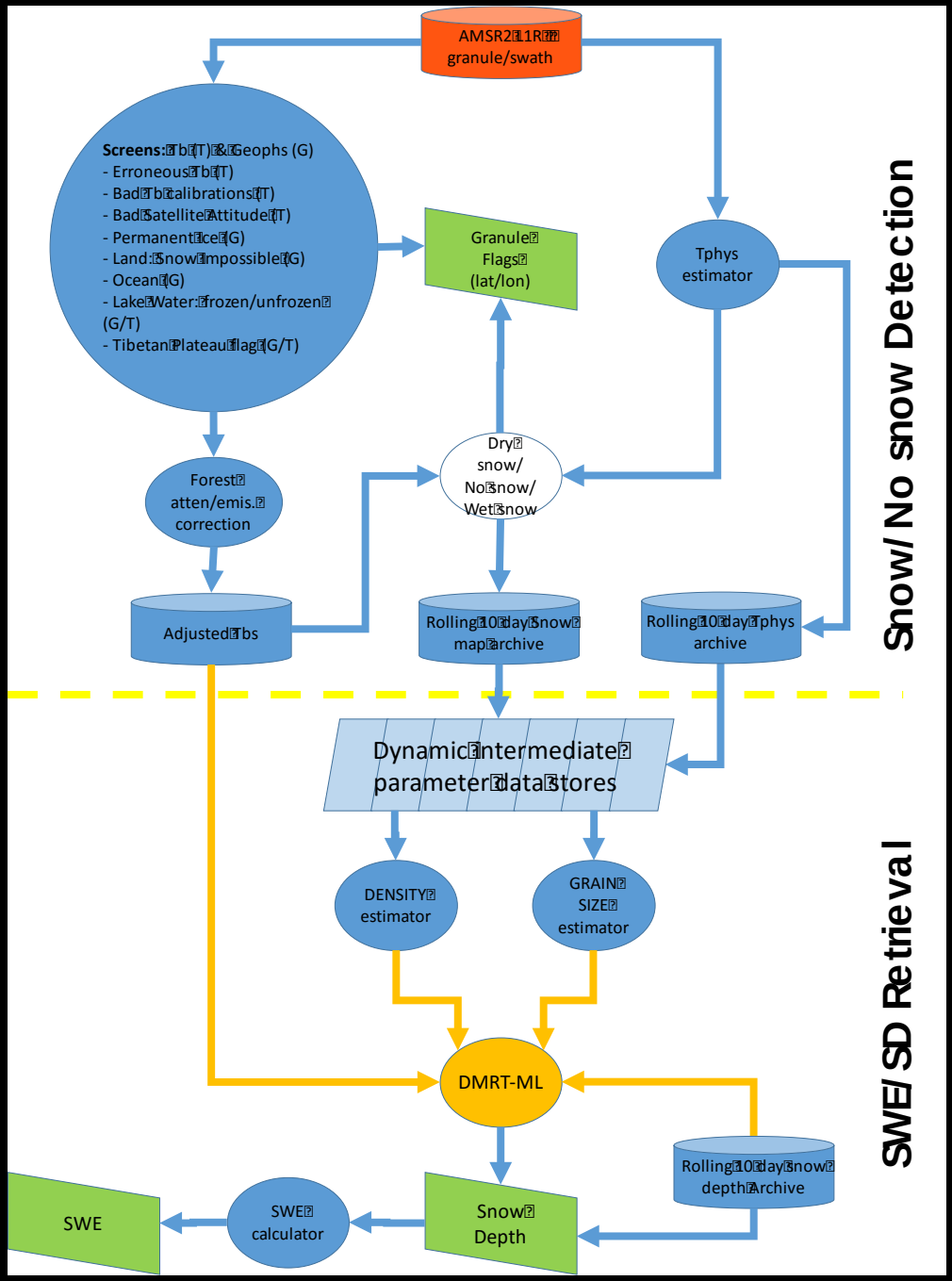
The AMSR2 Satellite-based Microwave Snow Algorithm (SMSA): a parsimonious snow depth and snow water equivalent approach

Richard Kelly, Nastaran Saberi & Qinghuan Li
University of Waterloo, Canada.

Satellite-based Microwave Snow Algorithm (SMSA)

- Estimate snow depth using AMSR2 and static ancillary data
  a purely space-based approach

- variable #1 *snow detection*
- variable #2 *snow depth estimation*


AMSR2 L1R granule/swath
Screens: Tb (T) & Geophs (G)
- Erroneous Tb (T)
- Bad Tb calibrations (T)
- Bad Satellite Attitude (T)
- Permanent Ice (G)
- Land: Snow impossible (G)
- Ocean (G)
- Lake Water: frozen/unfrozen (G/T)
- Tibetan Plateau flag (G/T)
Granule Flags (lat/lon)
Tphys estimator
Forest atten/emis. correction
Dry snow/ No snow/ Wet snow
Adjusted Tbs
Rolling 10 day Snow map archive
Rolling 10 day Tphys archive
Snow/ No snow Detection
Dynamic intermediate parameter data stores
DENSITY estimator
GRAIN SIZE estimator
DMRT-ML
Rolling 10 day Snow depth Archive
SWE
SWE calculator
Snow Depth
SWE/ SD Retrieval

