Snow accumulation mapping in the Yukon Territory, Canada, using combined MODIS, AMSR-E and *in situ* measurements

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Outline

- Motivation: study domain and IPY
  - What do we know (models and climatology)
  - Passive microwave: moderate SWE, but what is the variability / sensitivity?
- Data sets
  - *In situ* (CMC model) (0.25°)
  - MODIS (500m)
  - AMSR-E (native resolution)
- AMSR-E variability / sensitivity: (how) can we use AMSR-E data?
- Combined approach

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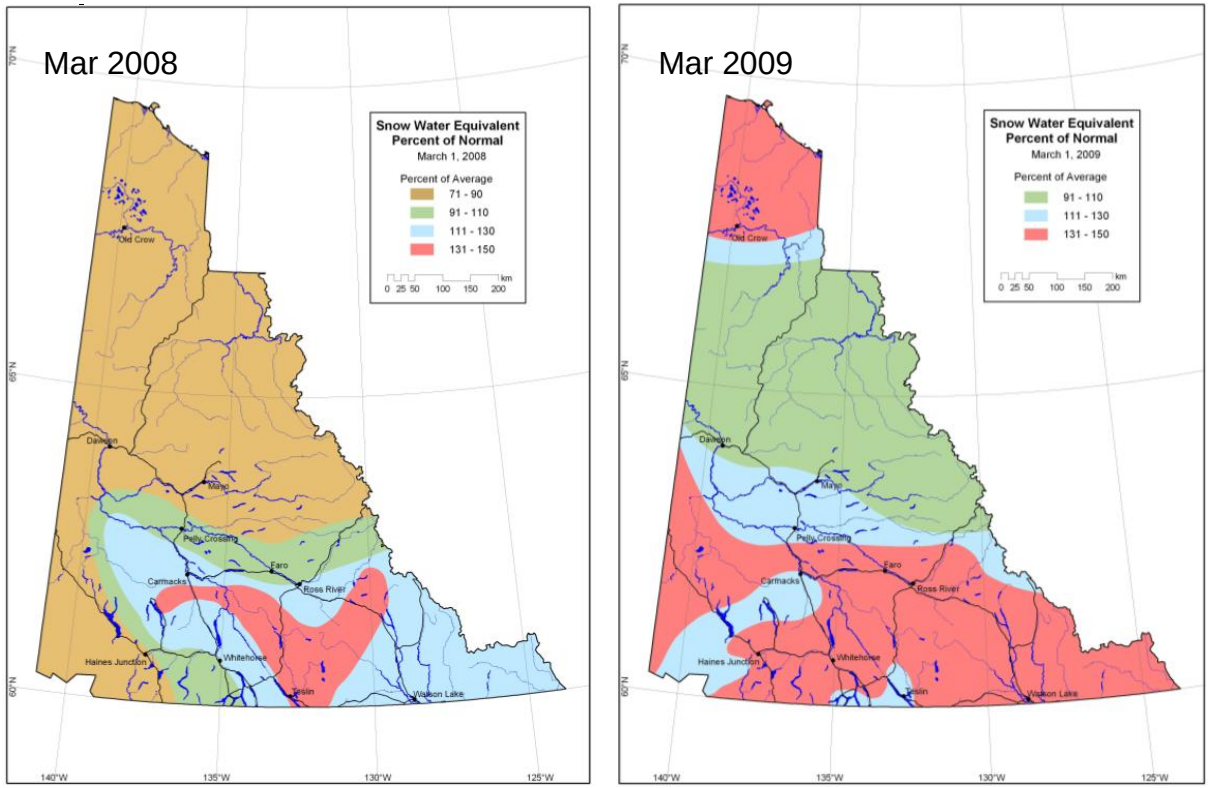
Motivation: *what do we know?*

(i) Traditional approaches – Yukon Snow Survey clim



Environment Yukon Snow Surveys (http://environmentyukon.gov.yk.ca) undertaken on 1 Mar., 1 Apr, 1 May each year. Shown is percent normal SWE on 1 March 2008 &1 March 2009

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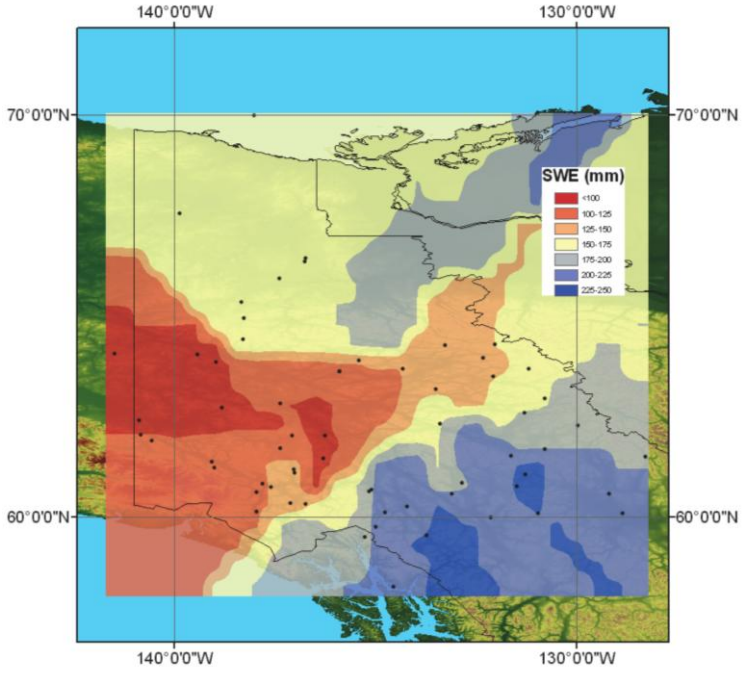
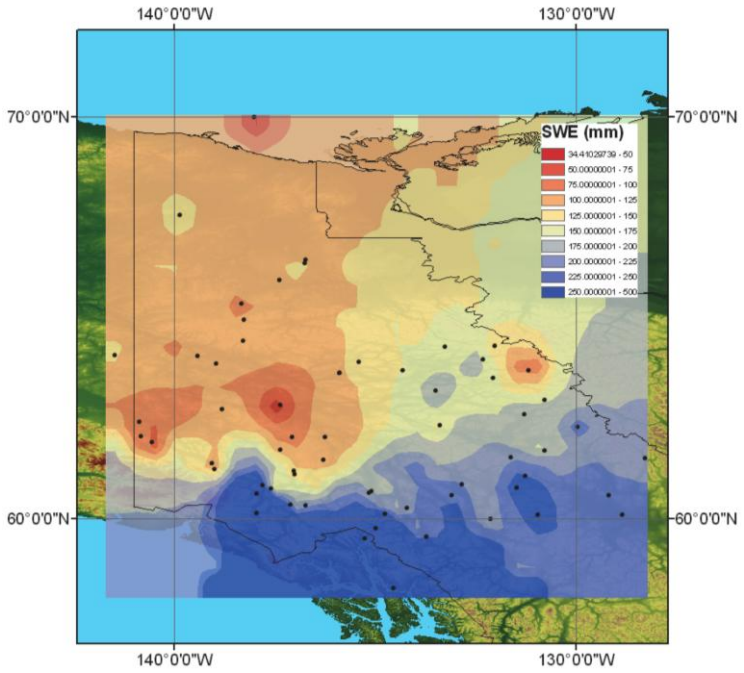
Motivation: *what do we know?*

(i) Traditional approaches – Yukon Snow Survey annual data

April 2008



Mar 2009



Krig-interpolated maps from snow course depth
Represents the data used by analysis models

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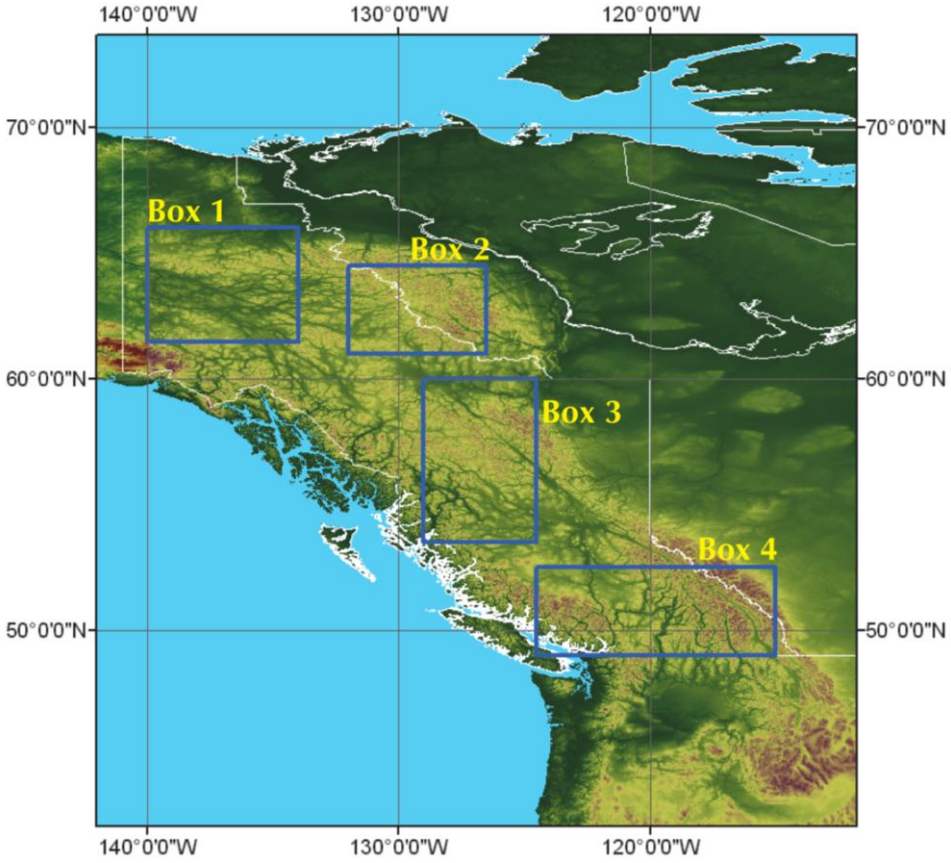
Motivation: *what do we know?*

