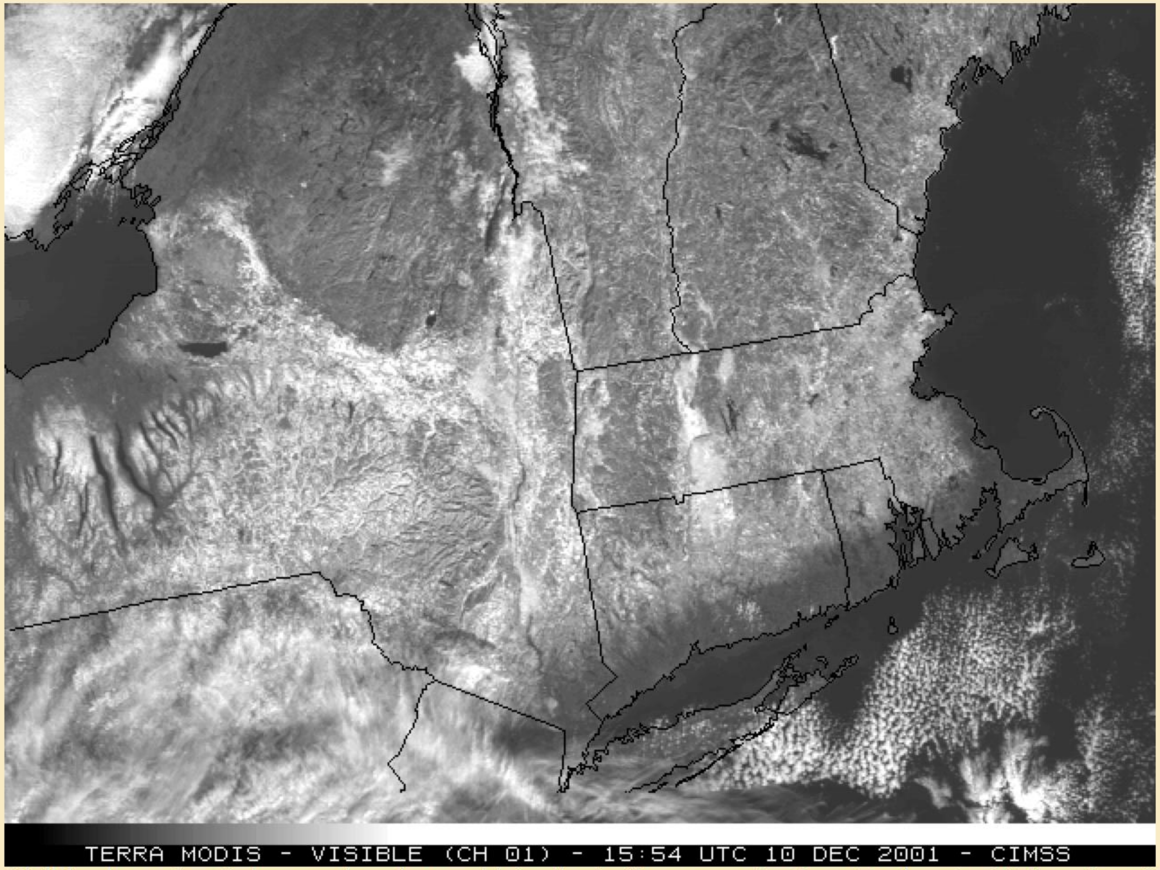
CURRENT STATE OF SNOW REMOTE SENSING OBSERVATIONS, FUTURE DIRECTION AND REMAINING CHALLENGES

Thanks to: Nick Rutter, Ian Davenport, Debbie Clifford, Adam Winstral

Outline

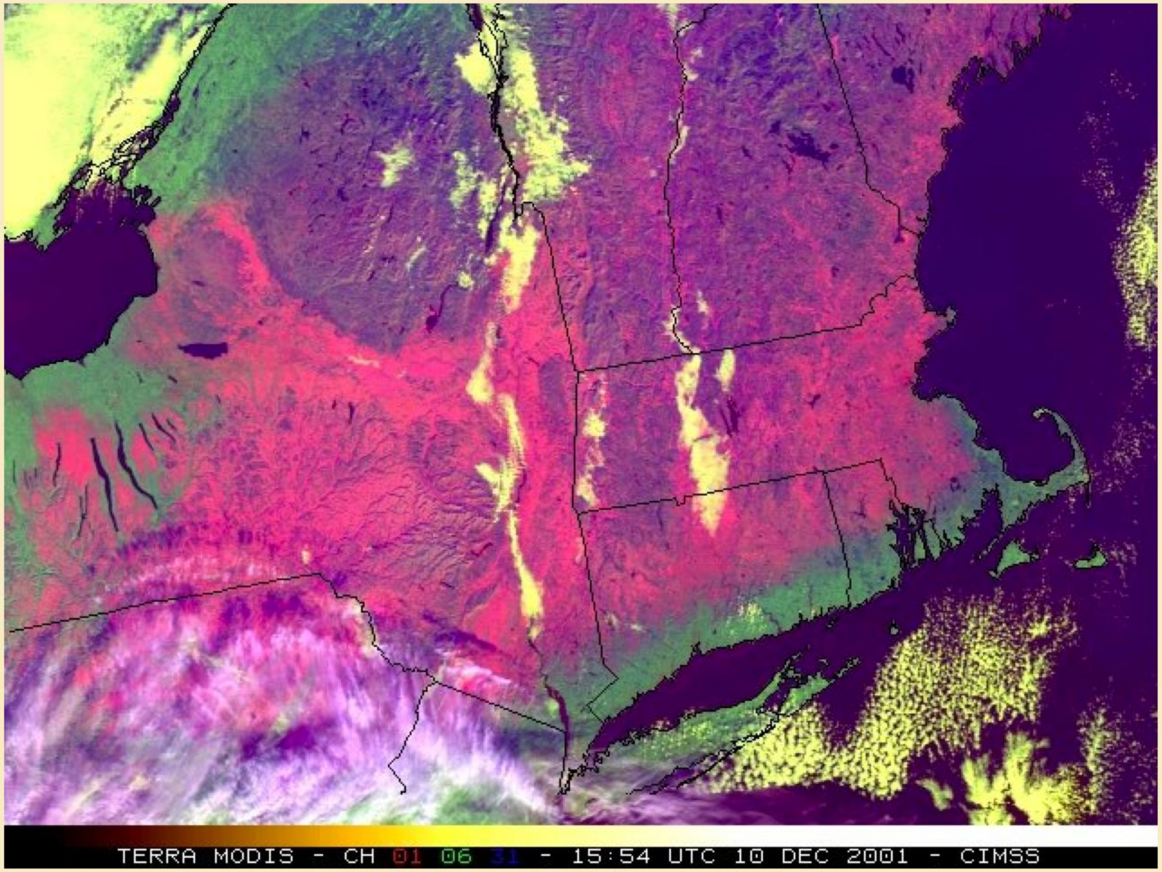
- VIS / NIR observations
  - Extent
  - Grain size
  - Snow mass (LIDAR)
- Microwave observations
  - Historical algorithms
  - Snow heterogeneity
  - Physics-based modelling
- Summary
- Future mission?