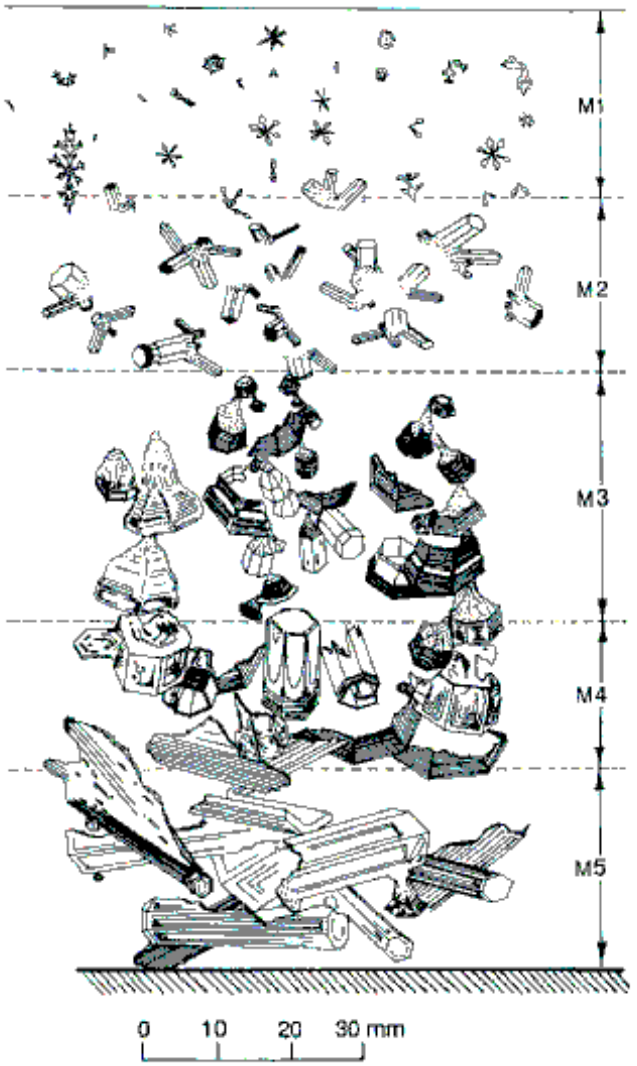
Variable #1: *snow extent*

Variable #2: *snow depth*

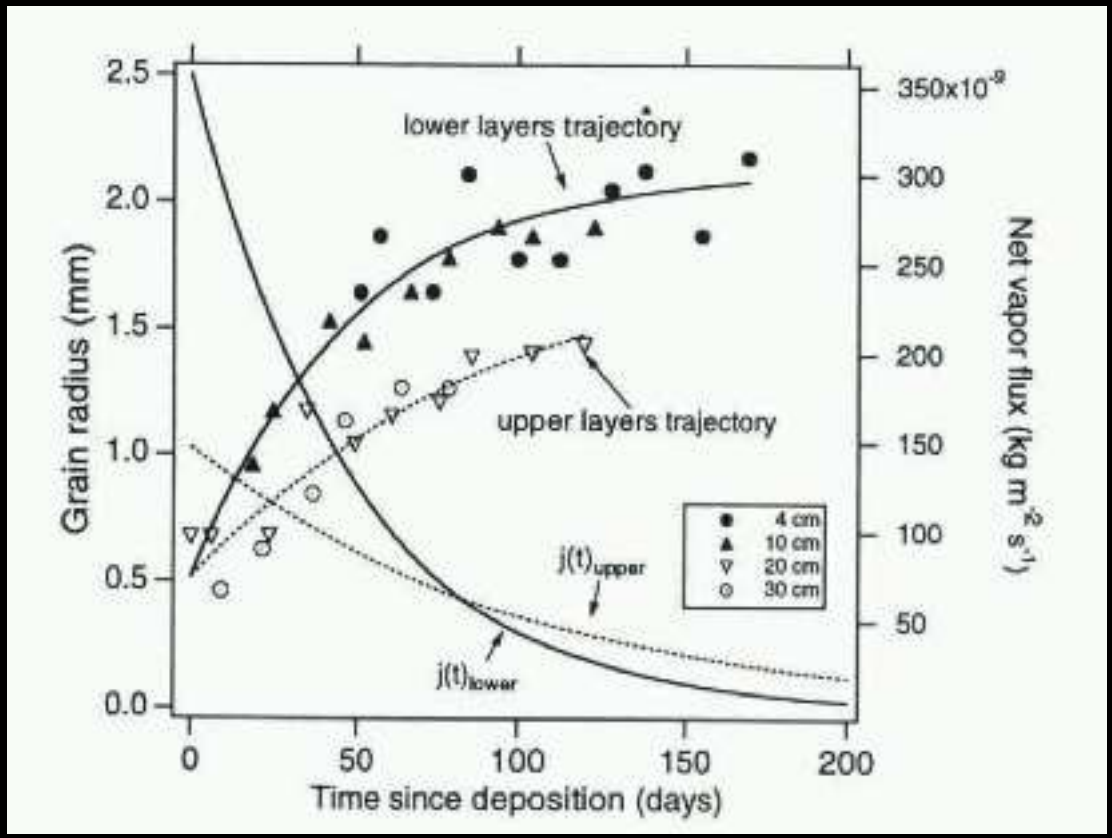
Once identified where the snow is, we perform the retrieval

- DMRT-ML (Picard et al, 2013) Inverted: *Estimate snow depth*
  - Snow temperature (Kelly et al. 2003, *updated*)
  - Grain size (Kelly et al. 2003)
  - Snow density (Kelly et al. 2003)
  - AMSR2 Tb36V & Tb18V GHz
- SWE is a natural bi-product (SWE = snow depth x density)
- Tphys (+/- 5K)
  - 62.4-0.05*v18+0.84*v23-0.40*h36+0.41*v89 [k] (Kelly *et al.,* 2003)