(ii) Climate models



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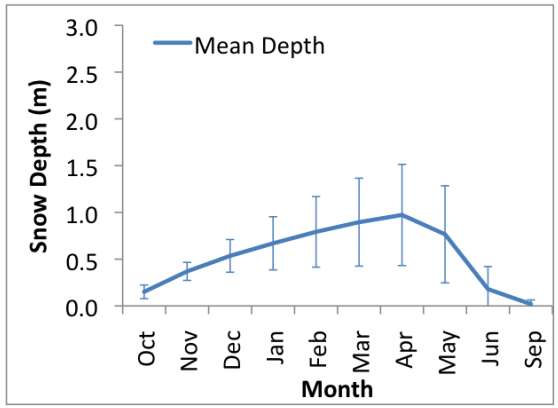
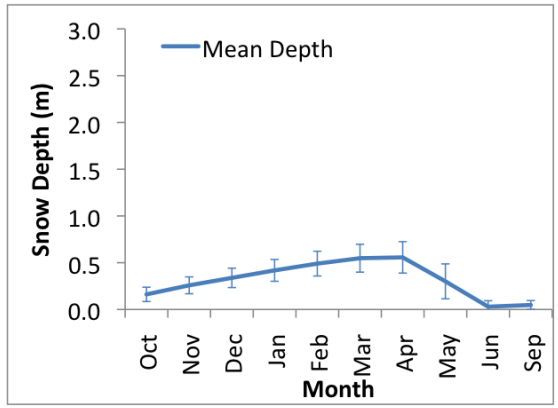
Motivation: *what do we know?*

(ii) Traditional approaches – climate models + SSM/I

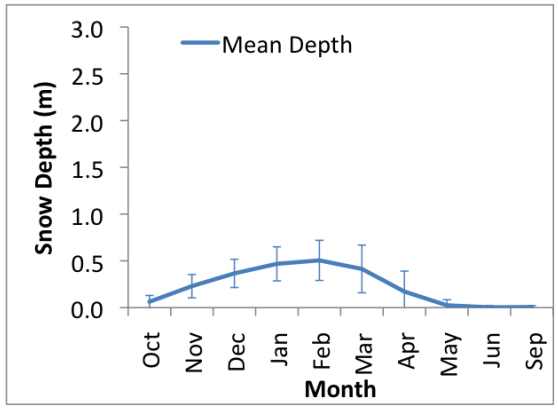
1979-2007 NARR Snow Depth



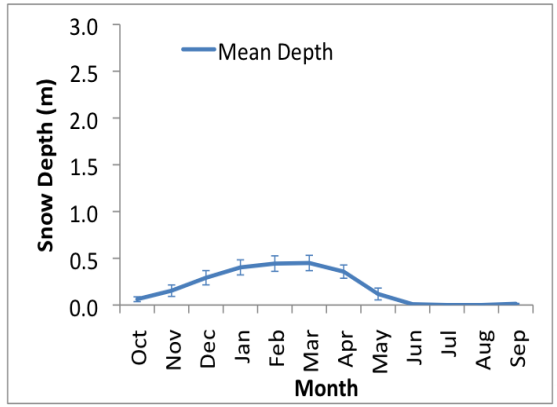
1979-2007 CGCM Snow Depth



1979-2000 CRCM Snow Depth



1979-2007 SSMI/SMMR Snow Depth



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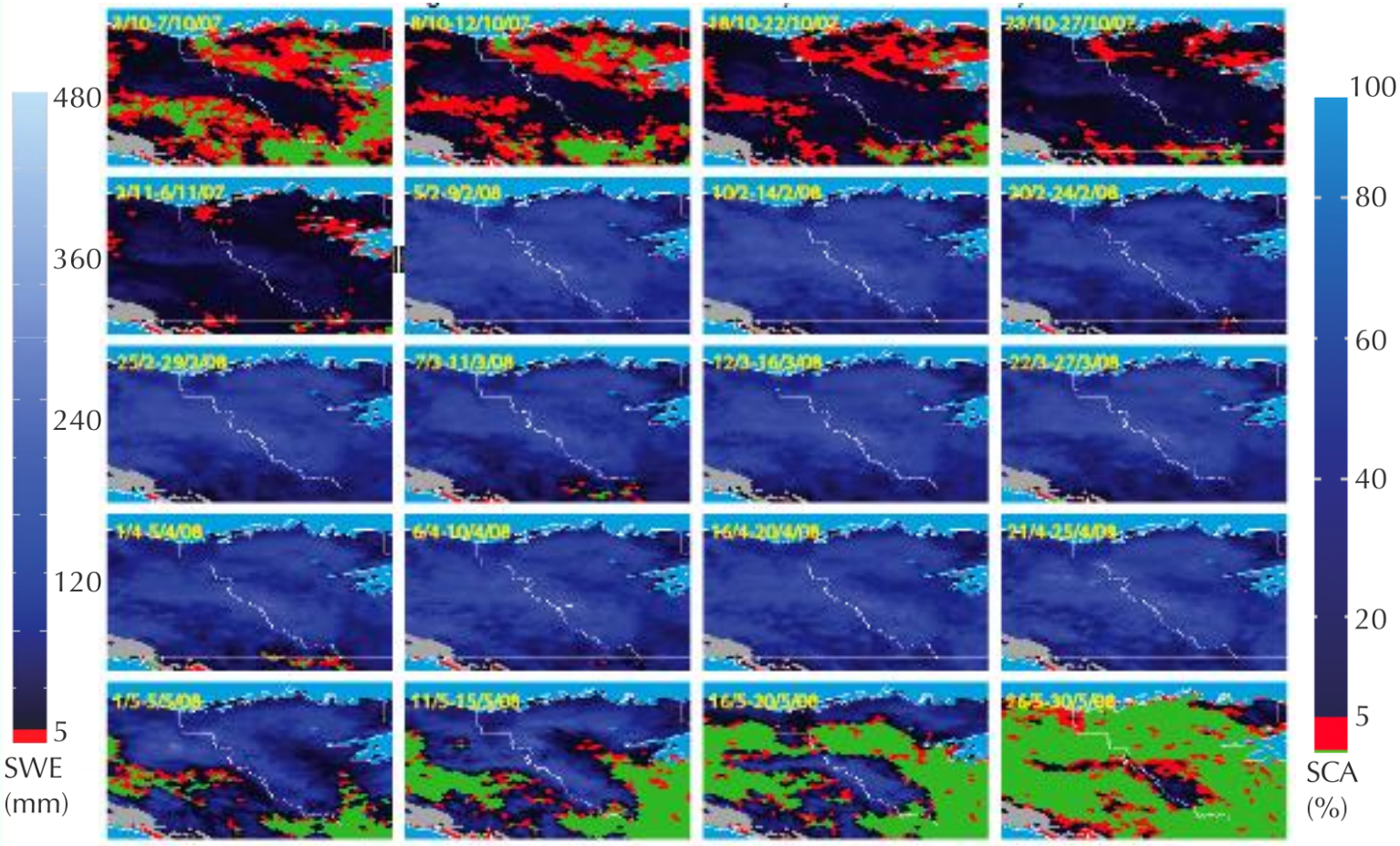
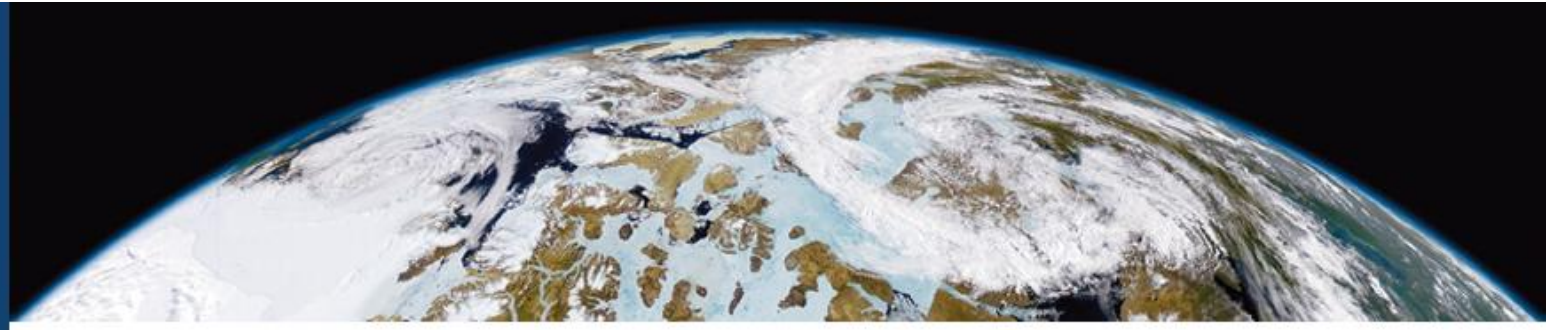
Motivation: *what do we know?*