VIS / NIR



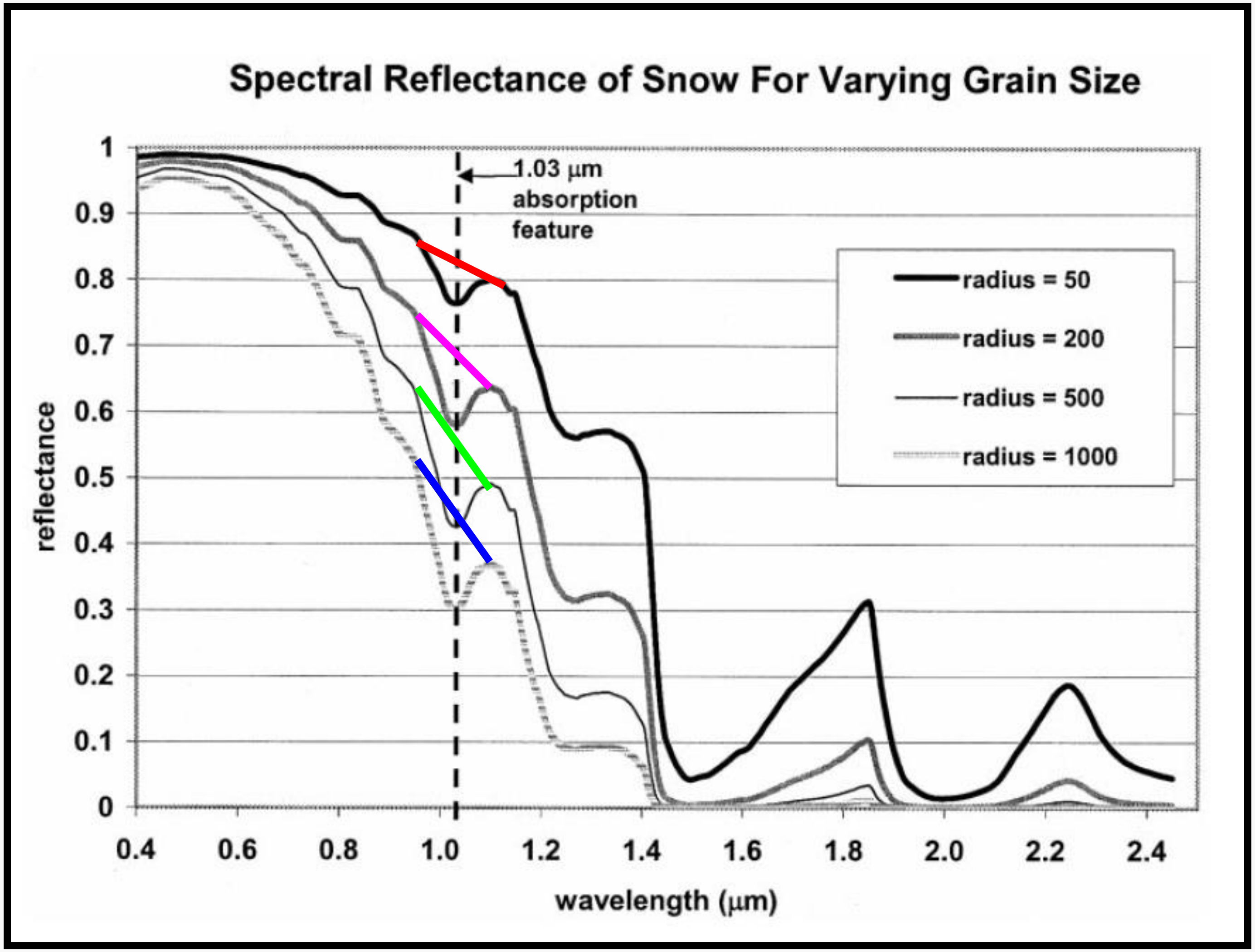
Visible channel - all three regions have a high albedo (Image credit: Scott Bachmeier, University of Wisconsin - Madison, USA)

Snow – cloud discrimination



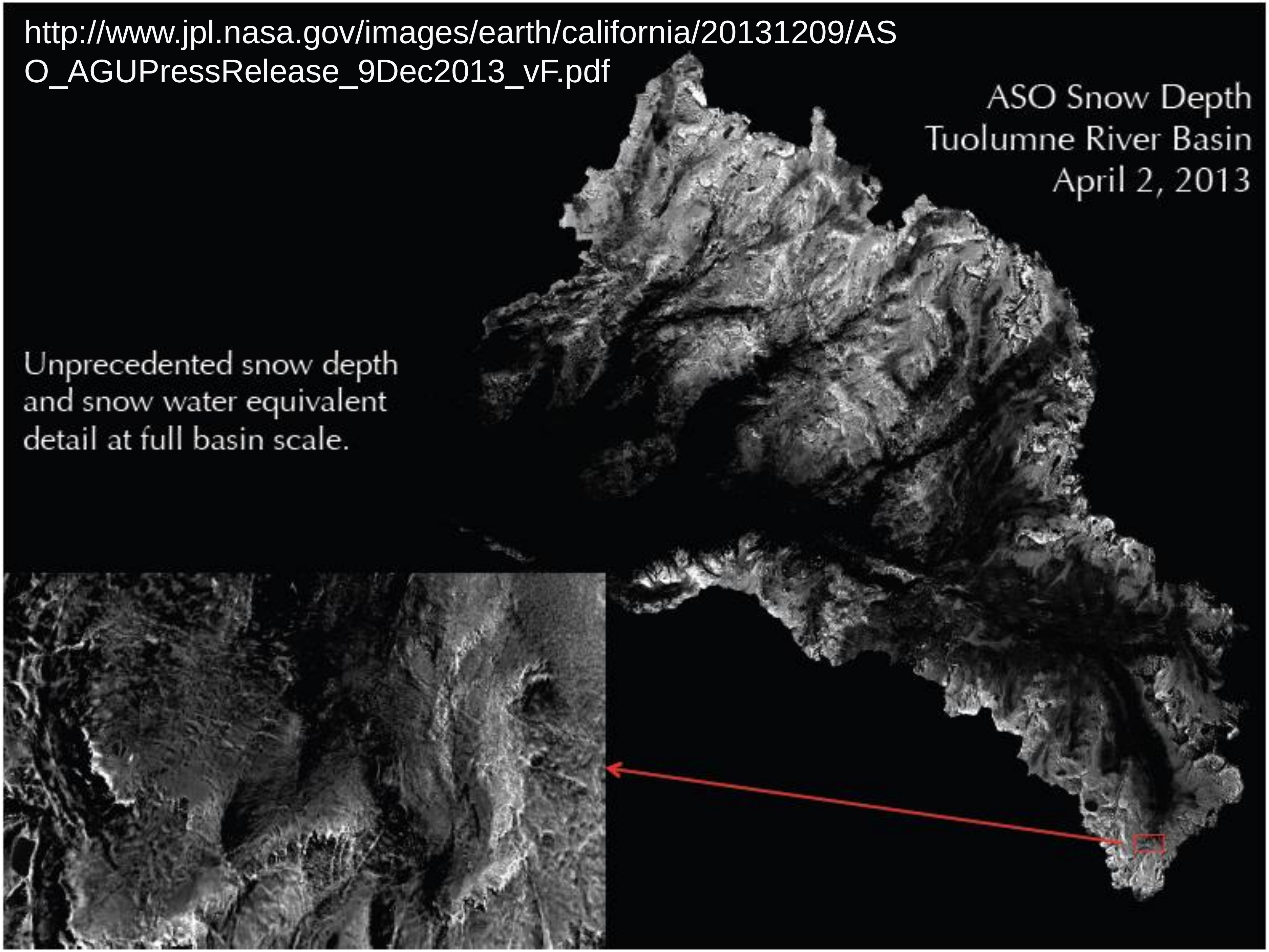
Colour composite - high cloud (white), snow (pink), low cloud (yellow)

VIS / NIR Remote sensing of snow



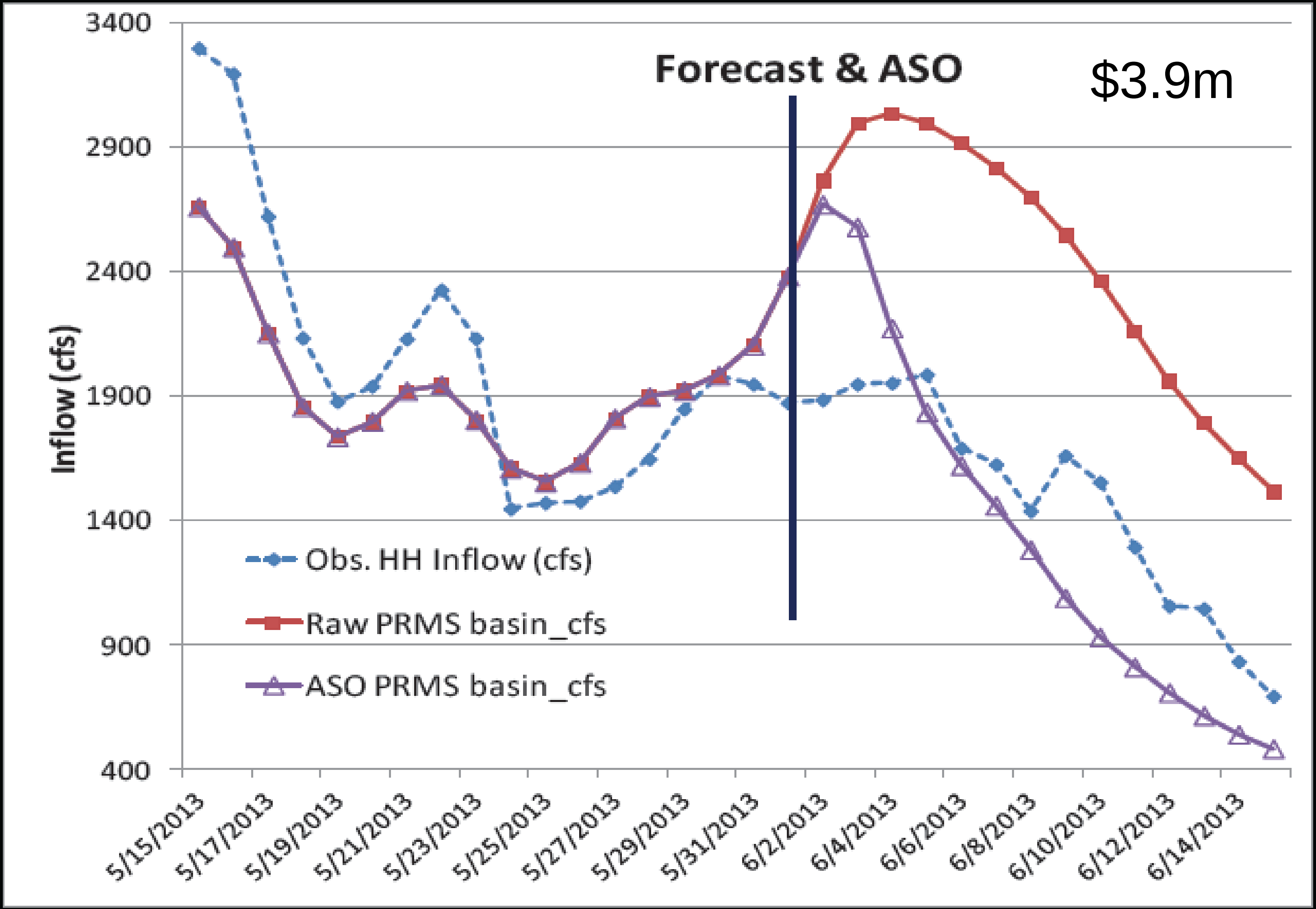
Surface / near surface

Nolin, A., J. Dozier (2000), A hyperspectral method for remotely sensing the grain size of snow, Rem. Sens. Env., 74 (2), 207–216 http://www.jpl.nasa.gov/images/earth/california/20131209/ASO_AGUPressRelease_9Dec2013_vF.pdf