Sturm & Benson (1997) *J. Glac.*

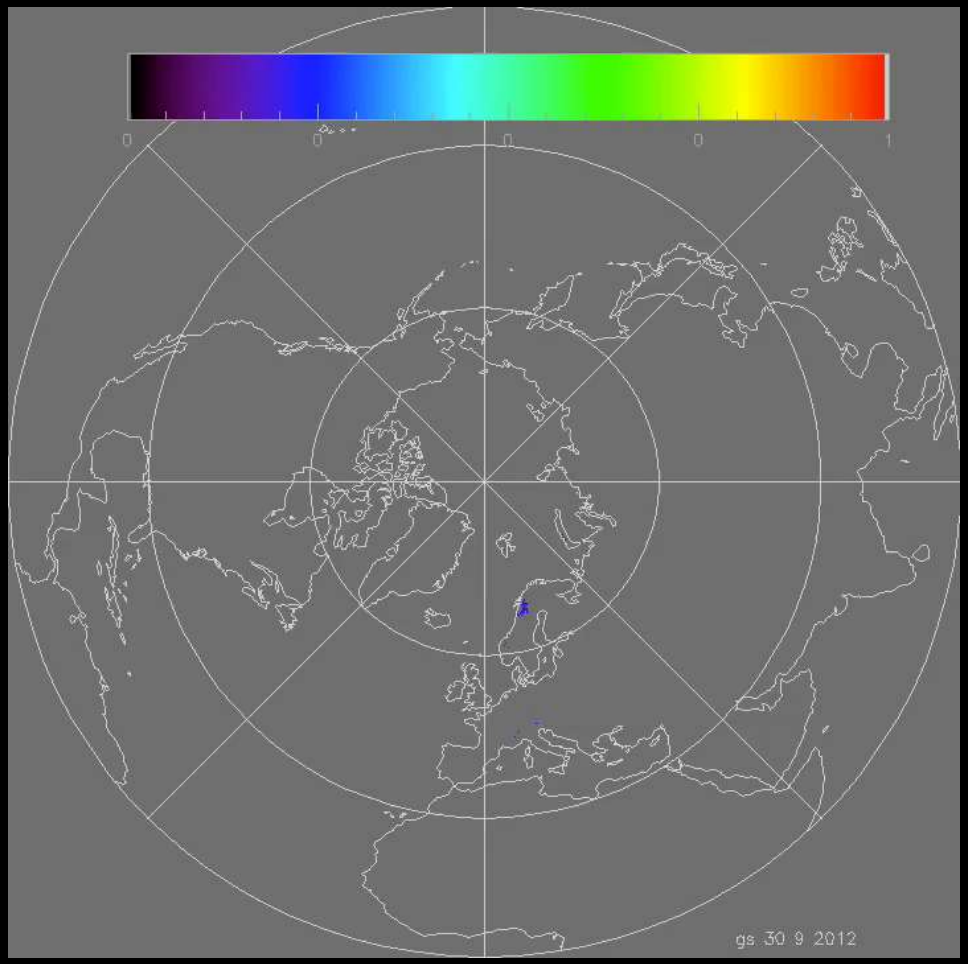


$$\frac{dr}{dt} = a\left(r_{¥} - r_0\right)\exp\left(at\right)$$

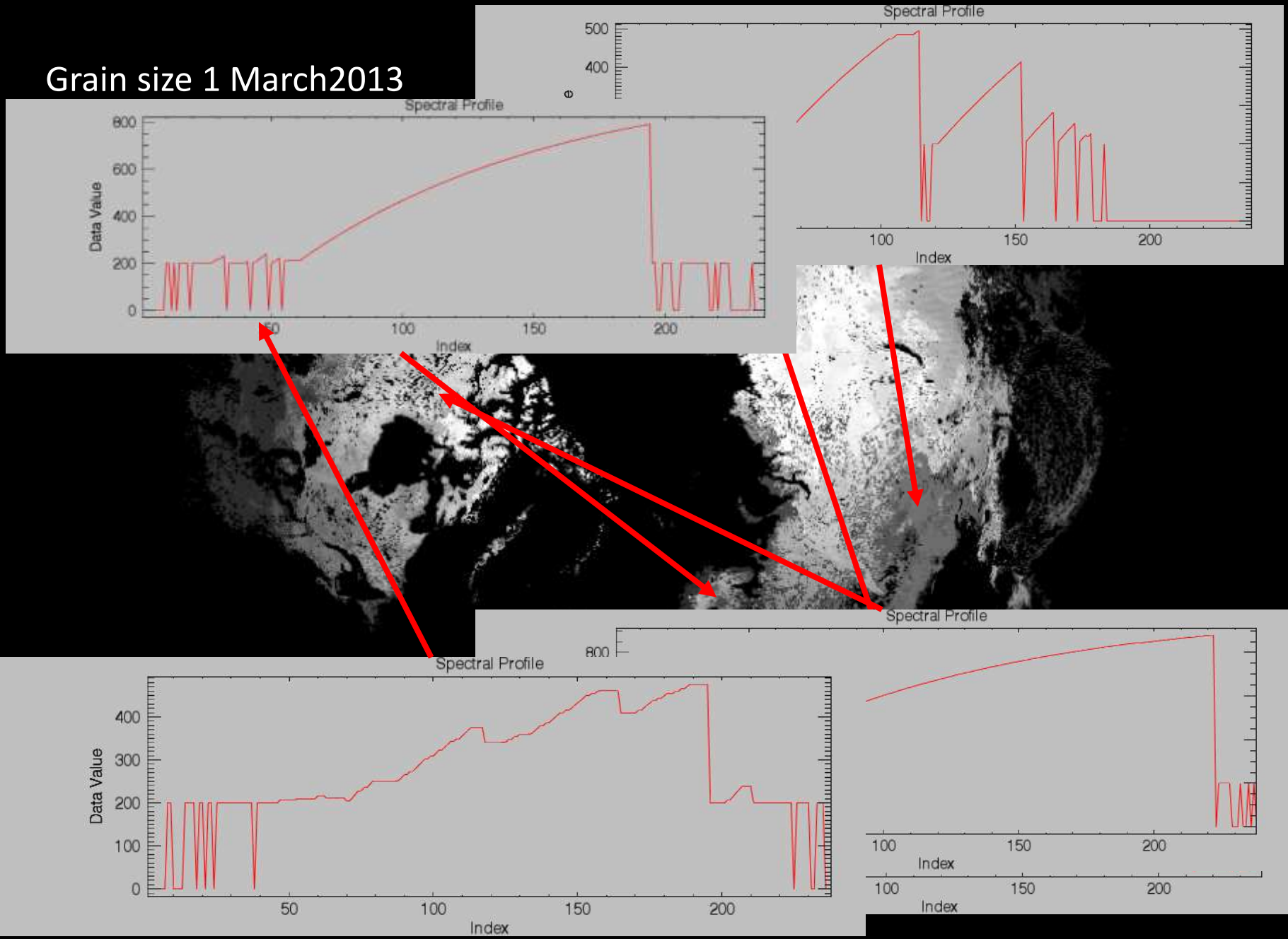


- DMRT-ML: d0 grin size (Picard et al, 2013) Inverted: *Estimate snow depth*
  - Tphys determines *Kinetic* or *equi-temperature* growth regime
  - Kinetic: use d0:
    - R_∞ = 0.98 mm
    - R_0 = 0.2 mm
    - α = 0.02 mm/d
  - Equi-temperature growth rate is constant
    - ETGR = 0.0001 mm/d

Grain radius (d0) progression 1 Oct 2012 – 31 May 2013 [mm]



Grain size 1 March2013



Estimating density

What do you need to track to achieve this?