(iii) Remote sensing – MODIS cf. AMSR-E SCA





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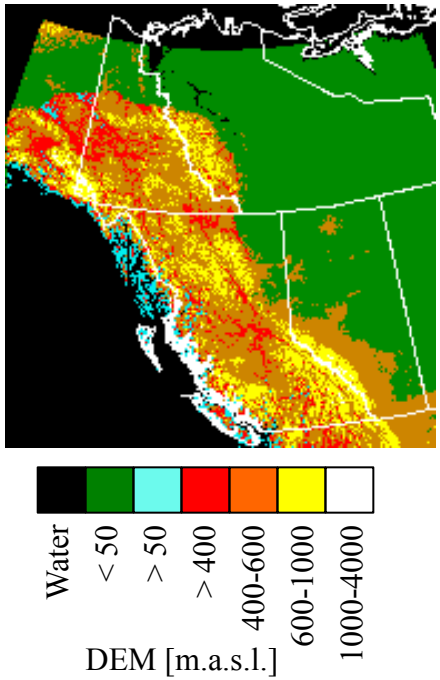
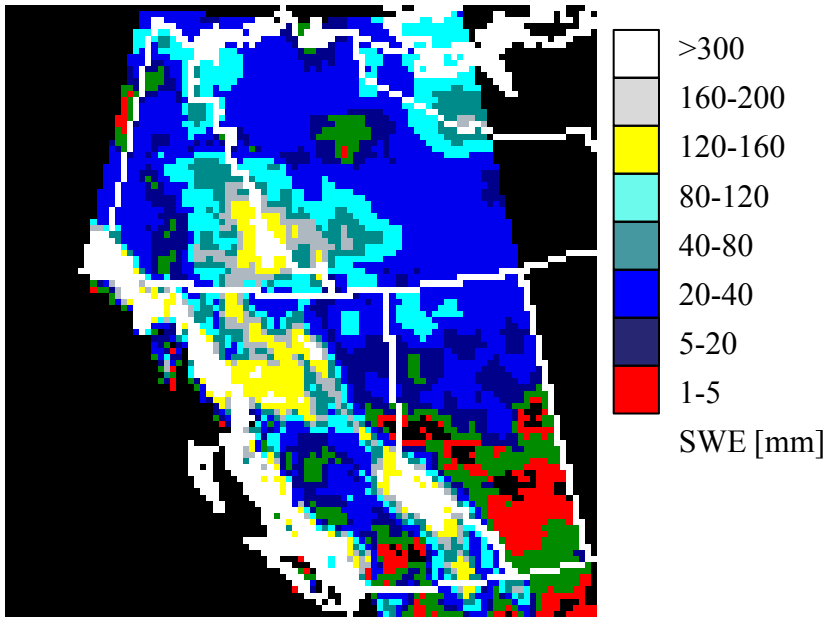
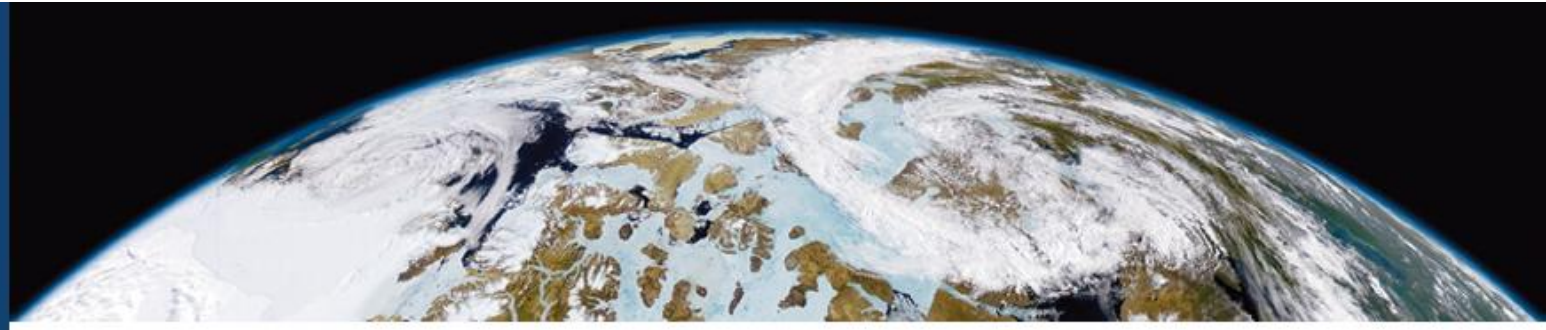
Data sets: *MODIS, CMC*

- MODIS SCA is considered a fairly mature product
- Canadian Meteorological Centre's (CMC) snow depth and SWE analysis product models snow depth & SWE daily at the 1/3° grid cell resolution.
- Simple density field converts to SWE (climatology is also used)
- Low accumulation bias and, therefore, early melt out bias





CMC SWE :: 1 April, 2008



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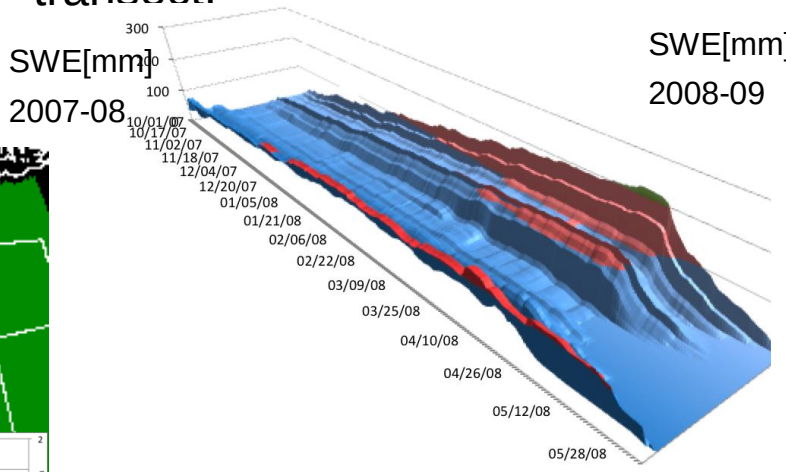
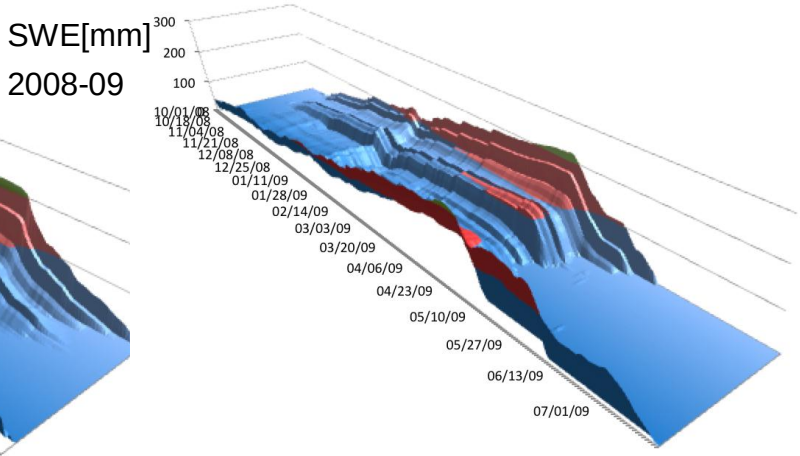
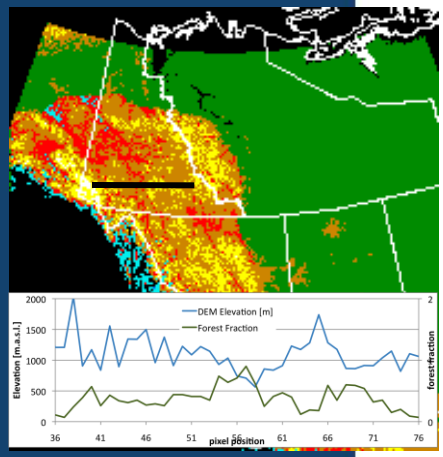
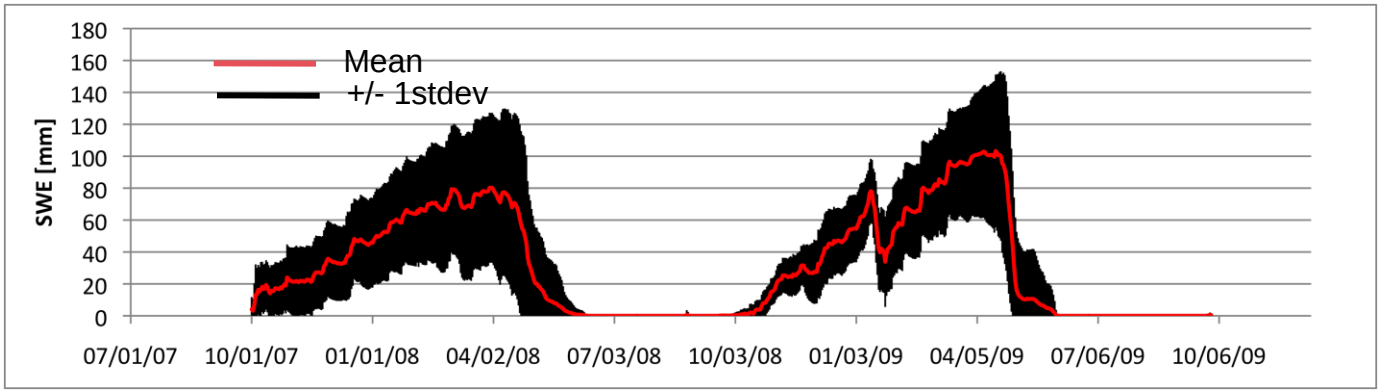
Data sets: *CMC variability*