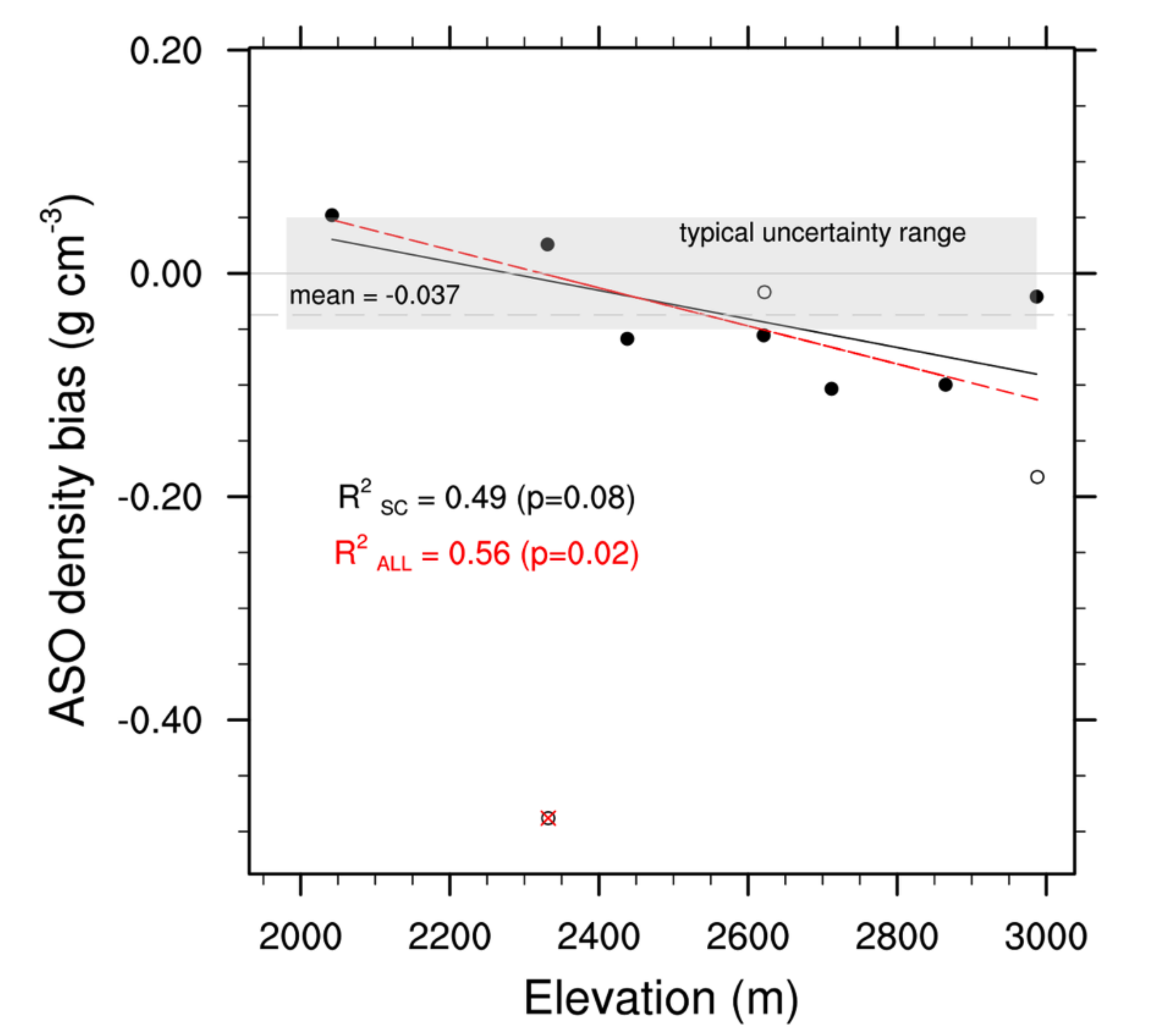


http://www.jpl.nasa.gov/images/earth/california/20131209/ASO_AGUPressRelease_9Dec2013_vF.pdf

Forecast corrected by ASO results



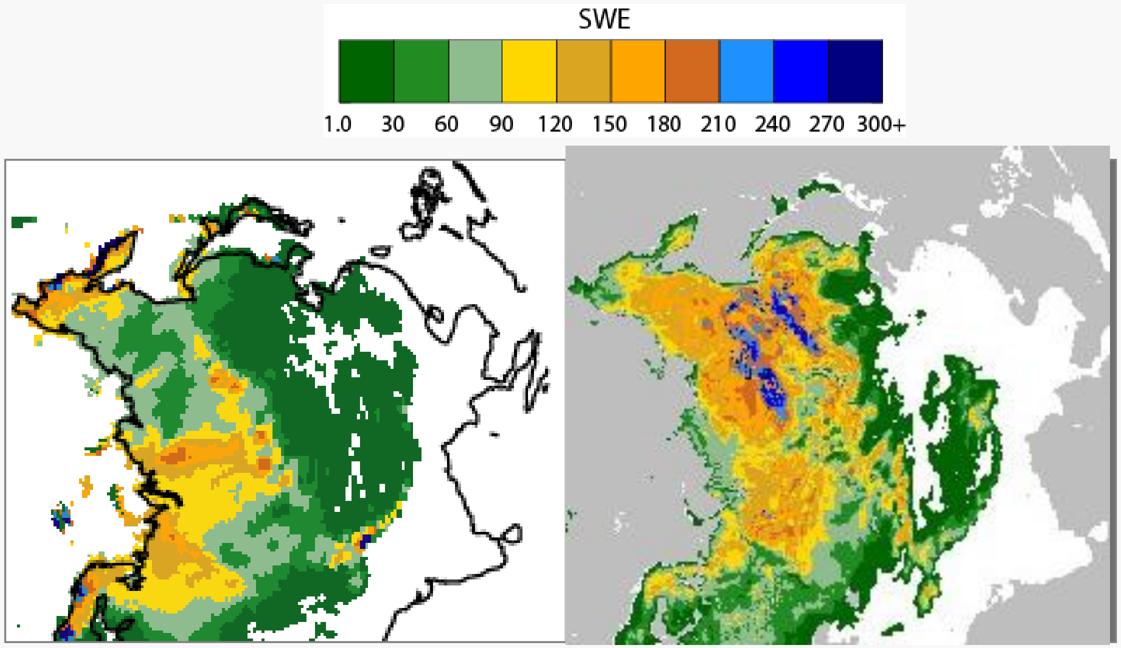
Isnobal Density



underestimation

overestimation

Absolute value is important!