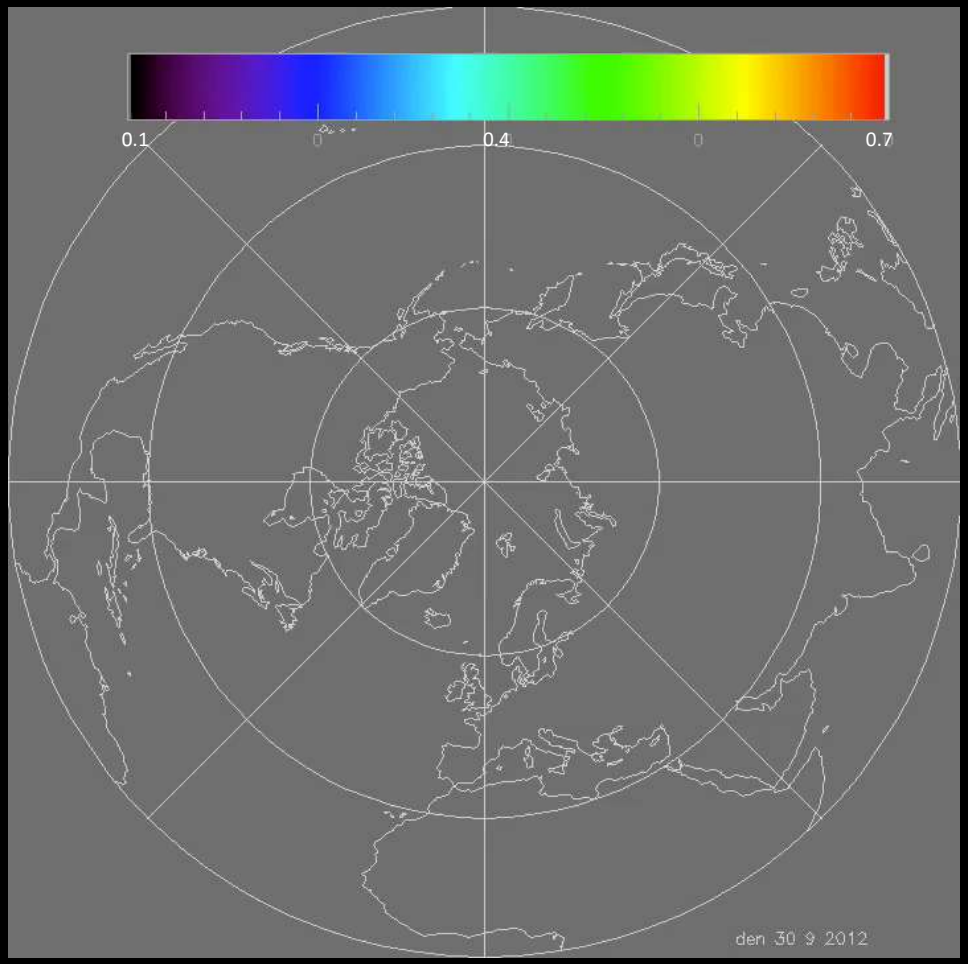
- Is it moderate / deep snow? [Detection]
- Number of snow days in the last 10 days
- Initial fresh snow density (Hedstrom and Pomeroy 1998) ~0.097 g cm^{-3}
- Which Sturm et al (1995) seasonal snow class?
- Upper and lower limits of early to late season snow (Sturm et al. 2010)

```
/* Sturm Classes Tundra, Taiga,  Maritime, Prairie,  Alpine*/
denminmax[2][5]={0.3630, 0.2170, 0.5979,   0.5940,   0.5975,    /* Maximum density */
                 0.2425, 0.2170, 0.2578,   0.2332,   0.2237};   /* Initial density */
```

- Rapid densification over initial 5 days to lower limit in Sturm snow class
- Use a simple logistic growth curve after day 5.

$$\frac{d(rho)}{dt} = \alpha_d(rho_\infty - rho_0)\exp(\alpha_d t)$$

Density progression 1 Oct 2012 – 31 May 2013 (kg m^{-3})



The Retrieval

- 1 layer DMRT-ML model
- Infinite background (difficult to parameterize soil background for DMRT at this time)
- Stickiness tau (τ) is set to 0.3
- *Forward mode estimates*
  - *Tb18: V & H*
  - *Tb36: V & H*

Look-up table Inversion

The retrieval inversion. Method:

A. In 2003 we used a polynomial inversion of DMRT look-up table

   $SD = a(Tb18V-Tb36V)^2 + b(Tb18V-Tb36V)$ [cm]
   where *a* & *b* specified by grain size and density

B. DMRT-ML constrained minimization using *Tb18-Tb36* (V or H) from a look-up table
   - Real time DMRT-ML code implementation = intractable

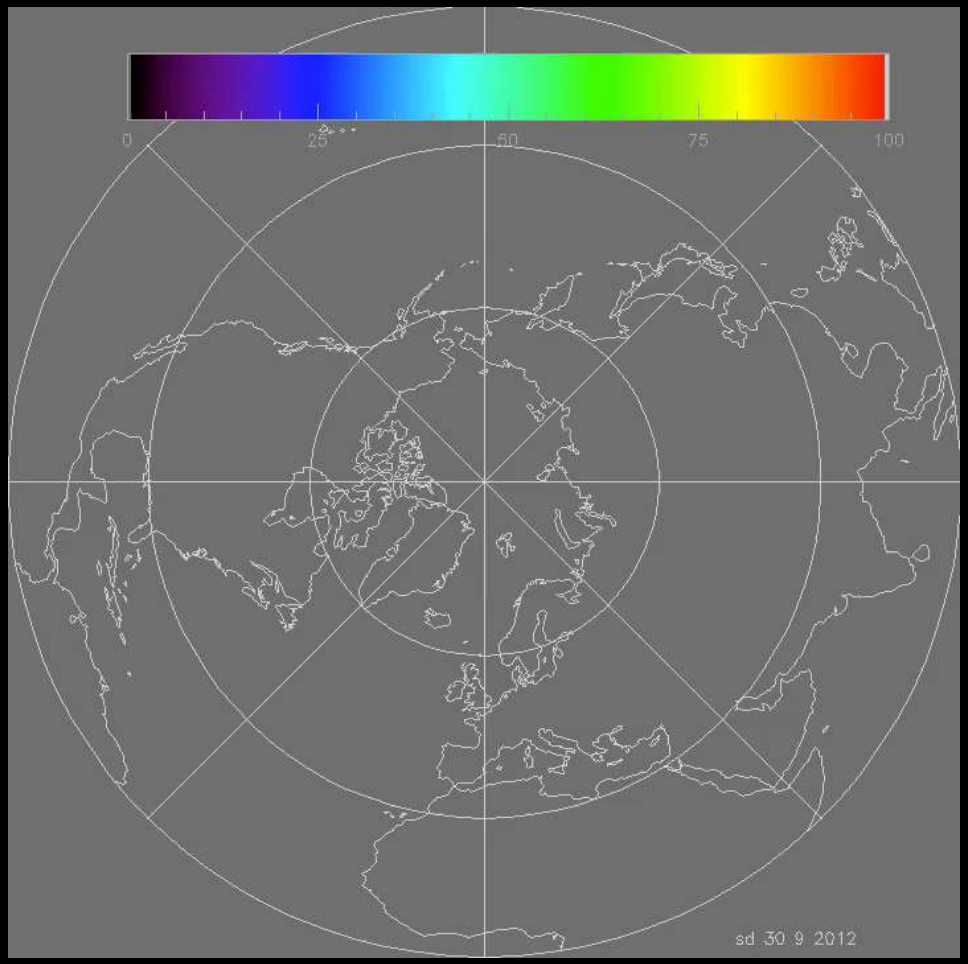
Constrained minimization

- Iteratively sweep the DMRT-ML *single layer* LUT with a constrained range of snow depths around *first guess (t-1) snow depth*
  - $TbXX_m$ is DMRT model
  - $TbXX_O$ is AMSR2-observed

