Environment Canada Environnement Canada

Canada

Surface based microwave radiometer measurements of snow in sub-arctic tundra environments: November 2009 to April 2010

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CSA ASC

With special thanks to the Canadian Space Agency for support

Outline

- Environment Canada passive microwave snow water equivalent algorithm development
- Canadian CoReH2O Snow and Ice Experiment: Churchill 2009-2010
  - Objectives
  - Study Site
  - Data Collected
- Preliminary analysis
  - Algorithm Validation
- Conclusions

Environment Canada SWE Algorithms

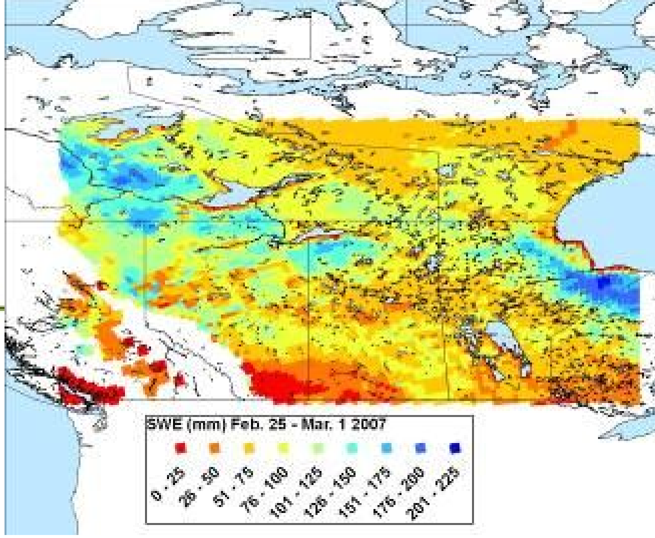
- Environment Canada has long history of using passive microwave remote sensors for estimating SWE

- Basic principles: frozen ground naturally emits microwave energy, and the overlying snowpack scatters those emissions

- Most SWE estimating algorithms are based on the brightness temperature (T_B) difference index between dual microwave frequencies
- 37-19 GHz is the most commonly used difference index
  - The greater the difference between these two frequencies, the greater the SWE estimate

- Long term satellite record available. The 37GHz and 19GHz frequencies are found on both past and present passive microwave remote sensors.
  - Scanning Multi-channel Microwave Radiometer (SMMR) – launched 1978
  - Special Sensor Microwave Imager (SSM/I) – launched 1987
  - Advanced Microwave Sounding Radiometer on EOS (AMSR-E) – launched 2002

Environment Canada SWE Algorithms



Suite of empirical, land cover specific algorithms
Focus on tundra regions for this presentation

SWE Algorithm	Approach	Experiments	References
Open prairie with wet/patchy snow indicator	37V-19V	Saskatchewan 1982	Goodison and Walker, 1995 Walker and Goodison, 1993 (A. Glaciology)
Boreal forest: Shallow snow	37V-19V (Separate equations for deciduous, coniferous, and sparse forest)	BOREAS 1994; Saskatchewan 2003	Goita et al., 2003 (Int. J. Remote Sensing)
Boreal forest: Deep snow	19V-10V	Manitoba 2004-2007; NWT 2005-2007	Derksen, 2008 (Remote Sens. Environ.)
Lake rich sub-arctic tundra	**37V**	**NWT 2005; SnowSTAR 2007; IPY 2008**	**Derksen et al., 2009 (J. Hydromet.) Derksen et al., 2010 (Remote Sens. Environ.)**

37V Tundra Algorithm Development

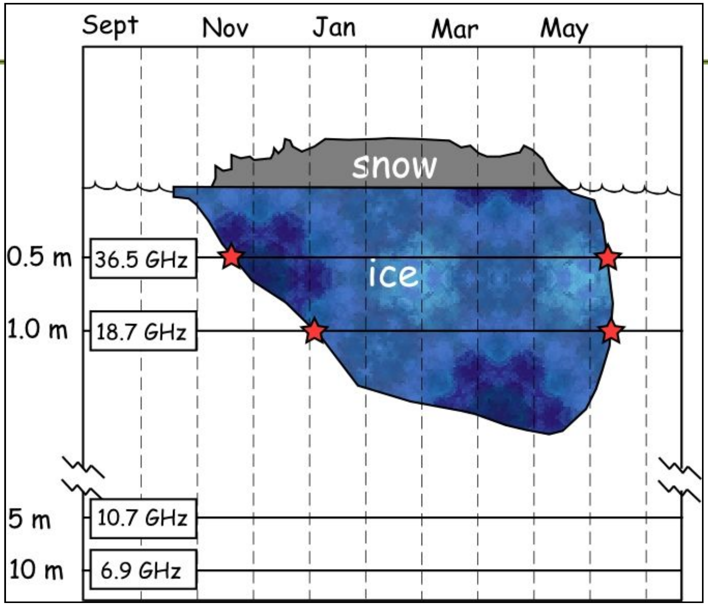
Requirements:

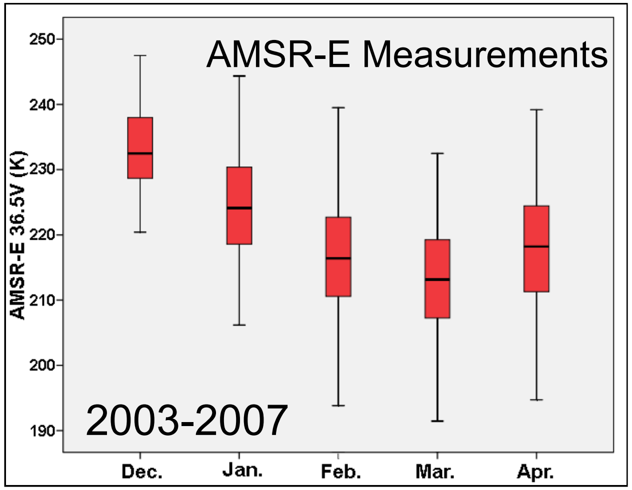
1. Insensitivity to lake fraction

Brightness temperature correlations with lake fraction evolve independently at each frequency due to differences in penetration depth.