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February climatology

SWE = 4.77 * (18H - 37H)

SNOW MASS FROM MICROWAVE

The basis of the Chang Algorithm

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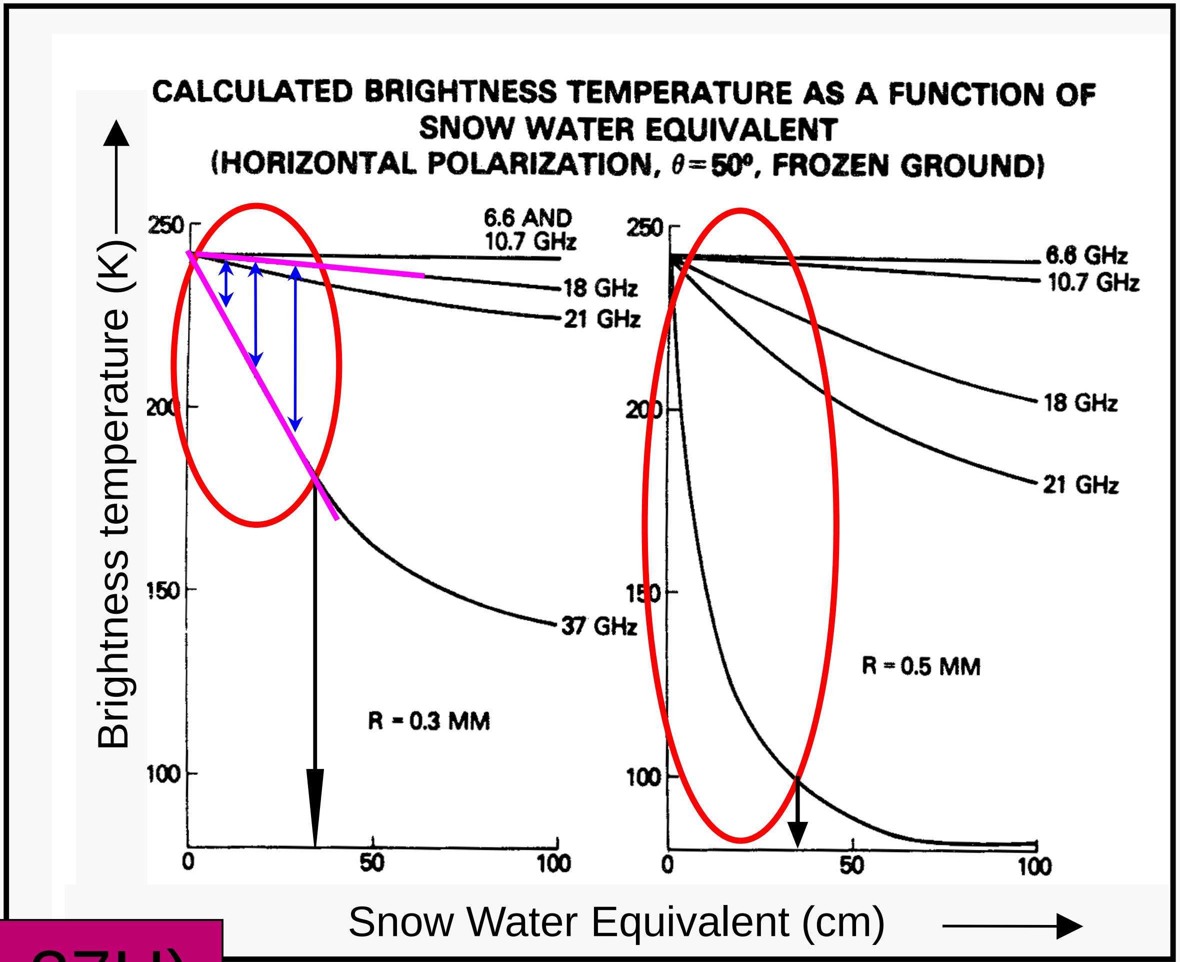
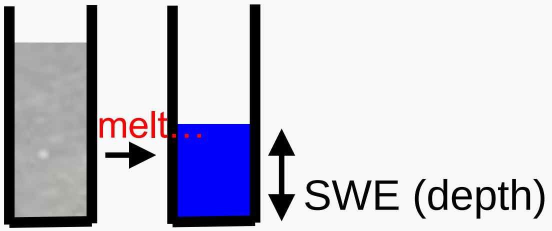
Microwave emission (Tb) vs snow mass (SWE) is derived using the Mie Scattering model





SWE = 4.77 * (18H - 37H)

Chang et. al. (1987) Ann. Glaciol. 9: 39-44

Other parameters must be known!

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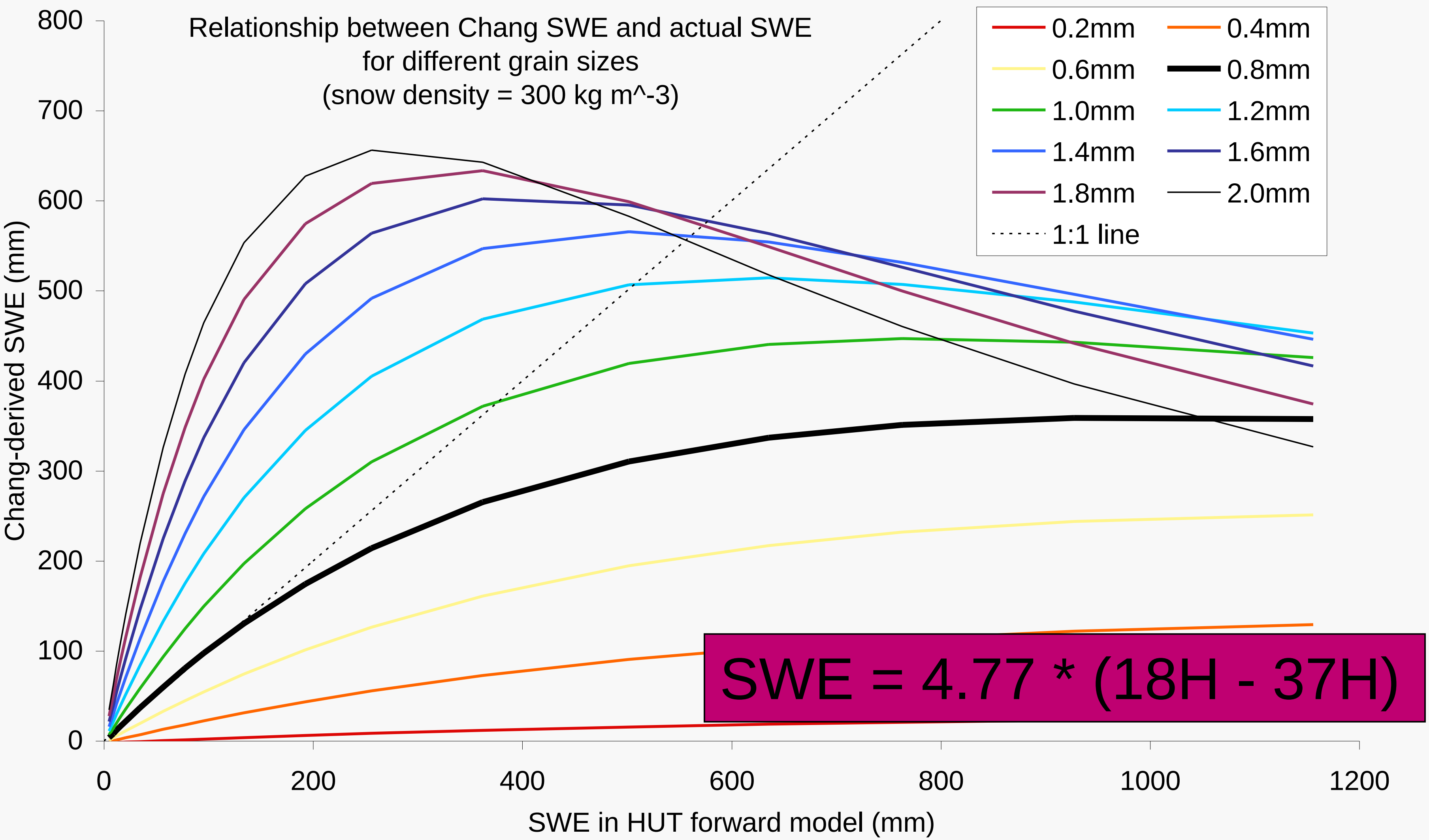
Sensitivity of snow mass algorithm to grain size



SWE = 4.77 * (18H - 37H)

Other approaches

SWE = 4.77 * (18H - 37H)