•Time series of SWE for 2007-2008 & 2008-2009 across a transect.









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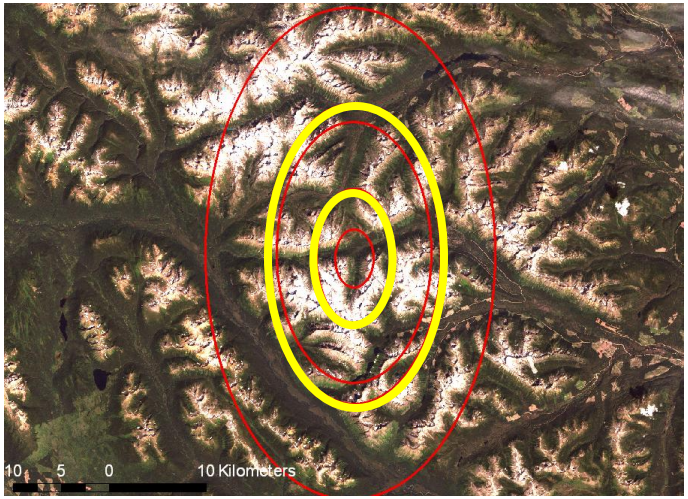
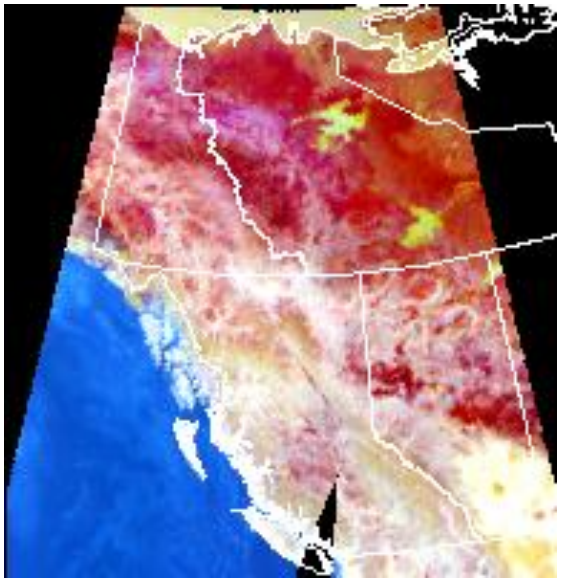
Data sets: *AMSR-E*

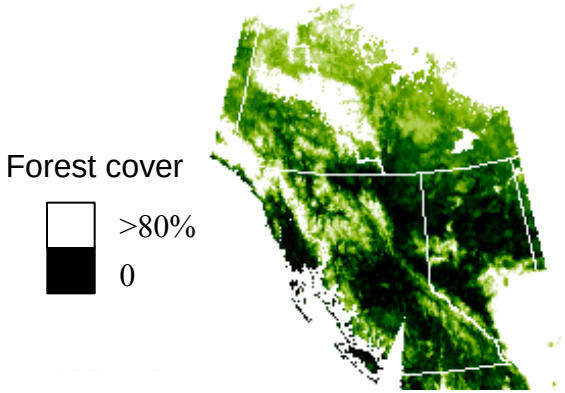
•12.5 km grid cell size

Center Freq. (GHz)	6.9	10.7	18.7	23.8	36.5	89.0
IFOV (km x km)	74 x 43	51 x 30	27 x 16	31 x 18	14 x 8	6 x 4



RGB Composite of 18V, 36V and 89V Tbs]





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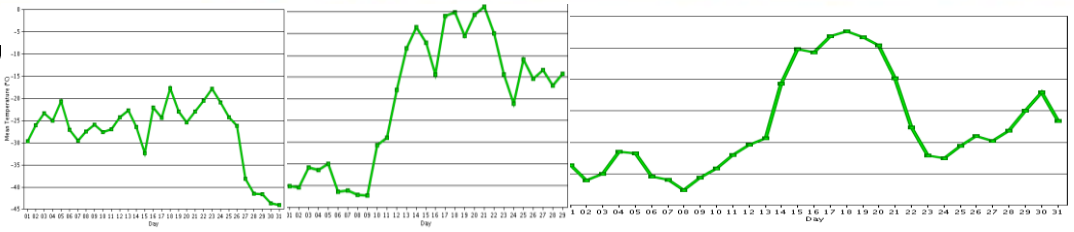
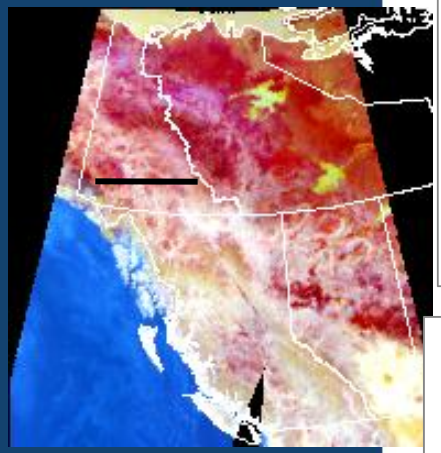
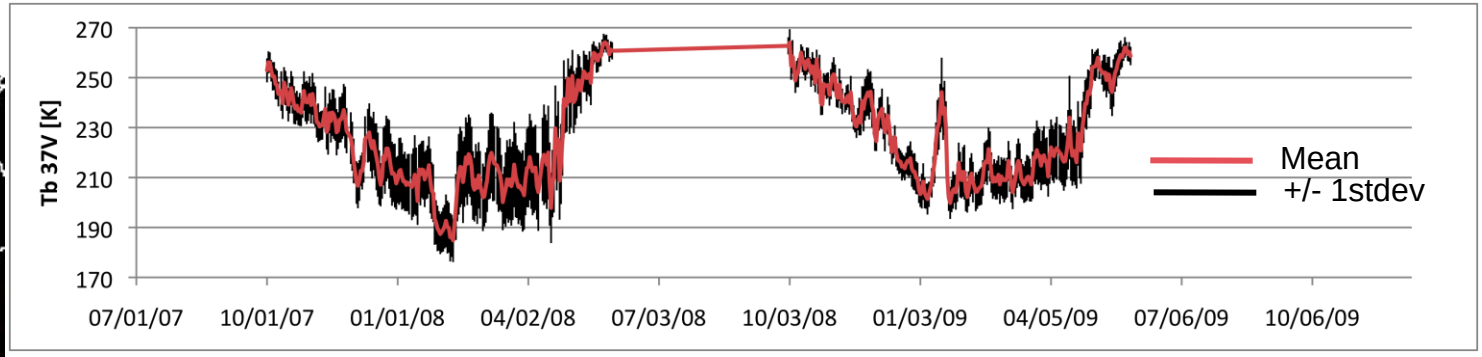
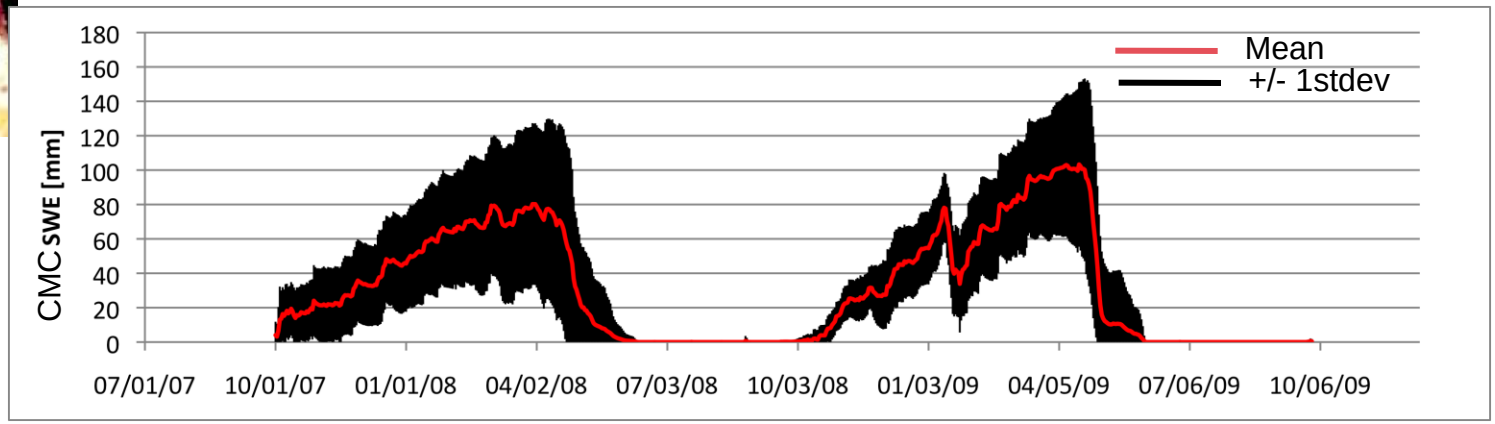
AM
•36