2. Account for slope reversal in T_B versus SWE late in the season

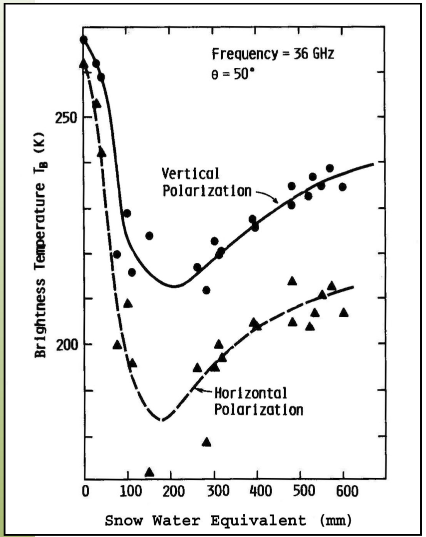
At a critical SWE threshold, snowpack evolves from a scattering to an emitting medium.





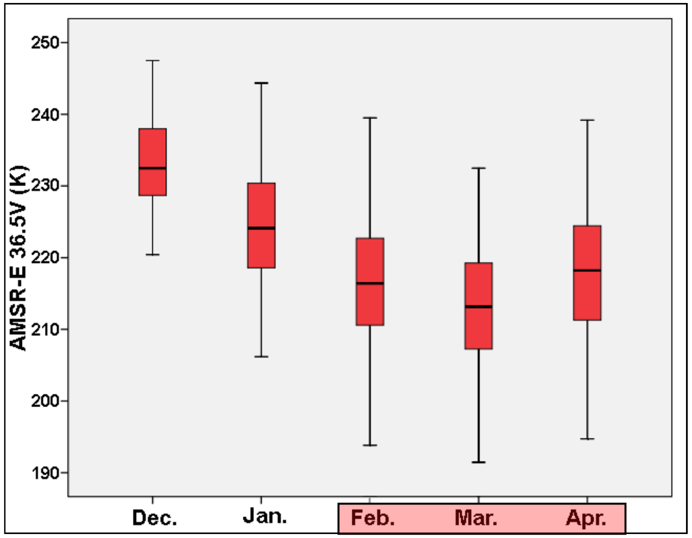
37V Tundra Algorithm Development

Theoretical



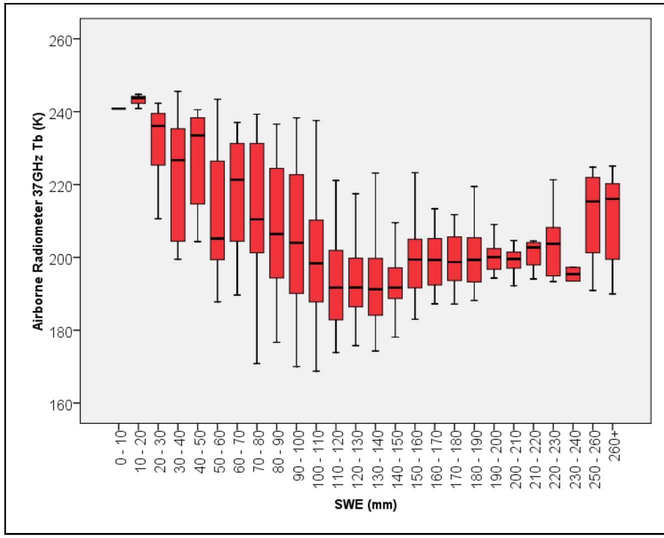
Adapted from Mätzler et al., (1982)

Satellite



2002-2007
434 AMSR-E grid cells

Airborne



1190 T_B's matched with 12,575 in situ SWE's

- Similar brightness temperature behaviour at 37 GHz captured from satellite and high resolution airborne measurements - confirm change in tundra snowpack behaviour from a scattering to an emitting medium at approximately 120 mm.
- Absolute cumulative change algorithm – convert to linear relationship

37V Tundra Algorithm Development

Next step in development is validation:

To observe evolution of brightness temperatures over the course of an entire winter season with very high resolution surface based radiometers, matched with coincident snow survey information.

Algorithm Validation Opportunity:

Canadian Phase-A Field Activities
The Canadian CoReH2O Snow and Ice Experiment 2009-2010

CoReH20 Mission Overview

The Cold Regions Hydrology High-resolution Observatory

CoReH20 is a proposed satellite mission which is aiming to be launched in 2016.

The European Space Agency (ESA) is currently in the competitive process of selecting a new satellite missions. One of three remaining candidates for this mission is the COld REgions Hydrology High-resolution Observatory (CoReH2O)

Churchill will be a focal point for field measurements during the 2009/10 winter season.

CoReH20 Mission Overview

The Cold Regions Hydrology High-resolution Observatory

Primary Objective:

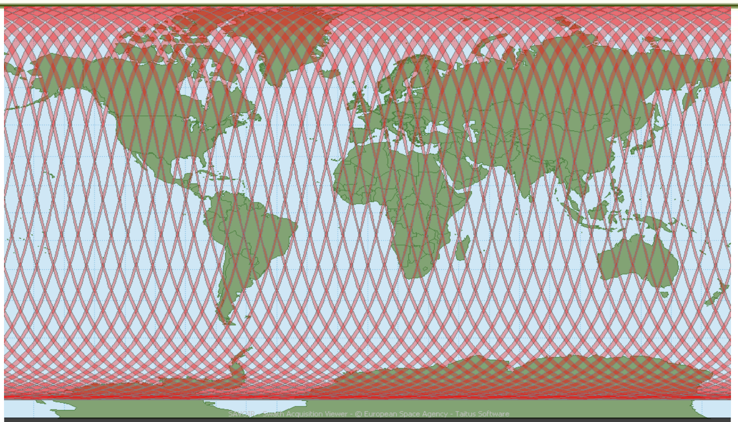
Quantify amount and variability of freshwater stored in seasonal snow packs, and snow accumulation on glaciers

