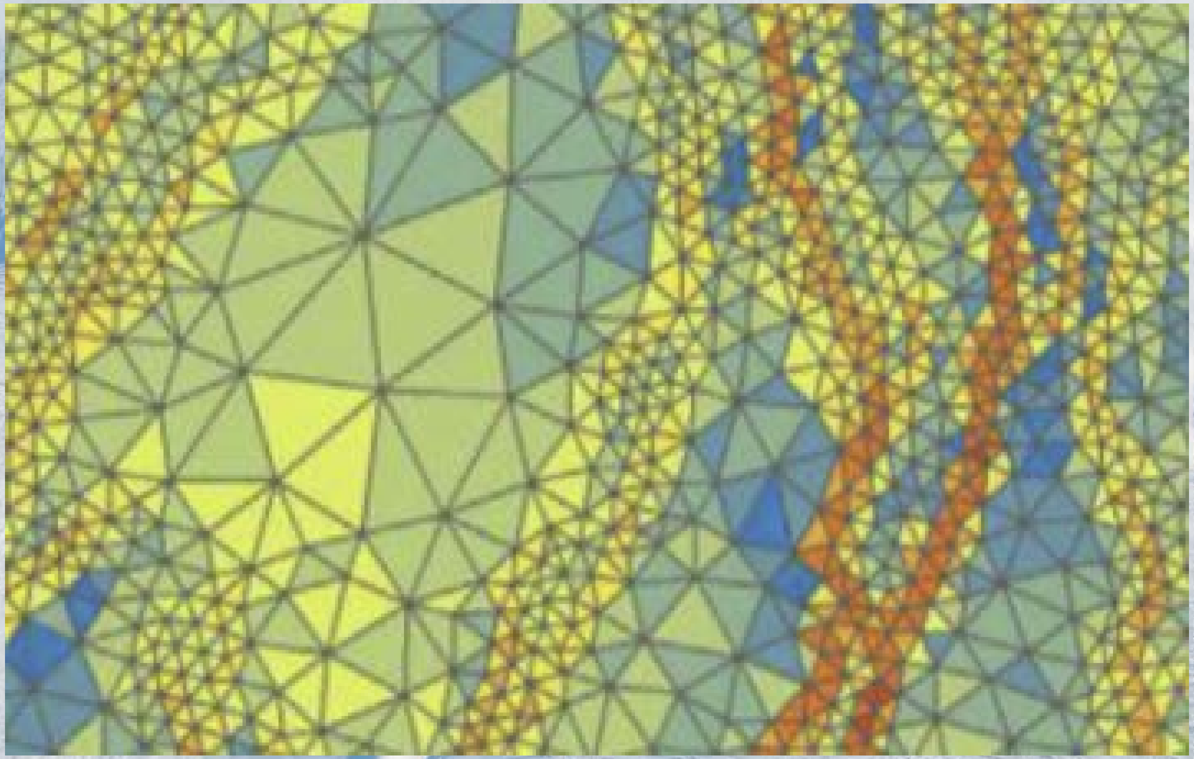


Fig. 6. A flow accumulation raster was used to conform the triangulation, in addition to elevation. Shown is the $\log_{10}$ of the calculated flow accumulation where high flow accumulation (e.g., stream) is shown in red, and low flow accumulation (e.g., source area) is shown in blue. Small triangles are present along the high flow paths, and larger triangles in the low flow accumulation areas on the uplands. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