- Minimization function between observed and LUT (model):
  - D_{t-1} is snow depth at *t-1*
    - *SweepRange = f(*$(Tb18_m - Tb36_m) - (Tb18_O - Tb36_O)$*)*
      f is an inverse exponential decay function – maintains inertia
    - *minD=*D_{t-1}*-0.25*SweepRange*
    - *maxD=*D_{t-1}*-0.75*SweepRange*
  - For each increment between *minD* and *maxD* we estimate *diff.* The minimum *diff* Is the SD

$$diff = \{(Tb18_m - Tb36_m) - (Tb18_O - Tb36_O)\}$$

Snow depth progression 1 Oct 2012 – 31 May 2013 (cm)



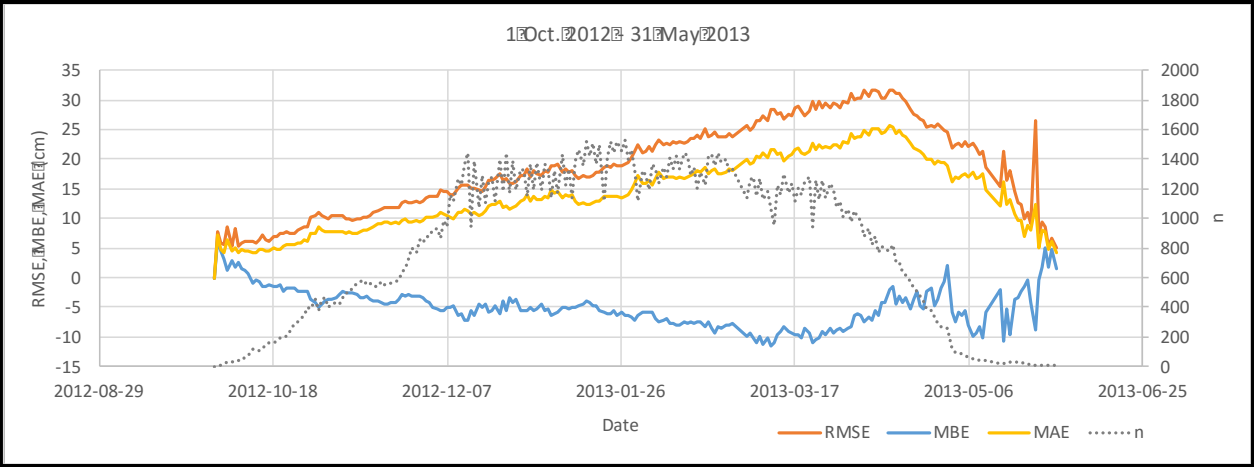
Evaluation

- Seasonally aggregated daily metrics for NH
- Seasonally aggregated station metrics for NH

Evaluation: aggregated daily global metrics

1 October 2012 – 31 May 2013				
	RMSE	MBE	MAE	n
SD < 100 cm	17.80 (20.85)	-4.27 (-7.26)	13.63 (15.32)	185,228
SD < 200 cm	18.69 (23.99)	-4.62 (-8.55)	13.93 (16.51)	186,306

1 October 2013 – 31 May 2014				
	RMSE	MBE	MAE	n
SD < 100 cm	20.18 (23.26)	-4.01 (-8.09)	14.71 (17.34)	174,716
SD < 200 cm	21.31 (30.56)	-4.47 (-11.60)	15.09 (20.47)	175,581