Technical Concept:

Instrument:	SAR at Ku-(17.2 GHz) and X-Band (9.6 GHz), co- and cross-pol
Repeat Time:	3 and 15 days / Dawn/Dusk orbits
Spatial Res.:	50 x 50 m (5 looks), ScanSAR (Swath >100 km);

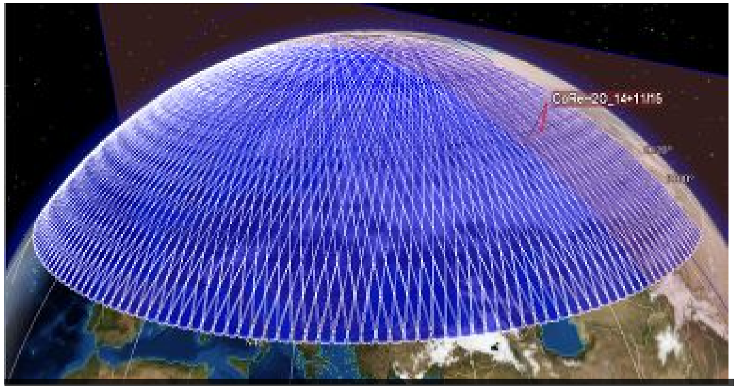
Science Objectives of Phase A Field Activities:

- Perform dedicated field measurements under different wet and multi-layered snow conditions in order to demonstrate robustness of the CoReH20 SWE retrieval algorithm.
- Explore potential synergy with passive microwave remote sensing and propose an approach to bridge the scale gap between active and passive observations of SWE.



Phase 1 cycle

3 days revisit, 666 km altitude, 100 km swath



Phase 2 cycle

15 days revisit, 645 km altitude, 100 km swath

Canadian Phase-A Field Activities:
The Canadian CoReH2O Snow and Ice Experiment 2009-2010

Experiment duration:
November 2009 – April 2010

Experiment location
Churchill, Manitoba

Remote sensing equipment deployment
- X- and Ku-band scatterometers (University of Waterloo): near continuous measurements during intensive and extensive observing periods;
- Passive microwave radiometers (EC): discrete samples during intensive observing periods

Field *in situ* snow measurements (UW, EC, CARTEL, NU)

Canadian Phase-A Field Activities:
The Canadian CoReH2O Snow and Ice Experiment 2009-2010

Calendar

November '09

Su	M	Tu	W	Th	F	Sa
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

December '09

Su	M	Tu	W	Th	F	Sa
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

January '10

Su	M	Tu	W	Th	F	Sa
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

February '10

Su	M	Tu	W	Th	F	Sa
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28						

March '10

Su	M	Tu	W	Th	F	Sa
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

April '10

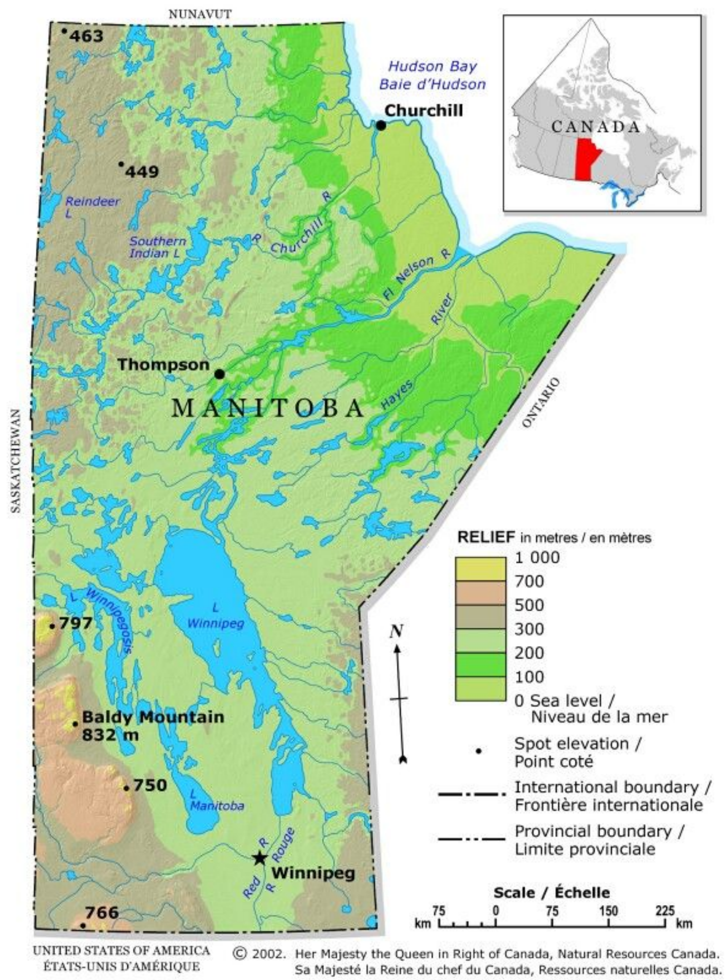
Su	M	Tu	W	Th	F	Sa
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	