$SD = b\,(\Delta TB)^2 + c\,\Delta TB$

b, c: $f(d_{eff}, \rho)$

MAY 1995 STURM ET AL. 1277

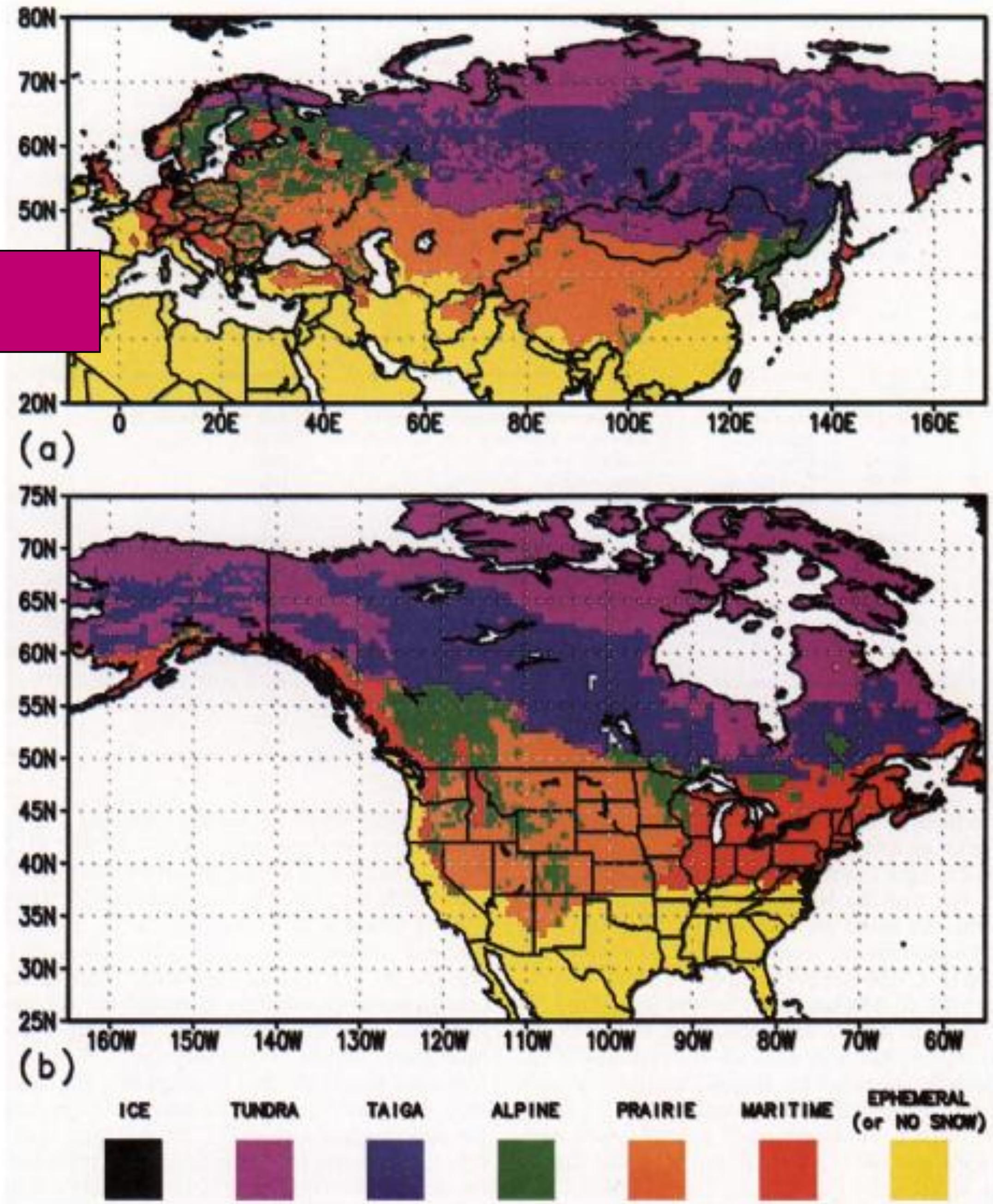
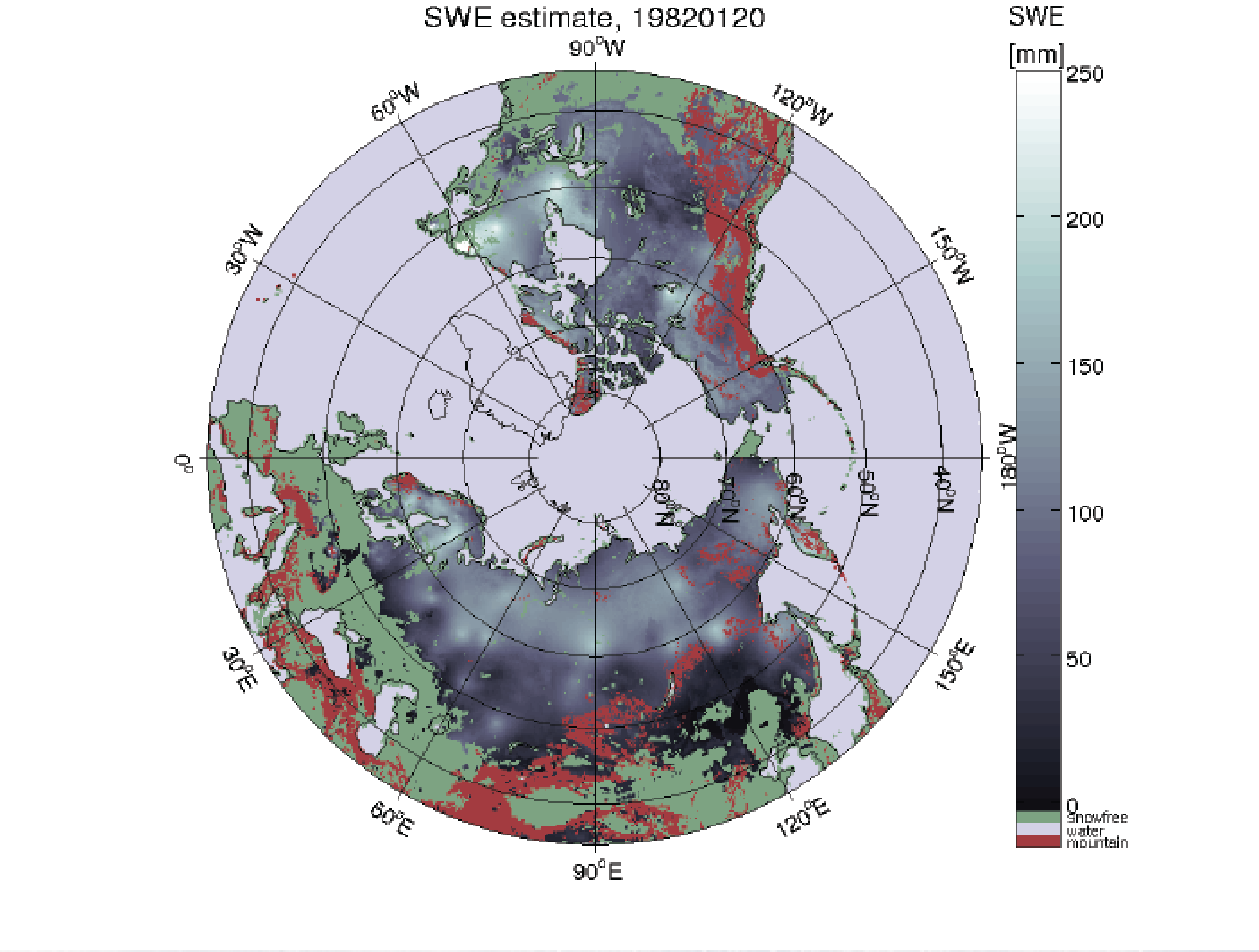


FIG. 10. Snow class distribution based on climate variables in (a) Eurasia and (b) North America.