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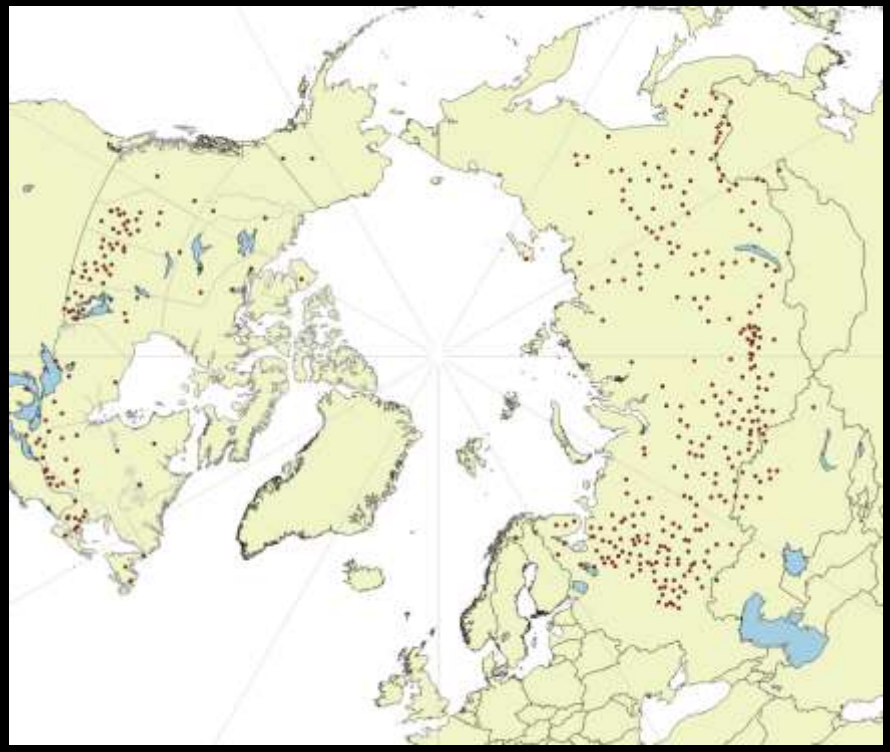
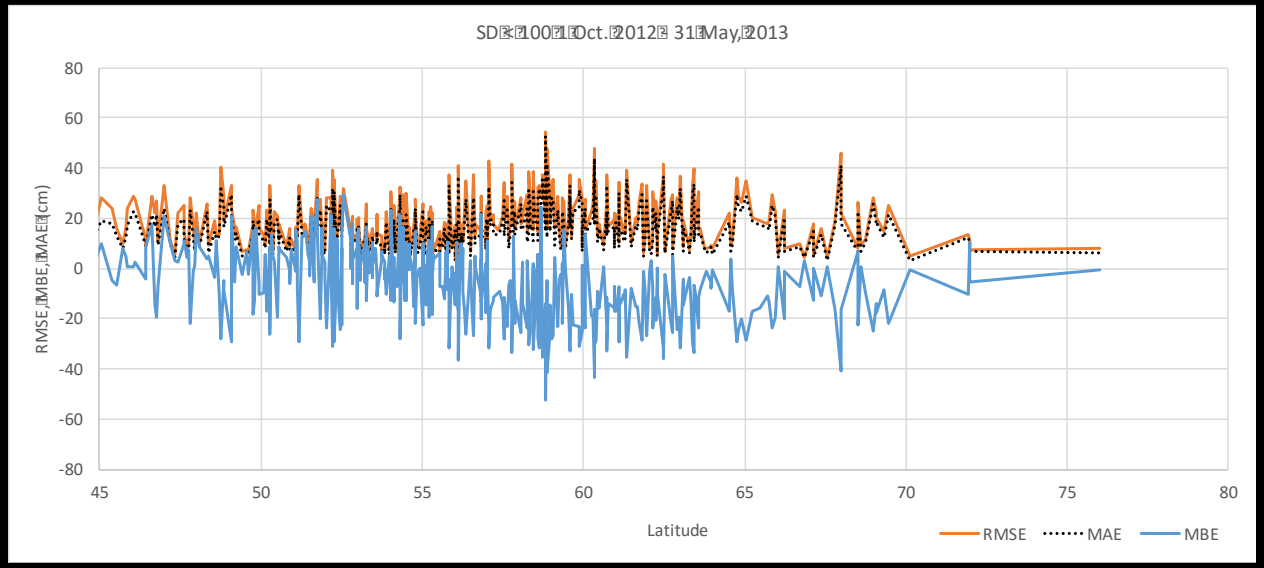
- Seasonally aggregated station metrics for NH



400 Stations with >100 days of snow in the winter 2013-14

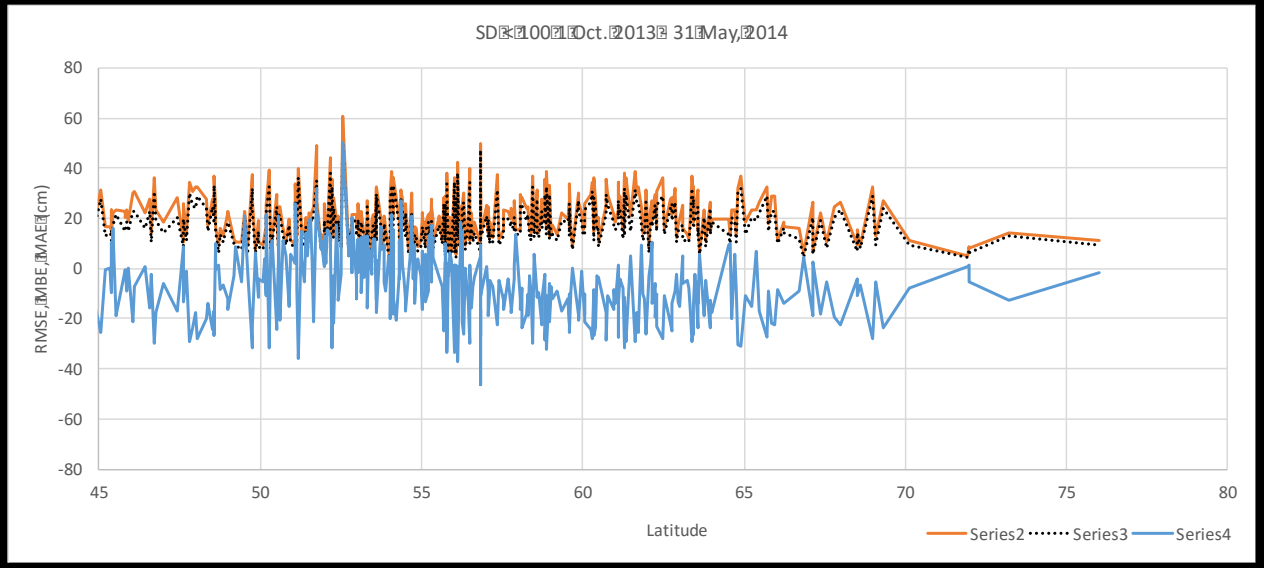
Evaluation: aggregated station metrics

1 October 2012 – 31 May 2013					
	RMSE	MBE	MAE	n	# of stations
SD < 100 cm	18.49	-6.49	15.36	70,582	456
SD < 200 cm	18.73	-6.74	15.58	70,898	457

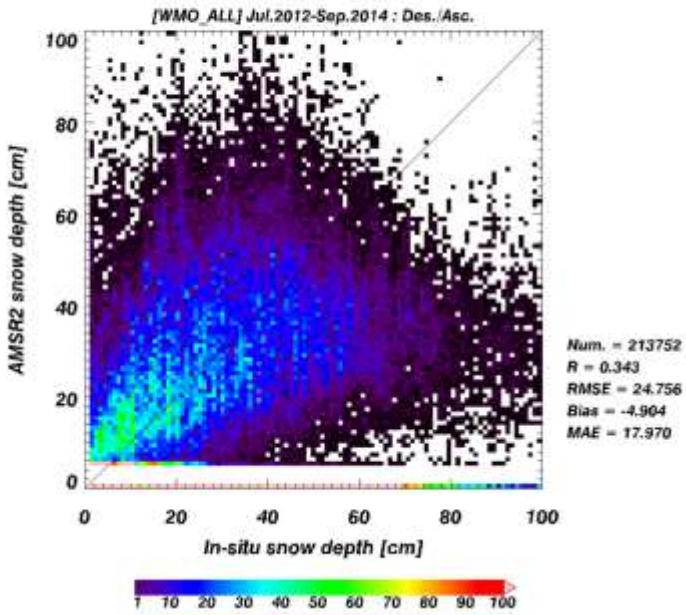
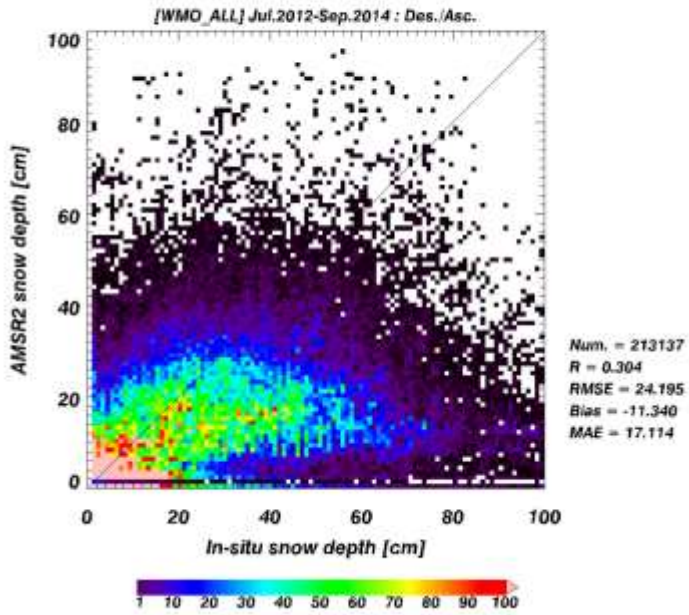