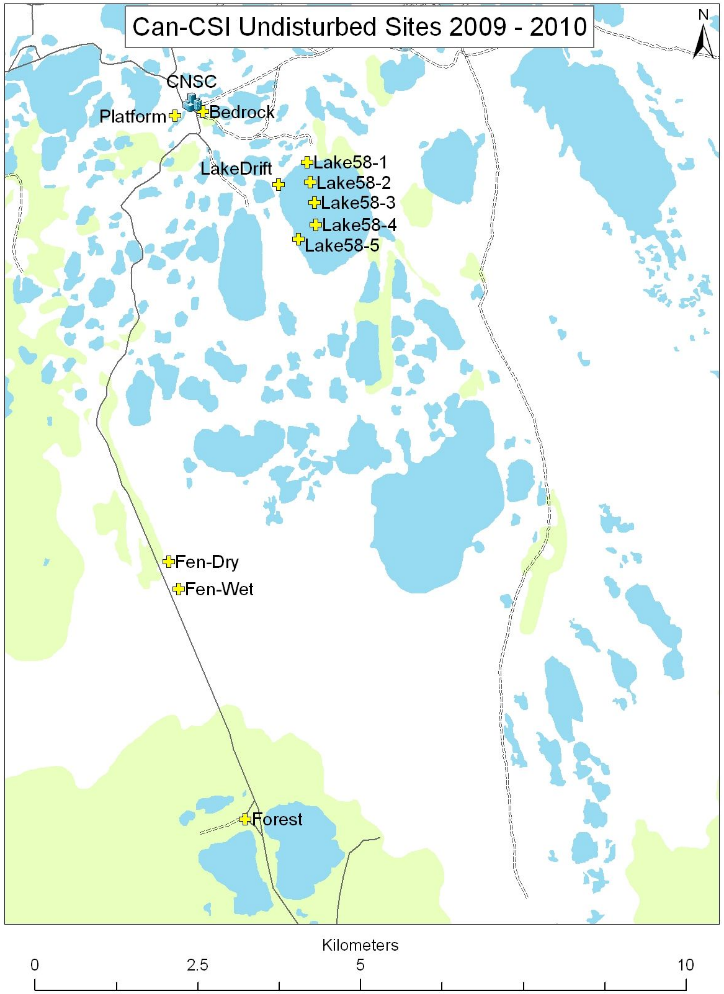
Yellow – Intensive Observation Periods (IOPs)
- detailed snow measurements coupled with sled-based radiometer.

Green - Extended Observation Periods (EPs)
- represents period of regular snow measurements (no radiometer).

Canadian Phase-A Field Activities:
The Canadian CoReH2O Snow and Ice Experiment 2009-2010

Study Area





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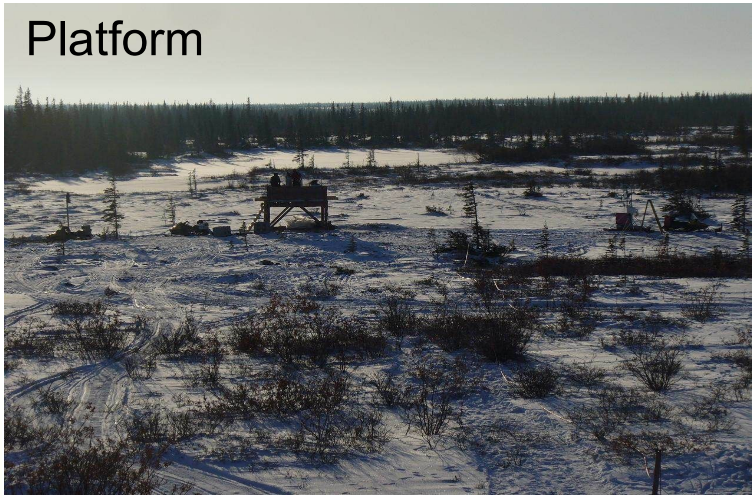
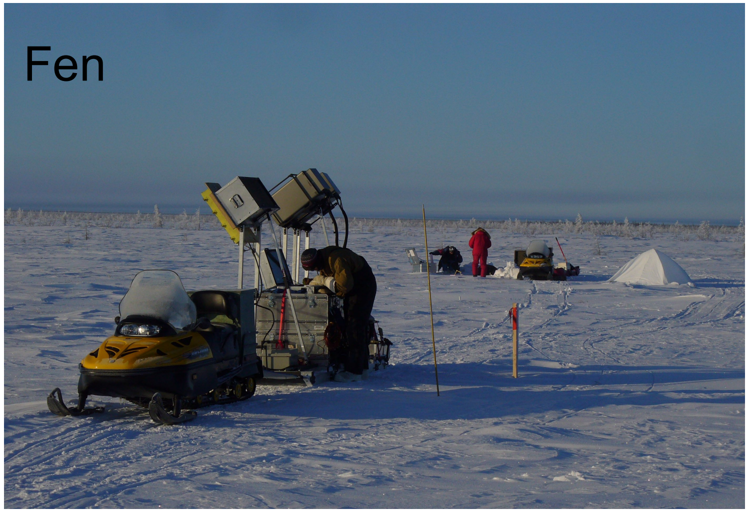
Canadian Phase-A Field Activities:
The Canadian CoReH2O Snow and Ice Experiment 2009-2010