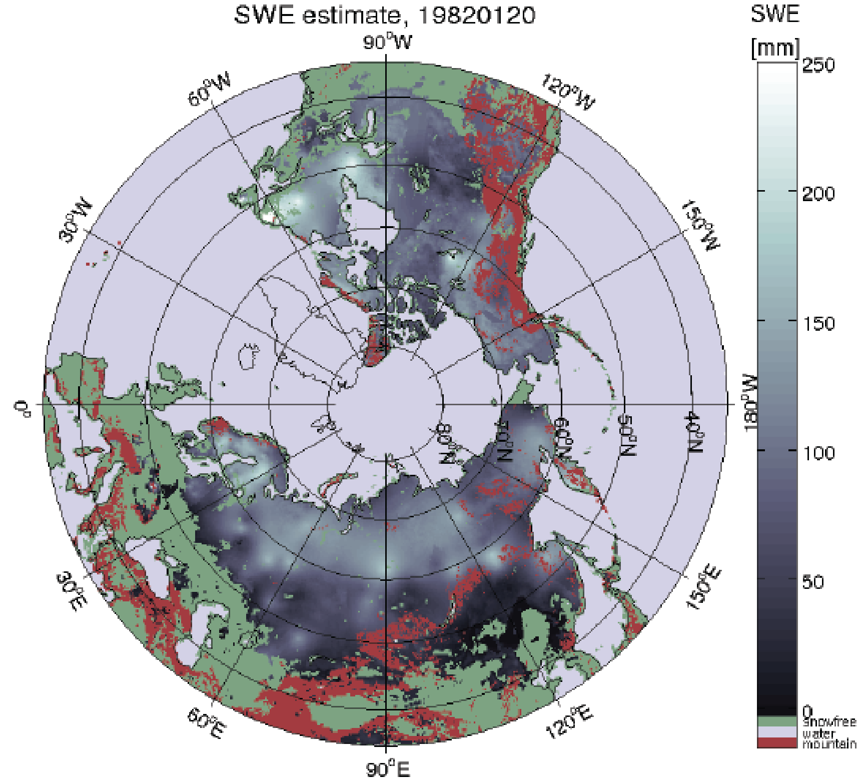
GlobSnow

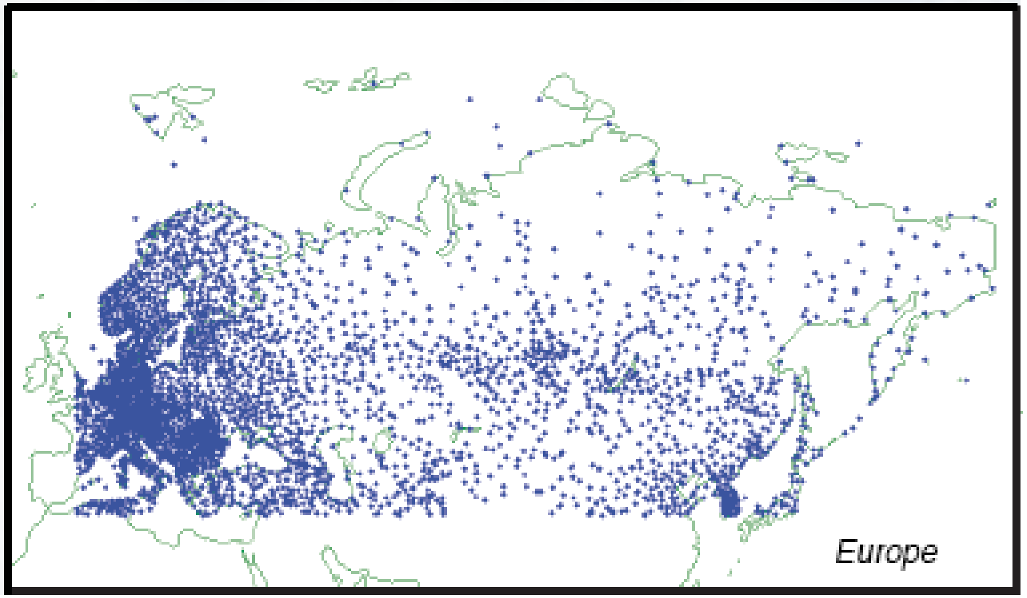


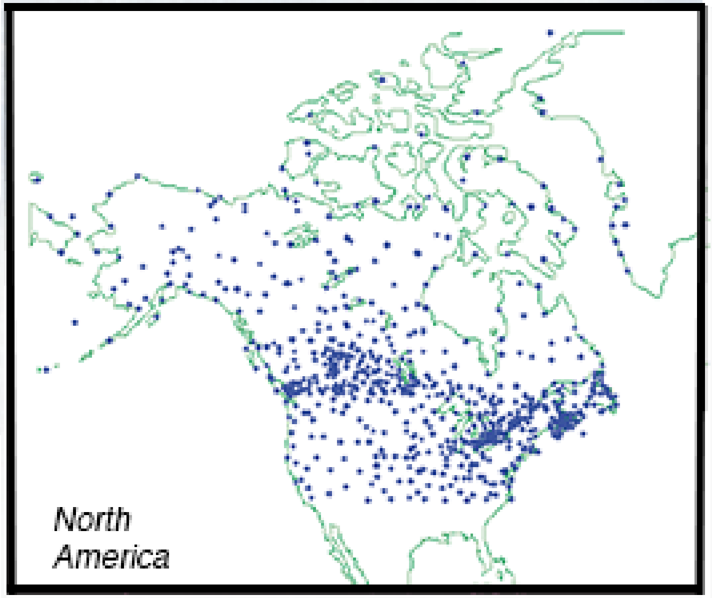
SWE estimate, 19820120
90°W
60°W
120°W
30°W
150°W
0°
180°W
80°N
70°N
60°N
50°N
40°N
30°E
150°E
60°E
120°E
90°E
SWE
[mm]
250
200
150
100
50
0
snowfree
water
mountain