Motivation
Data sets
AMSR-E variability
Combined approach
Conclusions

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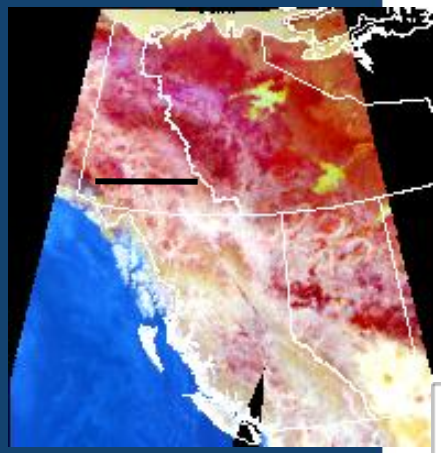
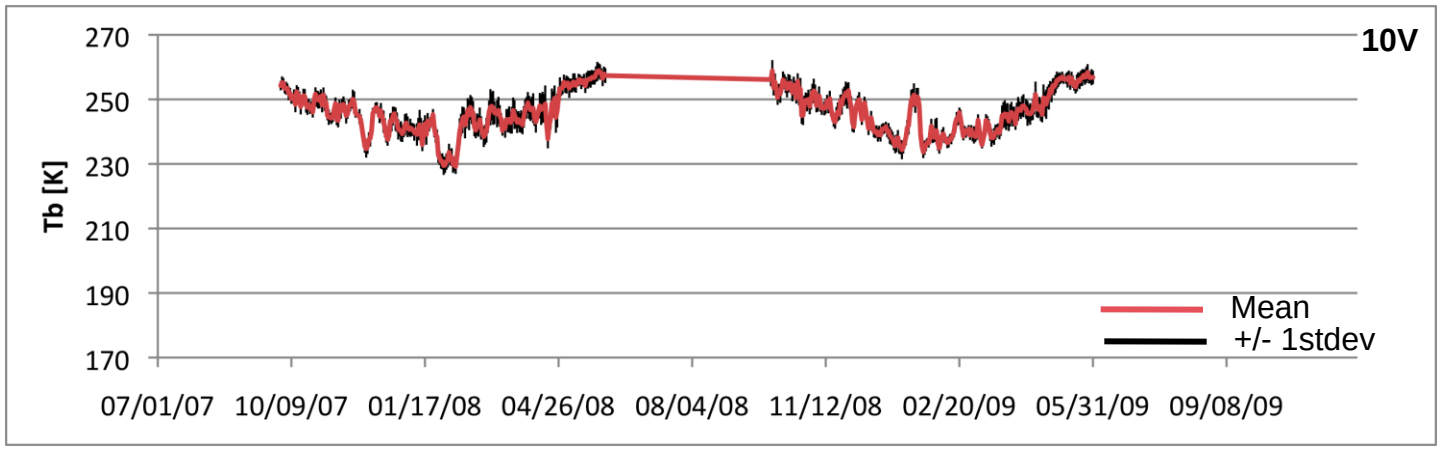
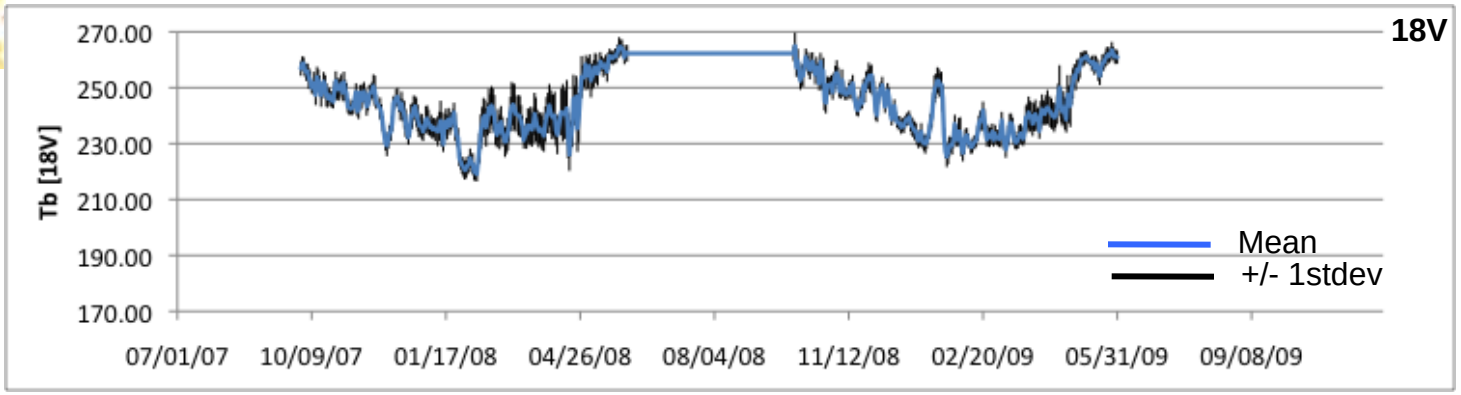
AMSR-E variability

•10V & 18V GHz transect time series







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AMSR-E variability

- AMSR-E variability behaves as expected in 'classical terms'
  - emissivity (ε) vs. T_{phys}
- We can make conjectures about the sequence of snowpack evolution in the 36 and 18 GHz time series.
- Typical non-inversion model approaches leverage:

$$Tb_V = \varepsilon T_{phys}$$

$$SWE = f(Tb_{V1} - Tb_{V2})$$

Assume that TbV36 saturates at ~100-150 mm SWE, Can we use volume scattering at 18 GHz?