Evaluation: aggregated station metrics

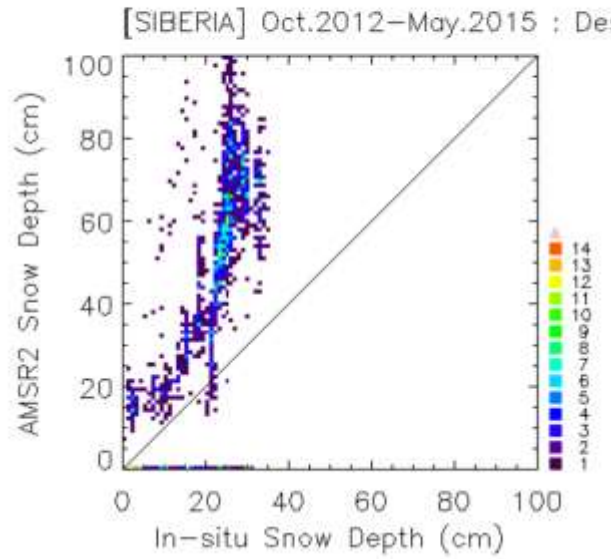
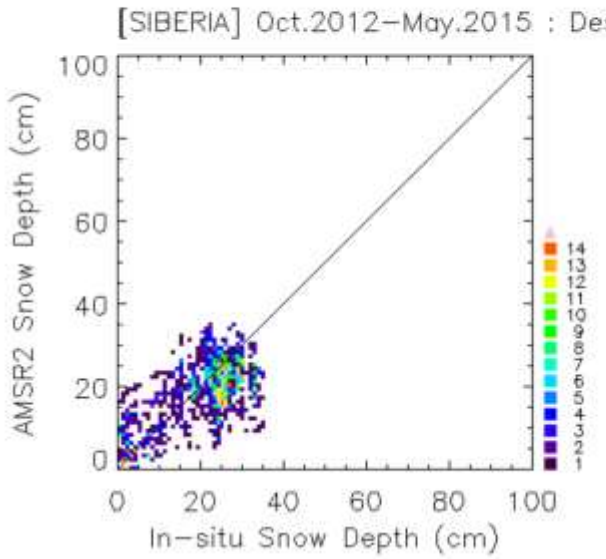
1 October 2013 – 31 May 2014					
	RMSE	MBE	MAE	n	# of stations
SD < 100 cm	20.32	-6.23	16.90	59,235	400
SD < 200 cm	20.37	-6.27	16.93	59,269	400



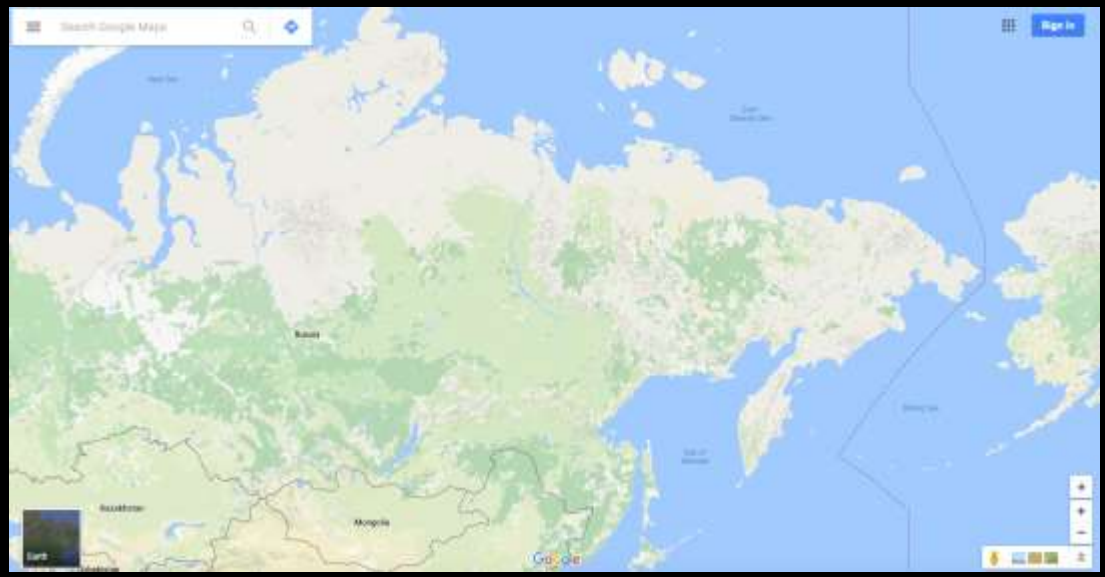
JAXA Validation approach global…

Node	V2	V3
"Asc/Dsc"		