GlobSnow

- Snow density 240 kg m^{-3}
- Single layer



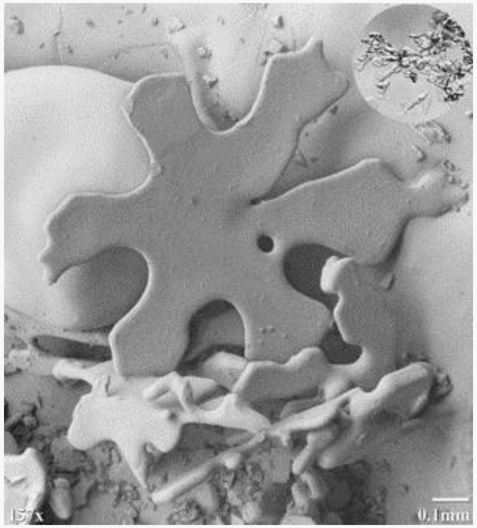


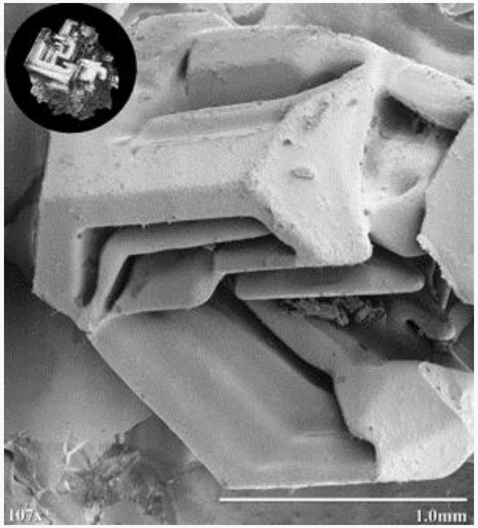


Stratigraphy

Courtesy Nick

Snow metamorphism

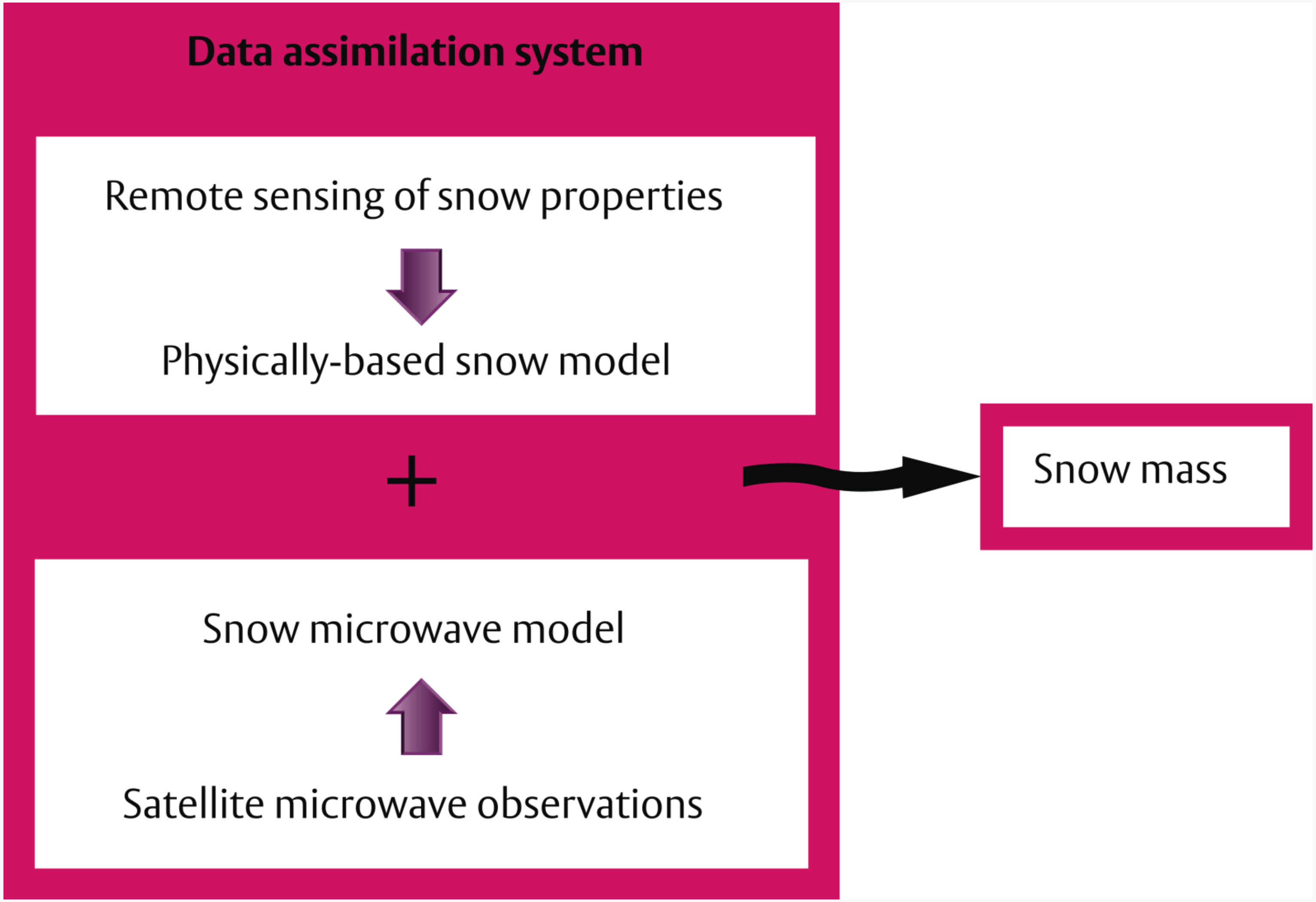




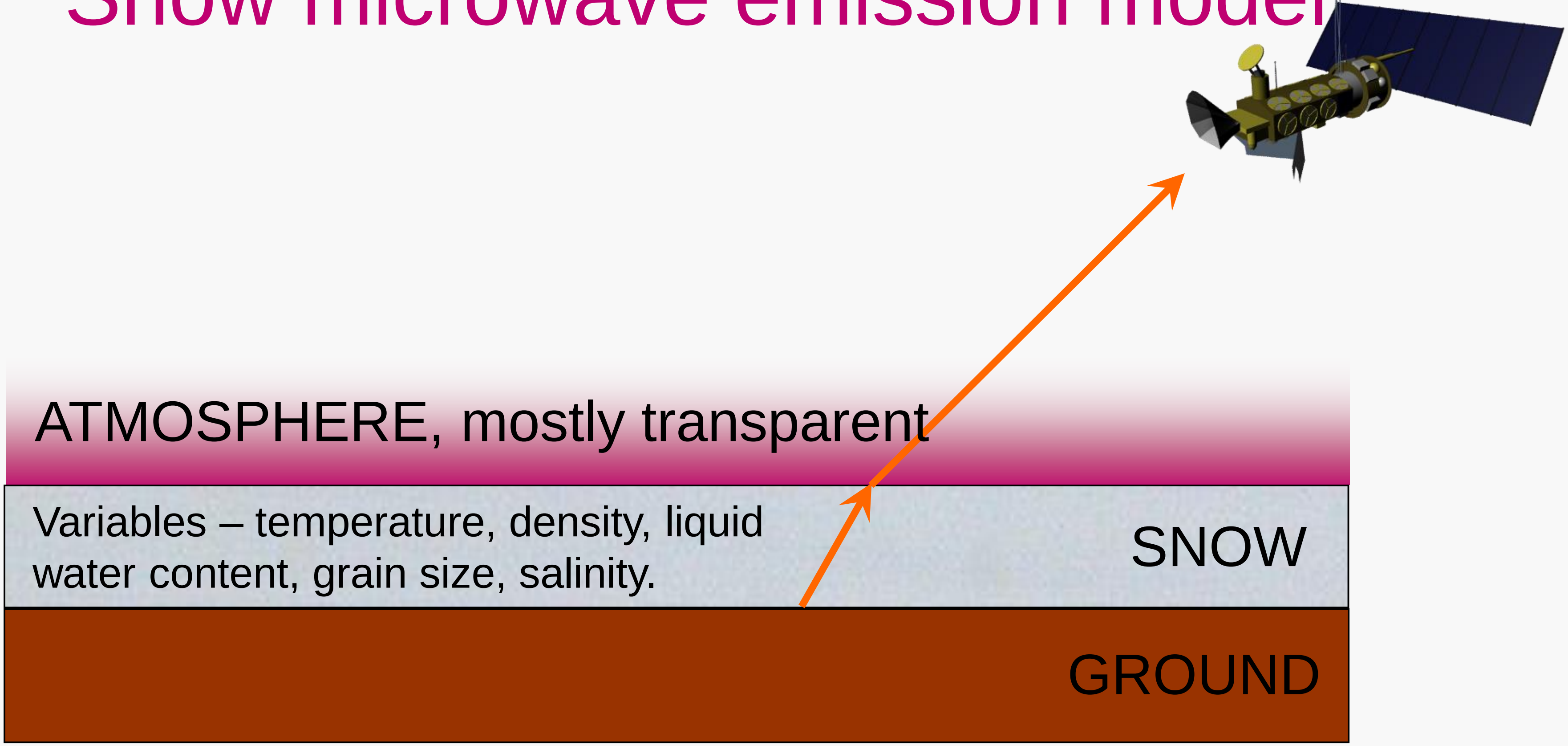
Electron and Confocal Microscopy Laboratory, Agricultural Research Service, U. S. Department of Agriculture.

Growth is driven by density, temperature and temperature gradient: snow models

Snow mass data assimilation system



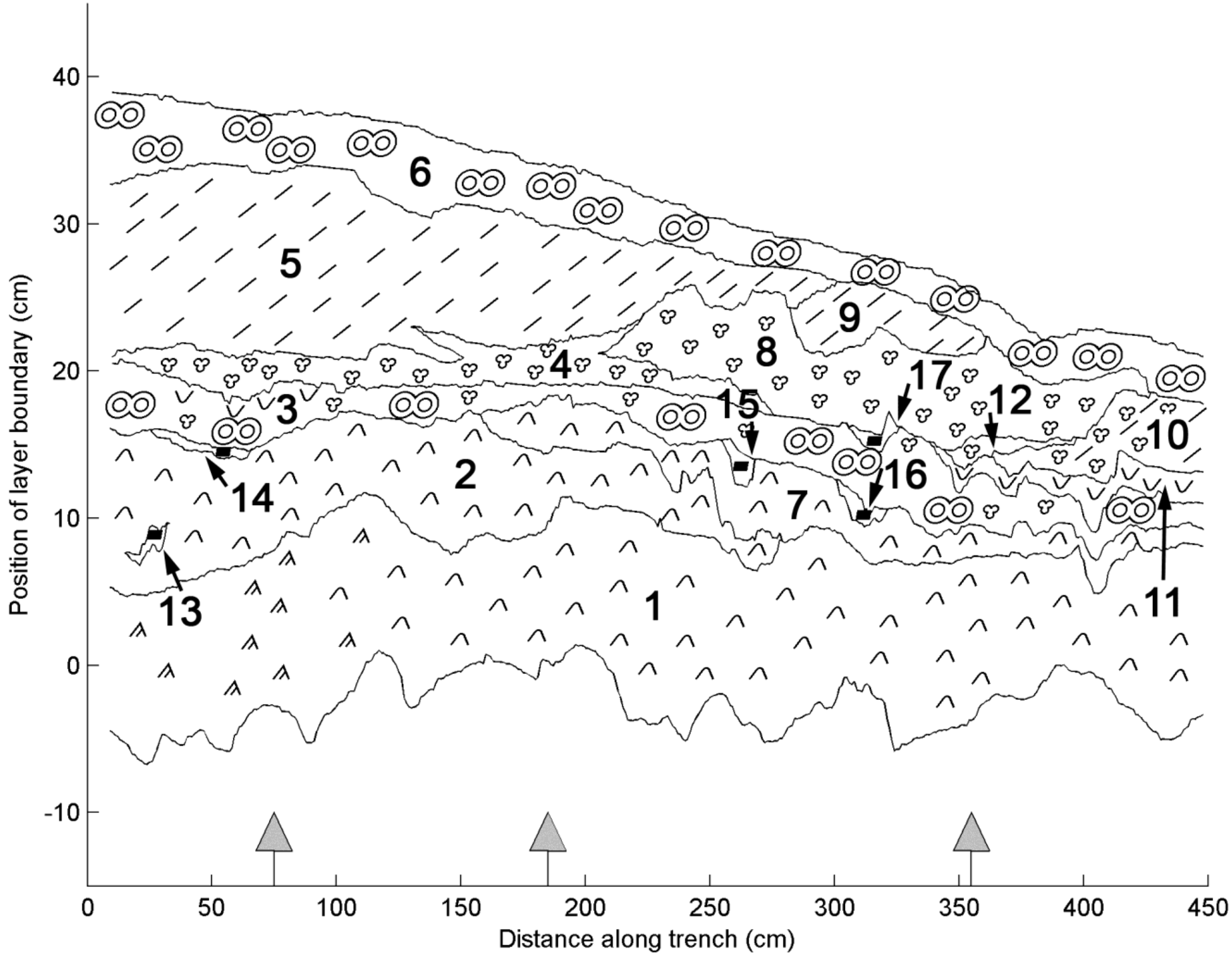
Snow microwave emission model



Includes multiple scattering within the snow layer, scattering and reflectivity via Fresnel equations