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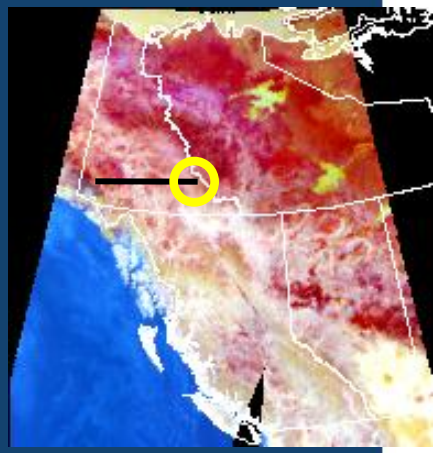
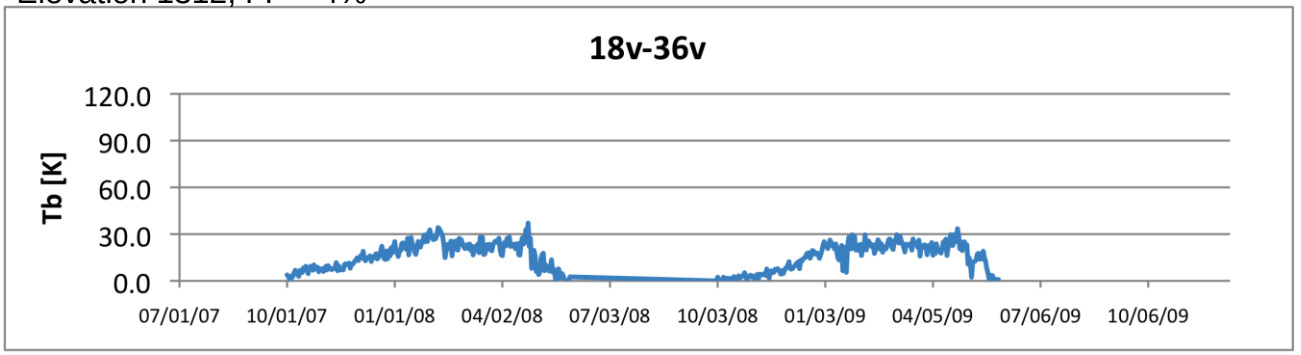
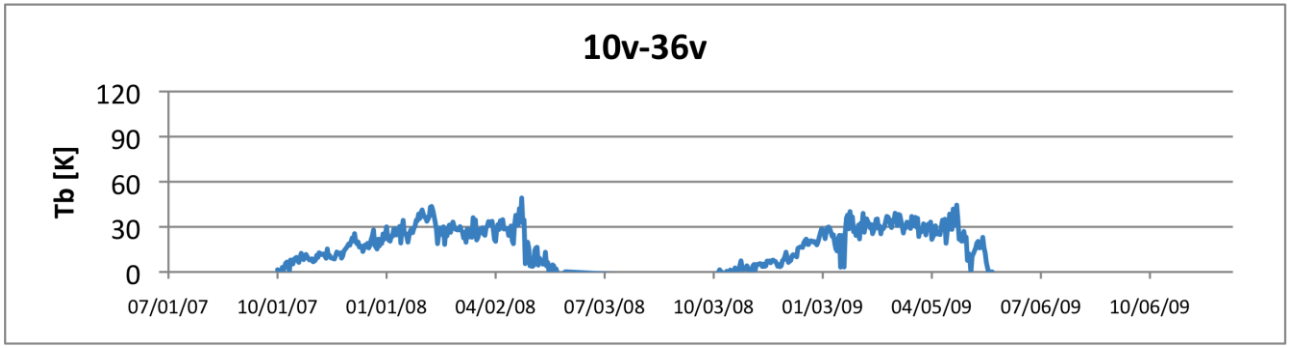
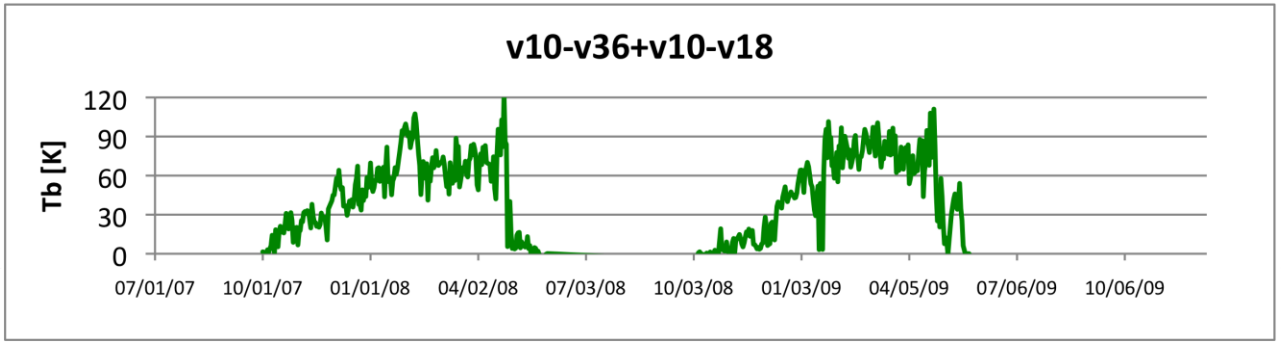


Elevation 1312, FF = 4%







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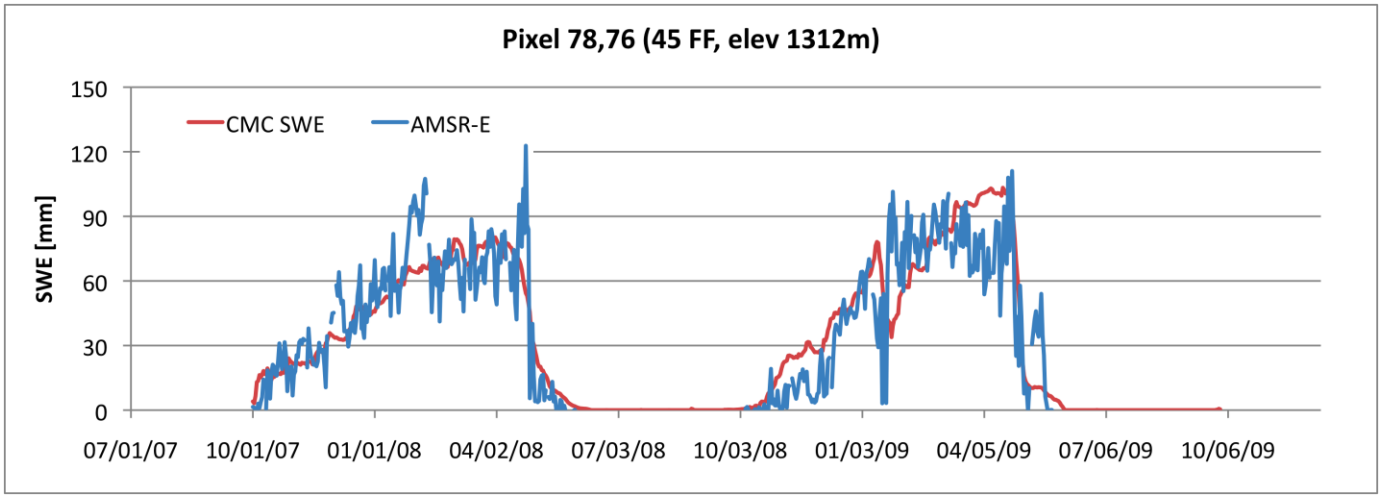
RMSE = 18.2 mm bias = -2.1 mm



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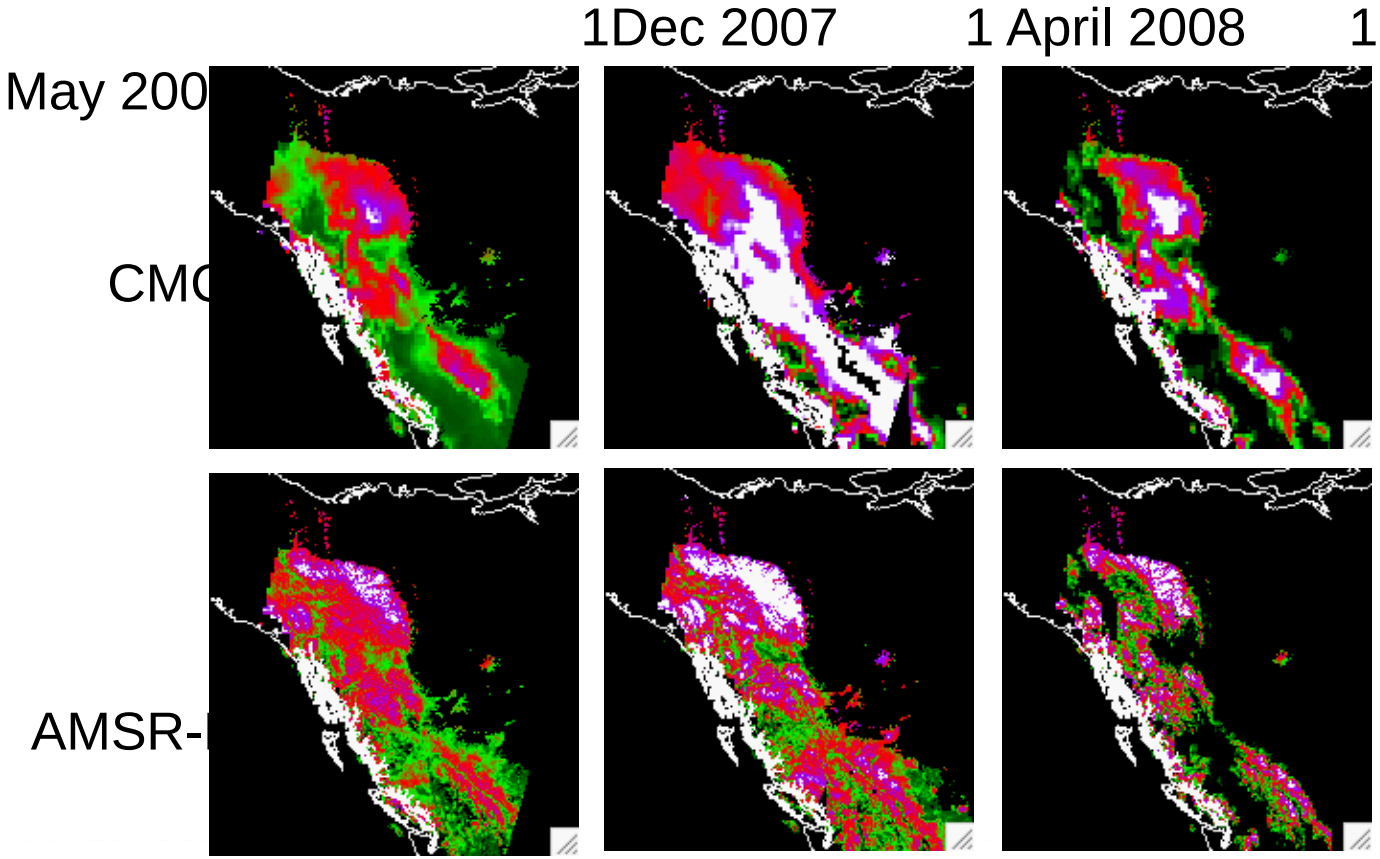
Developing a combined approach

•AMSR-E variability compared with CMC



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Comments

•MODIS snow cover products (not discussed) but are mature and are being used to develop SCE framework

•CMC is a great product to use, but…..