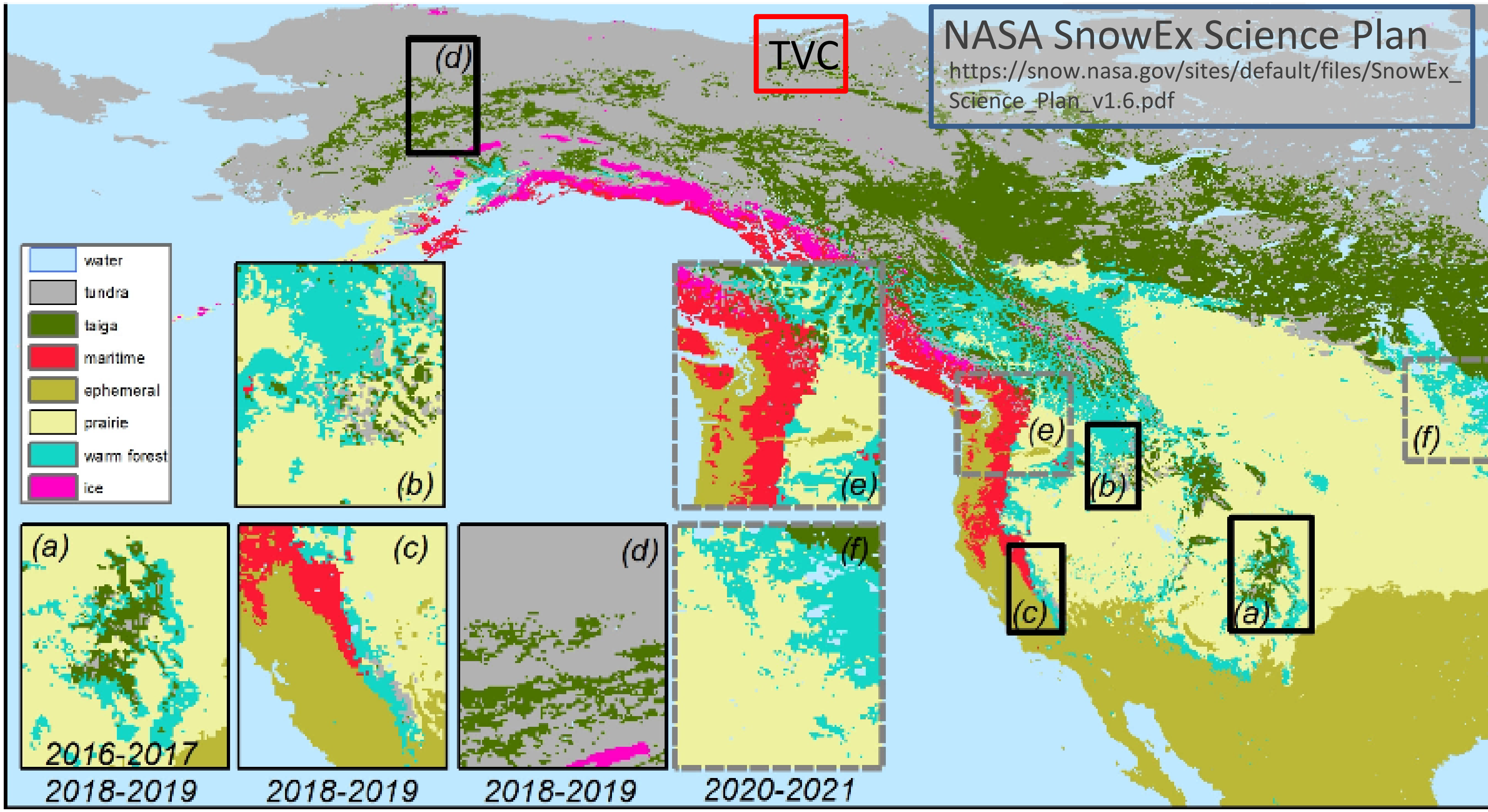
CHM – variable size triangular mesh



Allows high resolution simulations where required, and saves computer resources where large TINs are sufficient

5. Snow research and expanding our links to ABoVE and SnowEX

A possible Canadian Contribution to SnowEX



1. We do not have the capacity at TVC to house a full SnowEx campaign
2. But – coordinating and collaborating with SnowEx on future snow campaigns could be extremely worthwhile.
3. An Alaskan SnowEx and a Canadian TVC Snow campaign would be very interesting

How can our snow research better contribute ABoVE and SnowEx?

And how can we better leverage ABoVE and SnowEx products to enhance our snow research?

NSTP PFSN
GWF
Northern Water Futures
ArcticNet
NWT CIMP
Northwest Territories Cumulative Impact Monitoring Program
NSERC CRSNG
Cold Regions Research Centre
30 Years of Excellence
INNOVATION.CA
Trail Valley Creek Research Station
Polar Knowledge Canada
Savoir polaire Canada