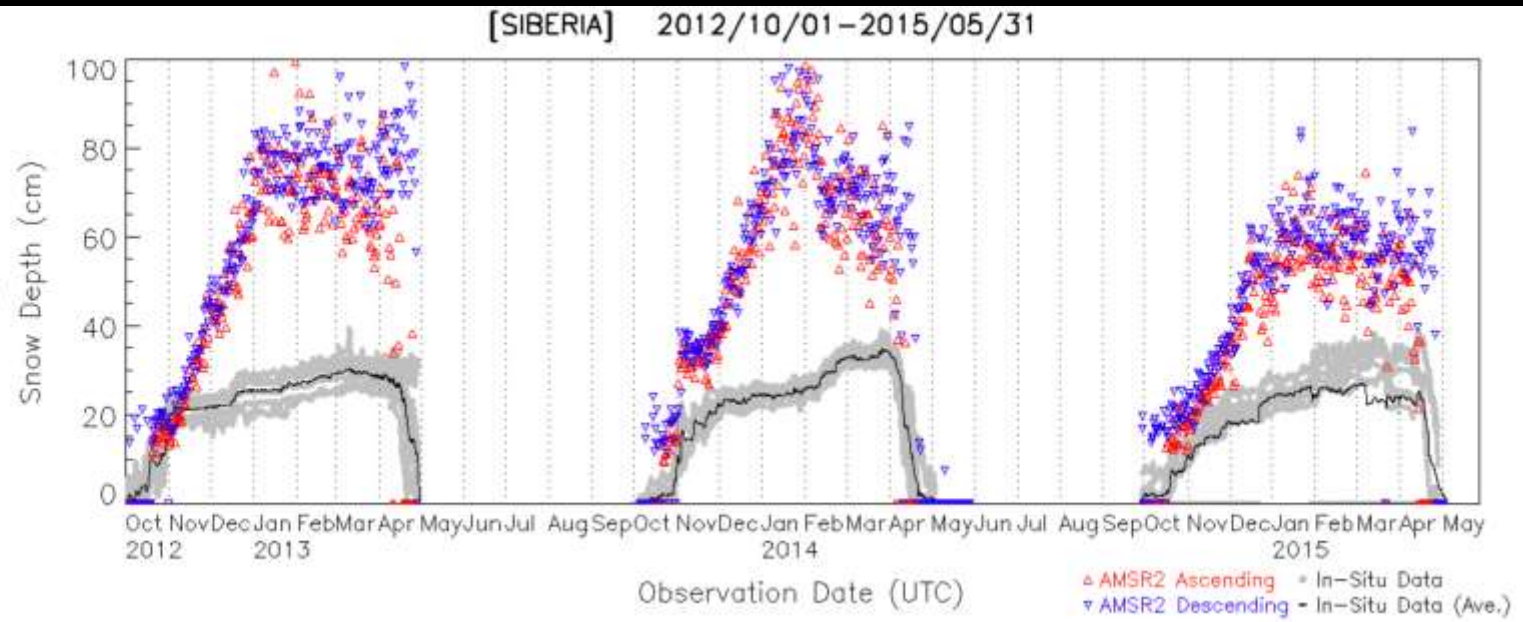
Matchup result for V2 & V3_ver04(SIBERIA_site:2012-2015)

Node	V2	V3
"Asc/Dsc"		

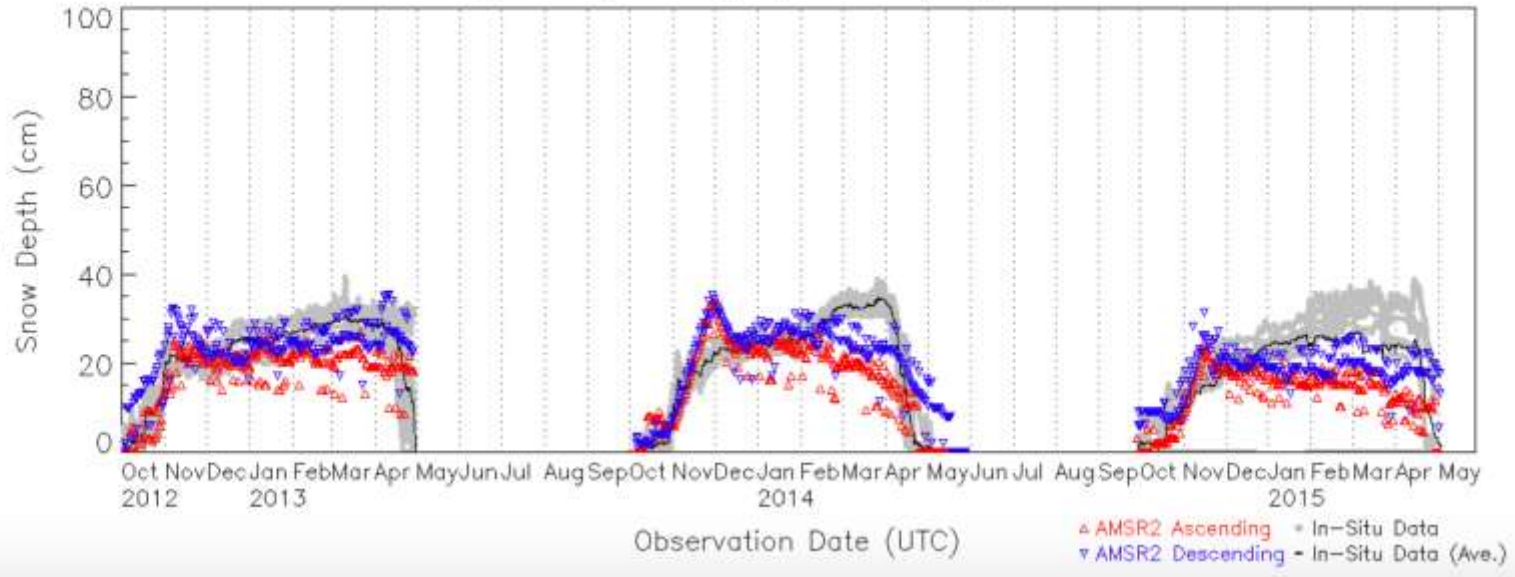
Siberia: Yakutsk



"Time series_V2"



"Time series_V3"



Conclusion

SMSA retrievals are improvements over current standard algorithm

- Snow mapping is better
- Evaluation metrics indicate that the snow depth estimates are improved but it depends about how you do it!
  - Snow depth patterns are better: mid latitude bias under evaluation

Notes

- DMRT-ML LUT is tractable.
  - Single layer for mid-latitudes is probably adequate. High latitude less so.
- Processing is time sequential (not snapshot)
  - Tolerant to <=10 days missing data.
- Output is L2 granule SD (JAXA) on lat/lon (L3 is PSG).
  - Internal memory storage is EASE2 (SD, SWE, GS, Density, Tphys)
- Product testing at JAXA continues (including uncertainty assessments).

Acknowledgements
JAXA/EORC