- It has known uncertainties at higher elevations (low elevation bias)
- It has uncertainties related to density conversion

•PM is being pushed to its limit…

- It is surprising that there is sensitivity in this region
- We are investigating how to leverage this sensitivity further, for example the spectral hysteresis effect at 18V and 36V

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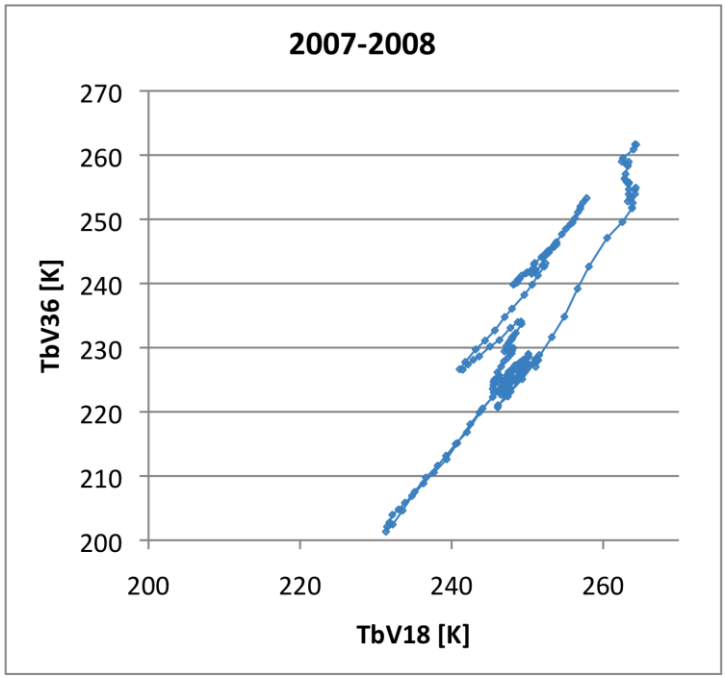
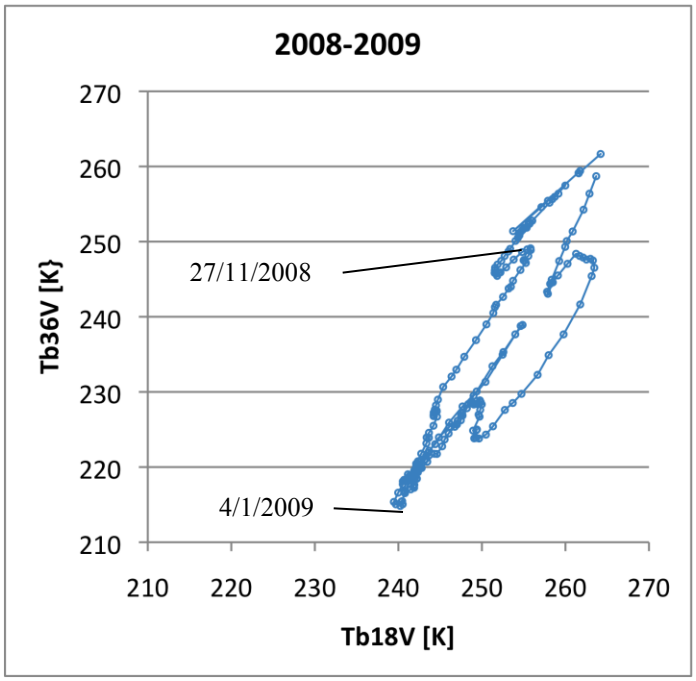
- The spectral hysteresis effect: 18V and 36V





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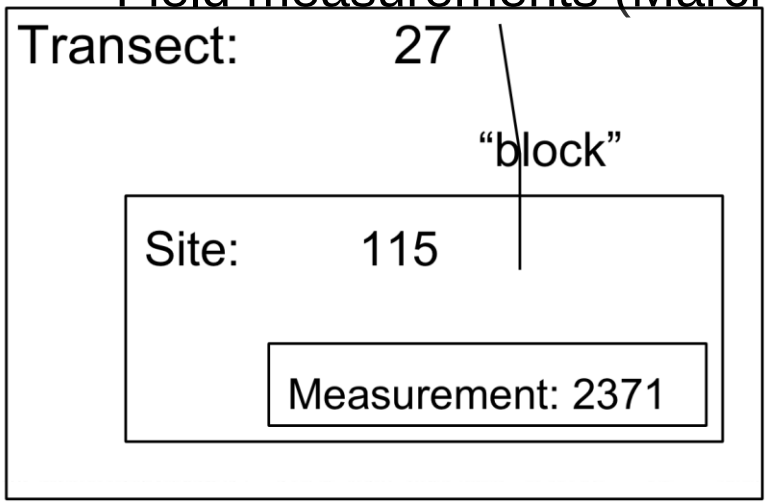
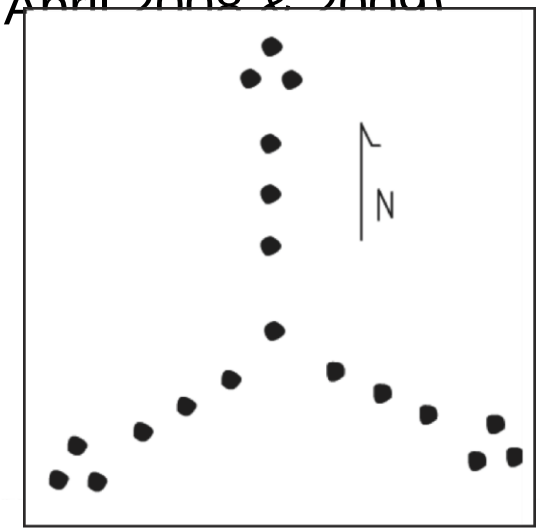
Validation/calibration

•We have also developed an *in situ* field data set using Linear Mixed Effects models (accounts for non-linearities in snow spatial distribution):

- DEM derivatives (slope, aspect, concavities, etc)
- Land cover characteristics from TM MLC & tasseled cap
- Field measurements (March/April 2008 & 2009)





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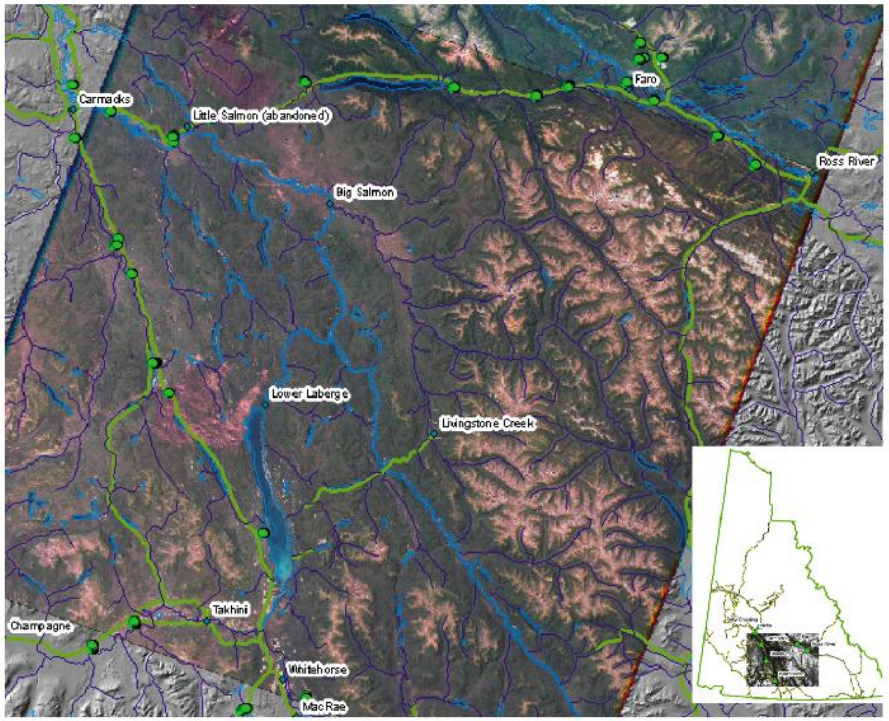
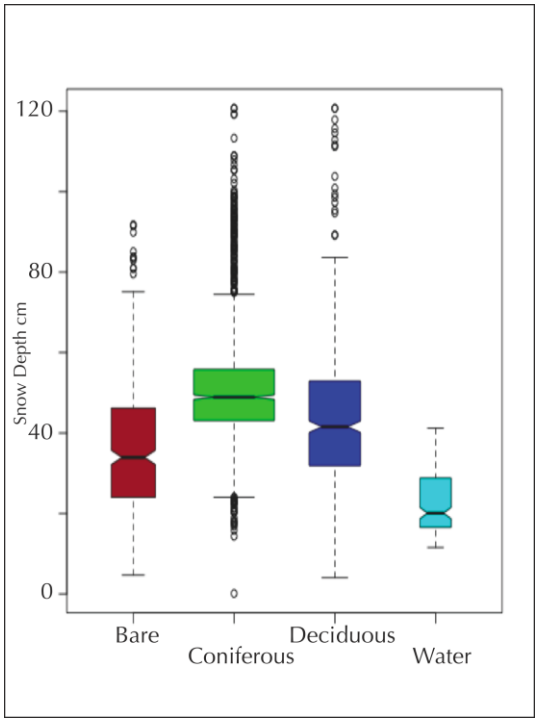
Validation/calibration (field sampling)