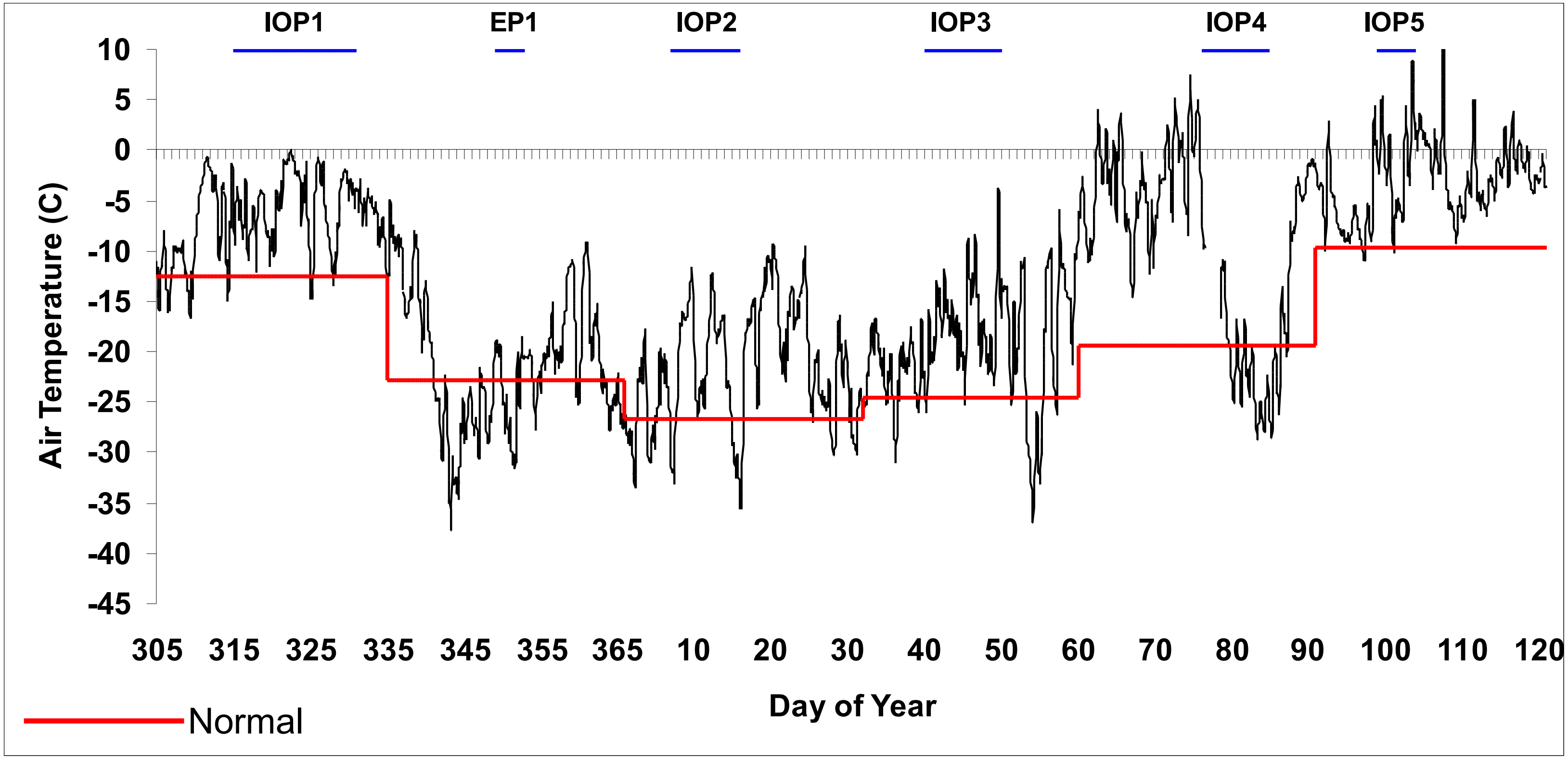
Main Study Sites





Canadian Phase-A Field Activities:
The Canadian CoReH2O Snow and Ice Experiment 2009-2010

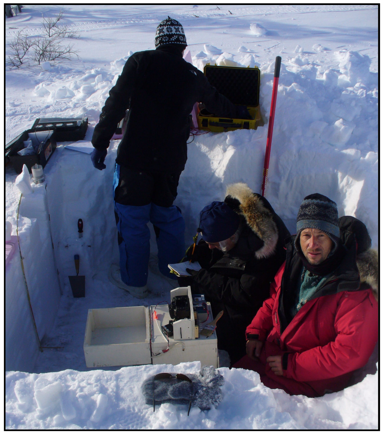
Study Area Air Temperatures

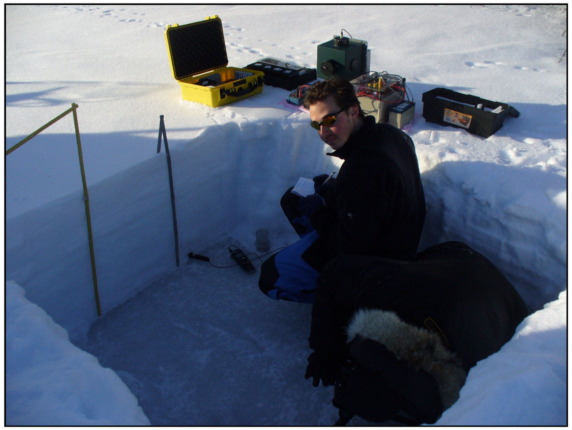


Canadian Phase-A Field Activities:
The Canadian CoReH2O Snow and Ice Experiment 2009-2010

In Situ Snow Measurements Overview

Landscape Scale Snow Survey - conducted on a weekly basis	
100m Snow Survey Transect	200 snow depths, 10 ESC-30 SWE cores, 5 ice thickness
Snow Pit	snow depth, snow stratigraphy, vertical profile of snow density, grain size, temperature and dialectrics
Micro-Scale Snow Survey - conducted at each disturbed/excavated/active-passive radiometer site	
Snow Pits	snow depth, snow stratigraphy, vertical profile of snow density, grain size, temperature and dialectrics, near-infrared photography (SSA), laser integrating sphere (SSA), macro-photography of snow grains





Canadian Phase-A Field Activities:
The Canadian CoReH2O Snow and Ice Experiment 2009-2010

Snow Accumulation / Ice Growth

November:

single layer snowpack

December:

majority of accumulation

January:

accumulation + metamorphosis

February:

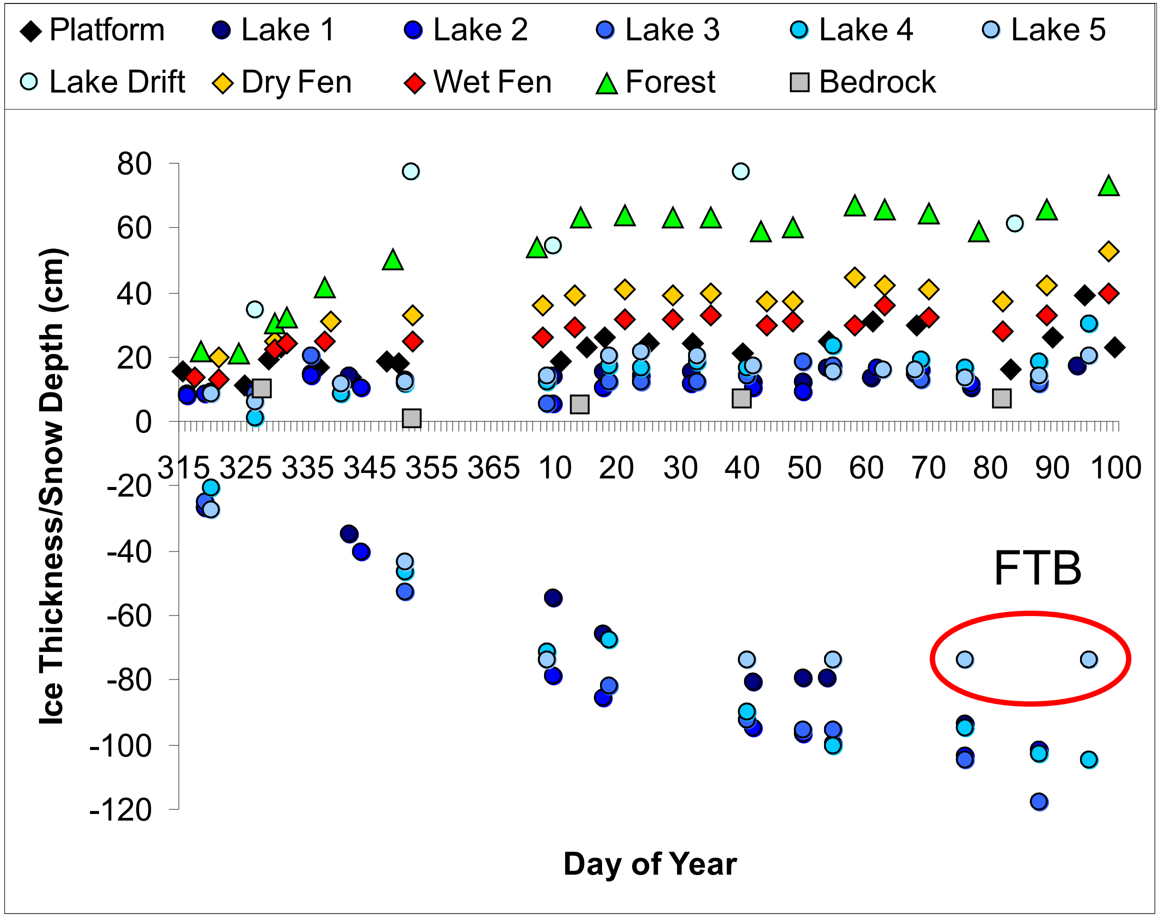
metamorphosis

March:

multiple crusts and lenses

April:

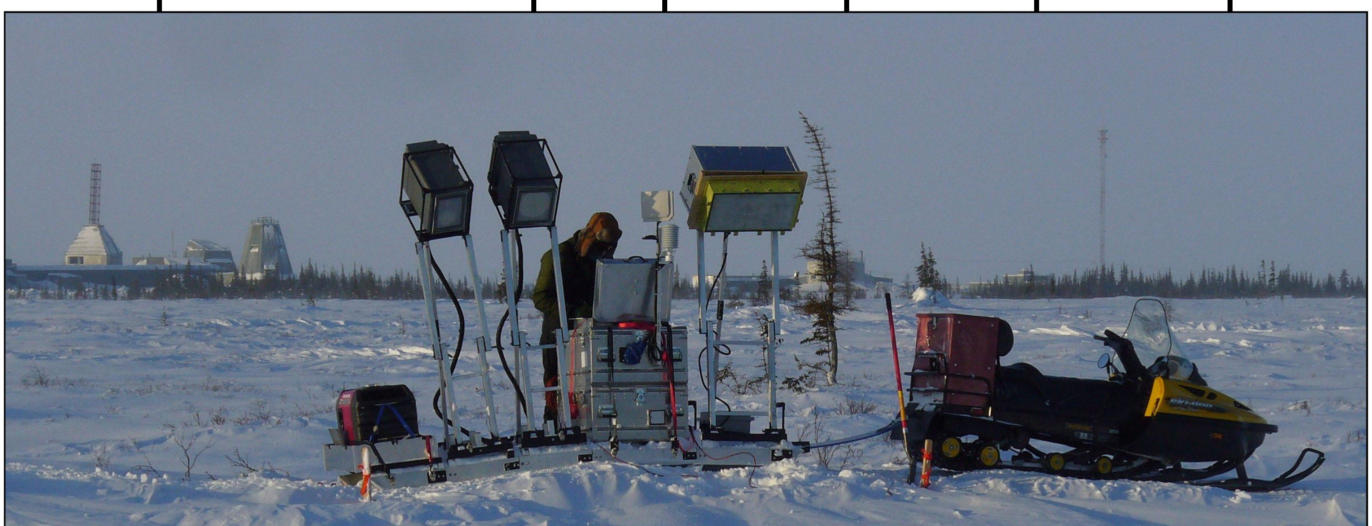
full melt onset



Canadian Phase-A Field Activities:
The Canadian CoReH2O Snow and Ice Experiment 2009-2010

Radiometer Overview

Frequency (GHz)	**6.9**	**19.0**	**37.0**	**89.0**
Bandwidth [MHz]	500	1000	2000	4000
Sensitivity [K]	0.2	0.04	0.03	0.08
Accuracy [K]	<2	<2	<1	<1K
❑$_{3dB}$ [°]	9	6	6	6
♋$_{i}$ [°]	53	53	53	53
Spatial Footprint (m)	1 x 1	0.6 x 0.6	0.6 x 0.6	0.6 x 0.6