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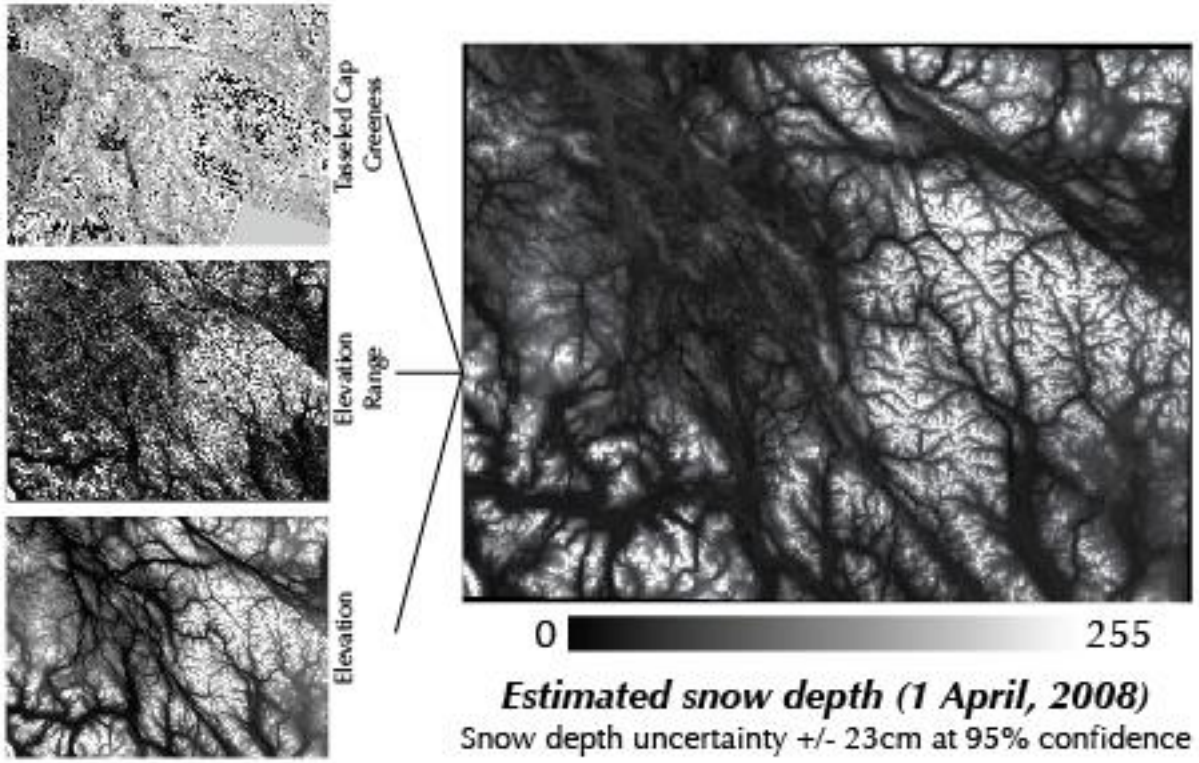
Validation/calibration



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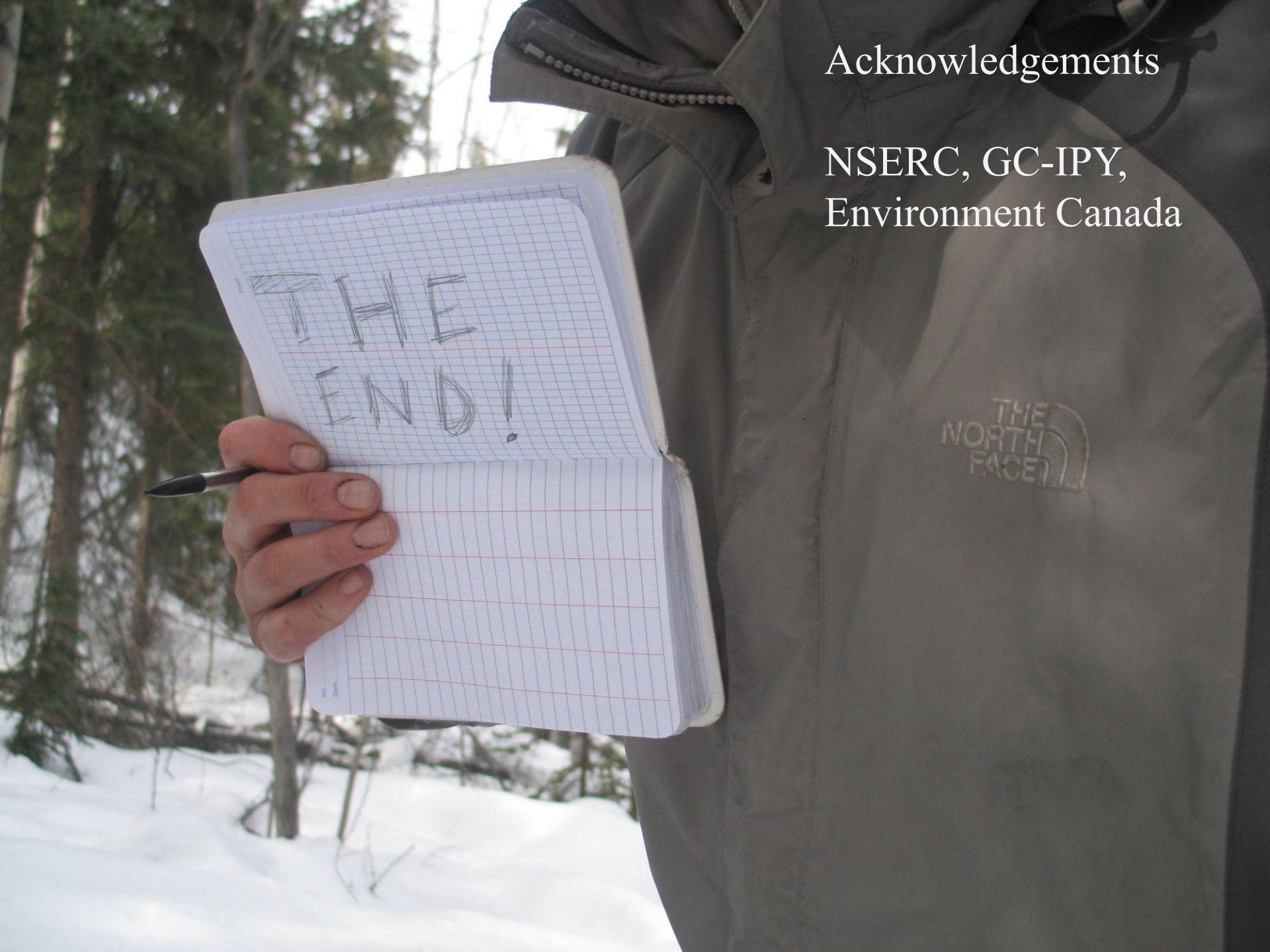
Conclusions

- Snow mapping in Yukon (and larger W. Canada mountain domain) is very challenging
- We are attempting to combine multiple satellite and model data sources to map snow accumulation.
- AMSR-E shows extended sensitivity at the 12.5 km grid scale resolution
- There is more information that can be leveraged from AMSR-E to help with estimates
- We have developed a regional high resolution snow map based on extensive field measurements that is also being used for calibrating and testing.
- We expect to have a maximum accumulation map with uncertainty estimates



Acknowledgements

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