Canadian Phase-A Field Activities:
The Canadian CoReH2O Snow and Ice Experiment 2009-2010

Summary of Radiometer Measurements

	Platform	Lake	Fen-Wet	Fen-Dry	Forest	Drift	Bedrock	*Total*
Undisturbed	12	24	10	11	13	5	3	***78***
Disturbed	10	28	16	7	14	11	0	***86***
Excavated	2	5	3	2	5	4	1	***22***
Active/Passive	1	3	10	1	2	2	0	***19***
Total	***25***	***60***	***39***	***21***	***34***	***22***	***4***	***205***

205 sets of radiometer measurements acquired at 139 unique locations:

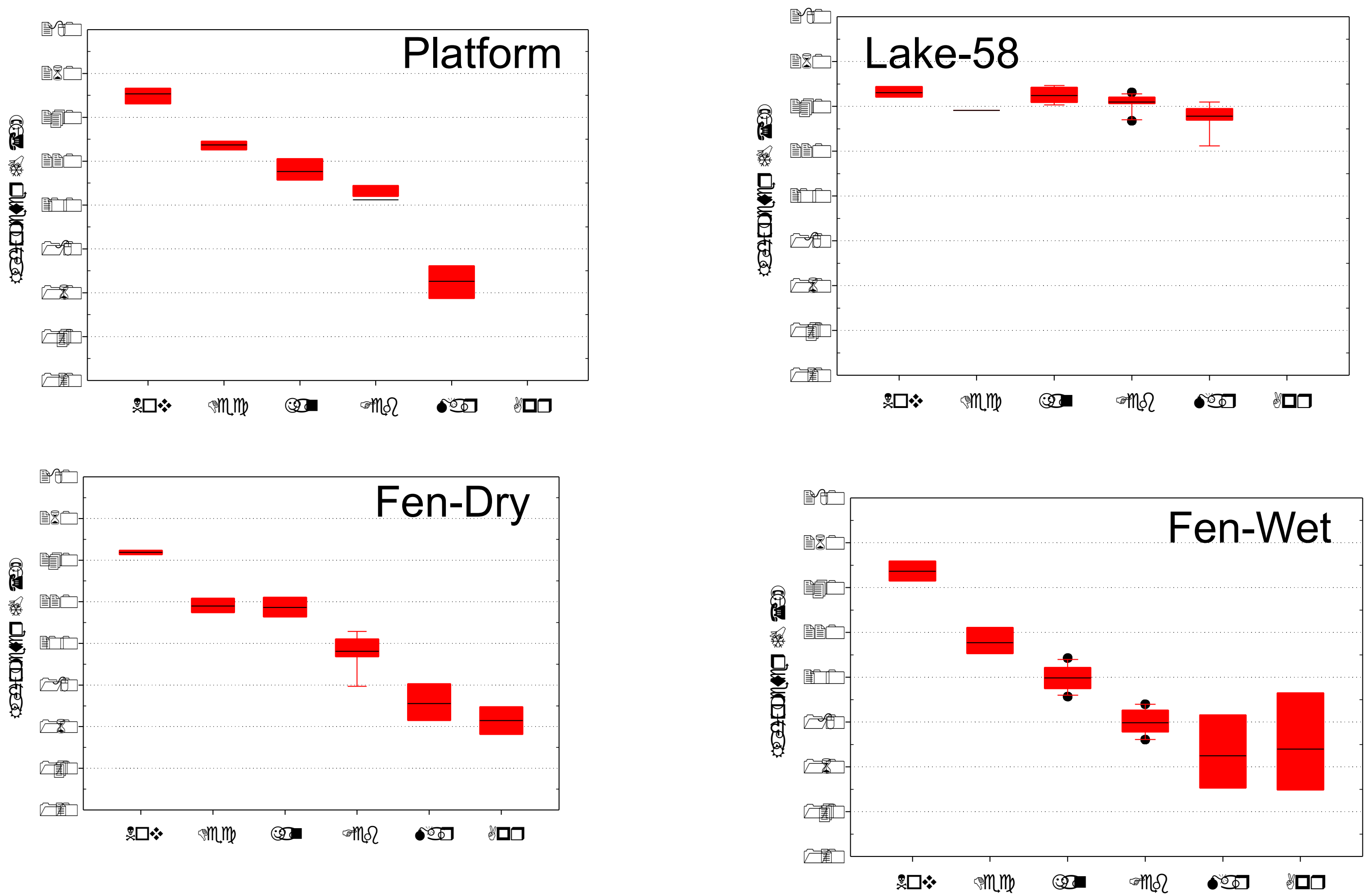
- 11 undisturbed locations (snowpit/ice core at end of season)
- 128 disturbed locations (excavated immediately after measurement)

Canadian Phase-A Field Activities:
The Canadian CoReH2O Snow and Ice Experiment 2009-2010

Undisturbed and Disturbed

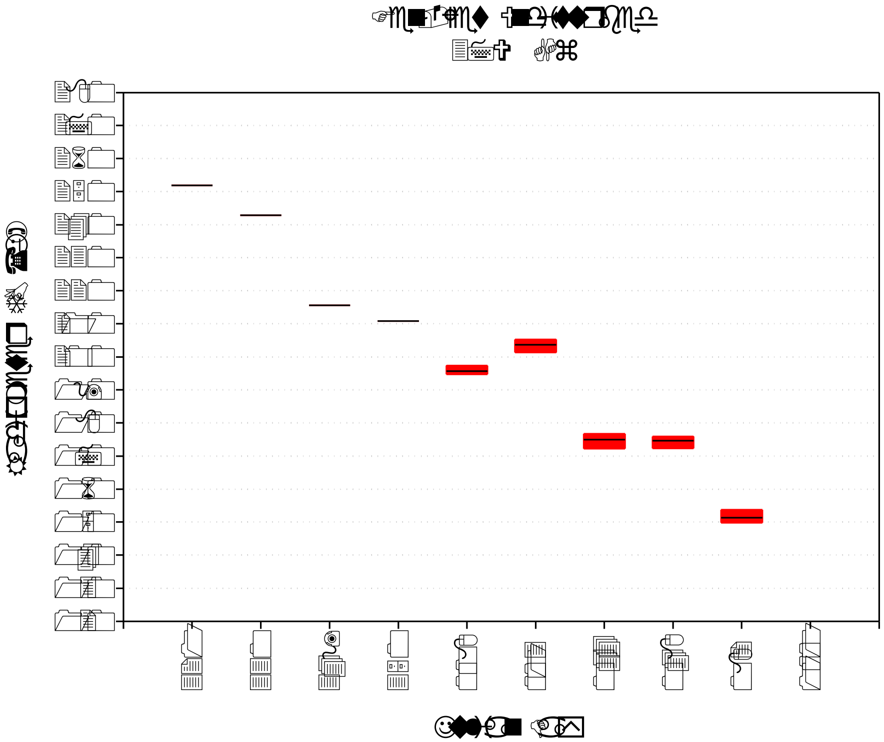
Preliminary Analysis:
37V SWE Algorithm Validation

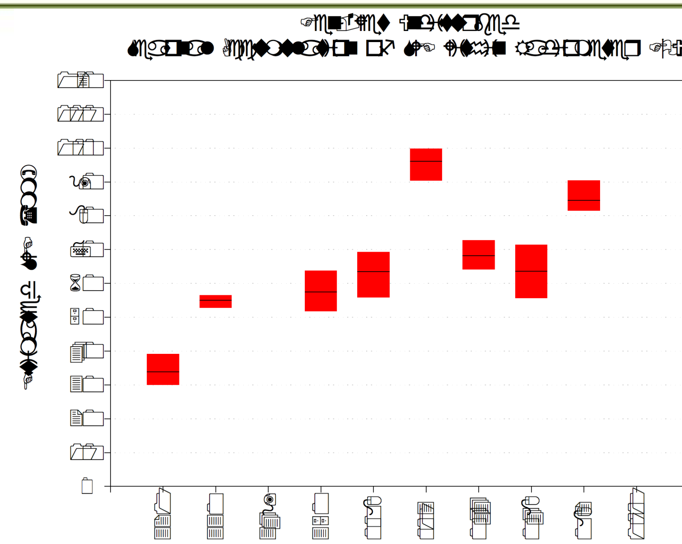
Seasonal Evolution of 37V GHz T_Bs

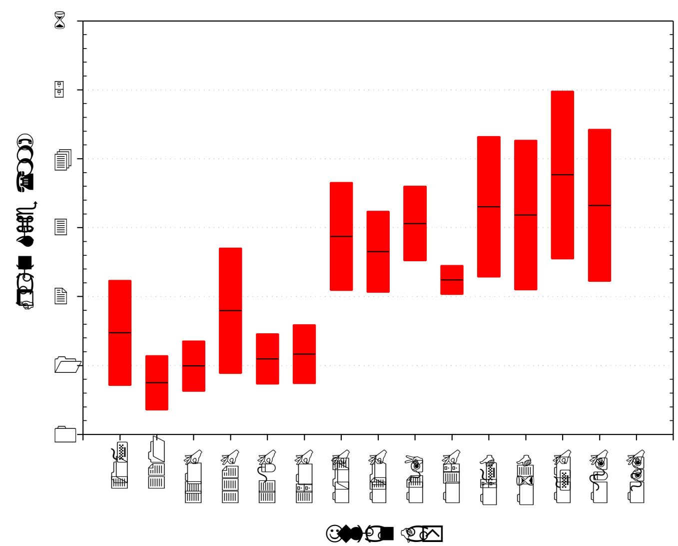


Preliminary Analysis:
37V SWE Algorithm Validation

Undisturbed Fen-Wet







Preliminary Analysis: 37V SWE Algorithm Validation

Discussion

Did not see the U-shaped curve in 37V GHz T_Bs over the course of the winter season.

Reasons:

1. Low snow year – Snowpack did not transition from scattering medium to emitting medium because SWE did not exceed 90mm. Majority of accumulation occurred pre-January. Previous studies showed 37V GHz inflection point to occur when SWE exceeds 120mm.

2. Snow grain metamorphism lead to continued depth hoar grain growth and increased scattering of 37V GHz emission.

3. Melt/Refreeze events in March and April lead to formation of ice lenses and melt crusts which further contributed to increased scattering of 37V GHz emission.

Preliminary Analysis: 37V SWE Algorithm Validation

Discussion

Absolute cumulative change 37V GHz tundra specific algorithm over estimated SWE compared to in situ measurements (~170mm vs. 85mm)

Reasons:

1. Issue of scale – satellite sensors do not have the same dynamic range of T_B's as high resolution airborne or surface based radiometers because they integrate varying snow cover properties over ten's of kilometres, including significant amounts of lake-cover which typically has lower SWE and smaller grains.

2. 37V GHz tundra algorithm was tuned to satellite TBs and the Baker Lake snow survey station – Single snow survey station might not be entirely representative of regional snow conditions.

Conclusions:
37V SWE Algorithm Validation

Absolute cumulative change 37V GHz algorithm may not perform well during low snow years when the snowpack remains a scattering medium.

Possible Solutions:

1. Need to adjust algorithm to indicate when the snowpack switches from a scattering to an emitting medium – take into account negative/positive change of T_B's. Possibly use different algorithms during each phase.

2. Use horizontal polarization as an indicator to identify if negative change due to scattering is more likely due to depth grain growth, melt/refreeze crusts or an increase in SWE – horizontal channel shows greater sensitivity to grain growth and ice crusts than to increase SWE.

Questions?