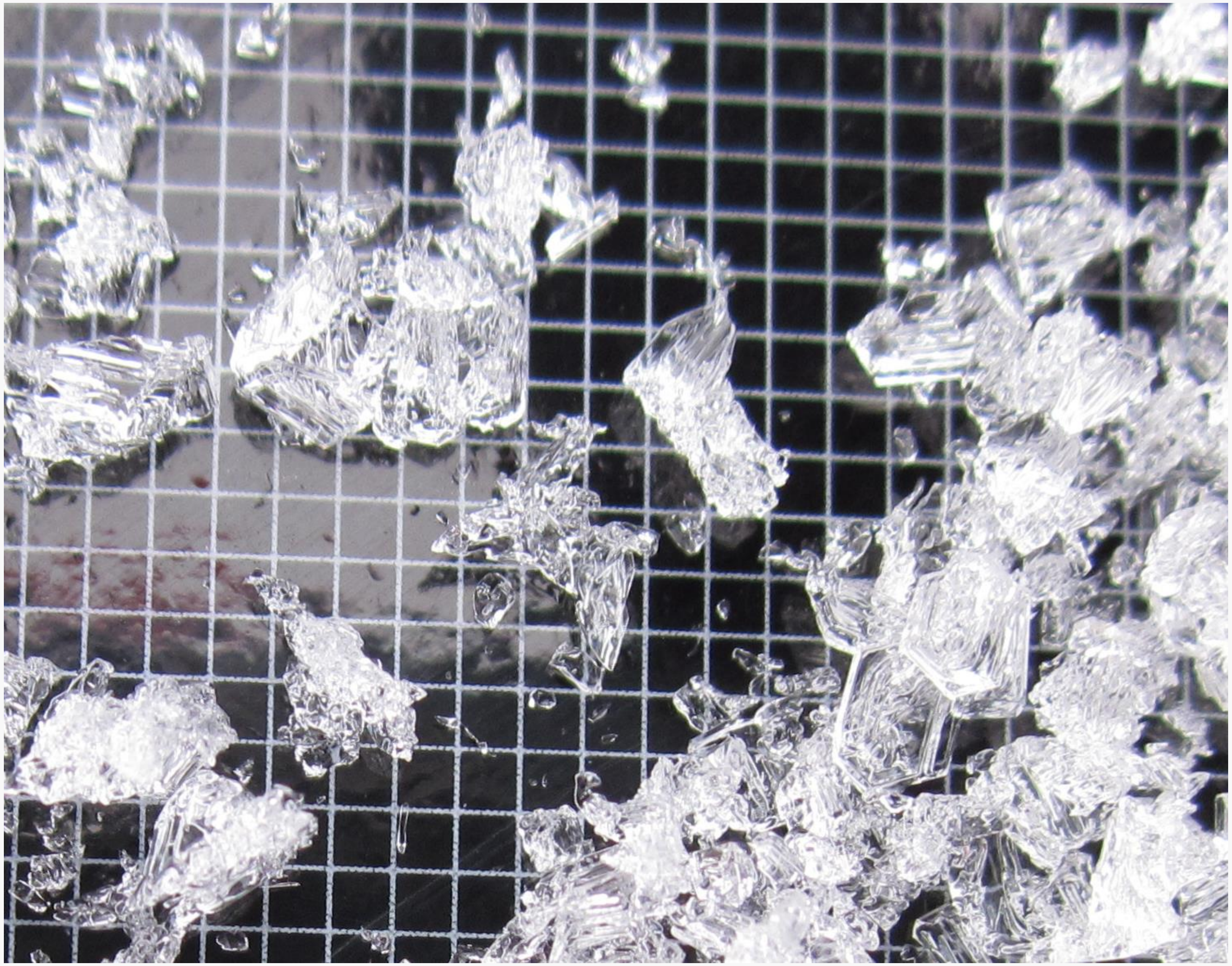
$$T_B\left(d^-,\theta\right) = T_B\left(0^+,\theta\right) e^{-(k_e - q k_s)\sec\theta\, d} + \frac{k_a T_s}{k_e - q k_s}\left(1 - e^{-(k_e - q k_s)\sec\theta\, d}\right)$$

Accuracy of emission models



Bias: 36-68K

A note on snow microstructure



D_{max}
vs D_{opt}
vs D_{eff}

A range of length scales!

micro snow

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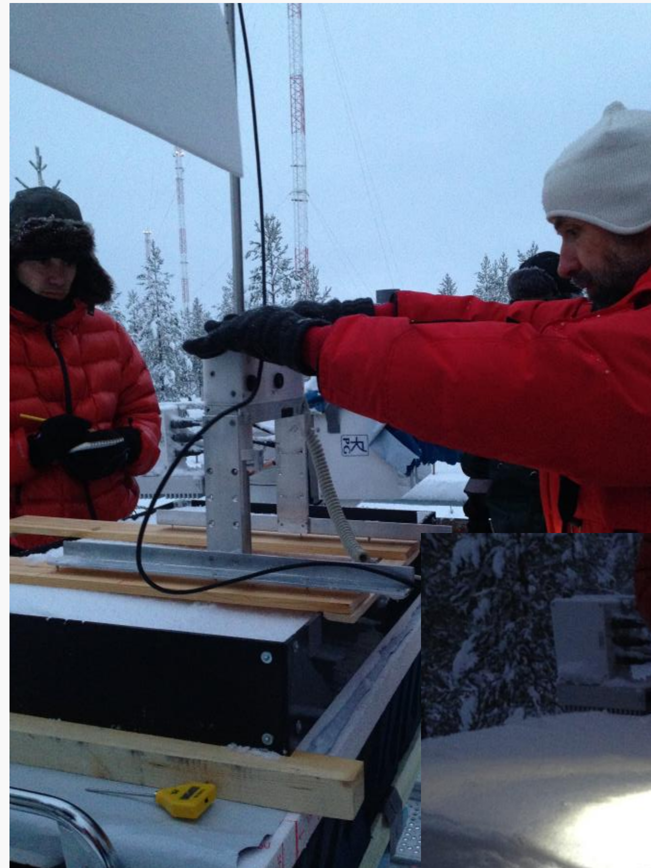
ASMEx



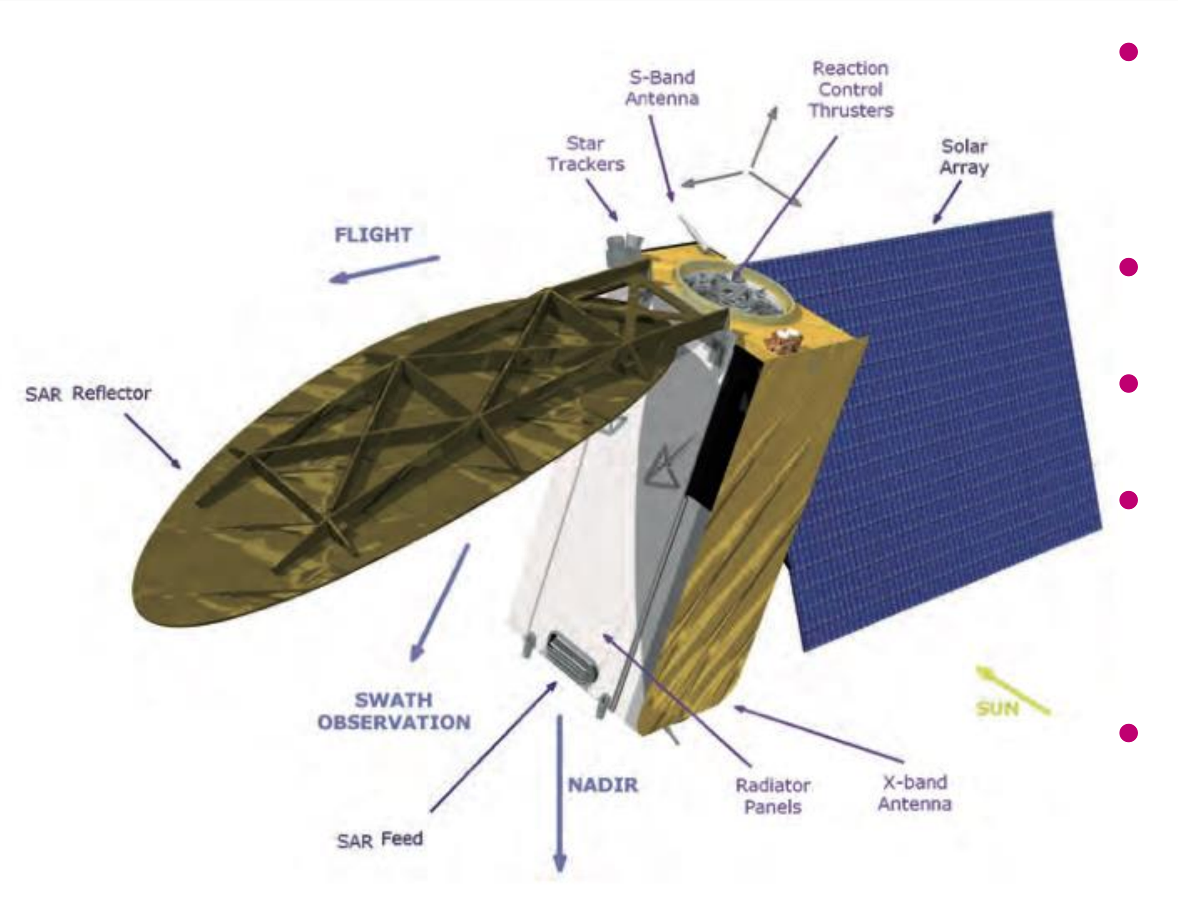
More data needed…

Summary

- Snowpack information is valuable
- Sensors have different benefits and assumptions
- Other information is required to give snow mass estimates (stratigraphy, density, grain size….)
- Snowpack evolution models can give snow parameters
- Microwave emission models need further development
- Know which direction to go in but….

Without a snow mission there will be minimal funding for algorithm and model development

The ~~future~~ past….CoReH20?



- Dual-band SAR (9.65 / 17.25GHz)
- 6am / pm overpass
- Revisit: 3 / 15 days
- Resolution:
  few 100m
- Launch in 2019?

What do we want?

Mission Requirements

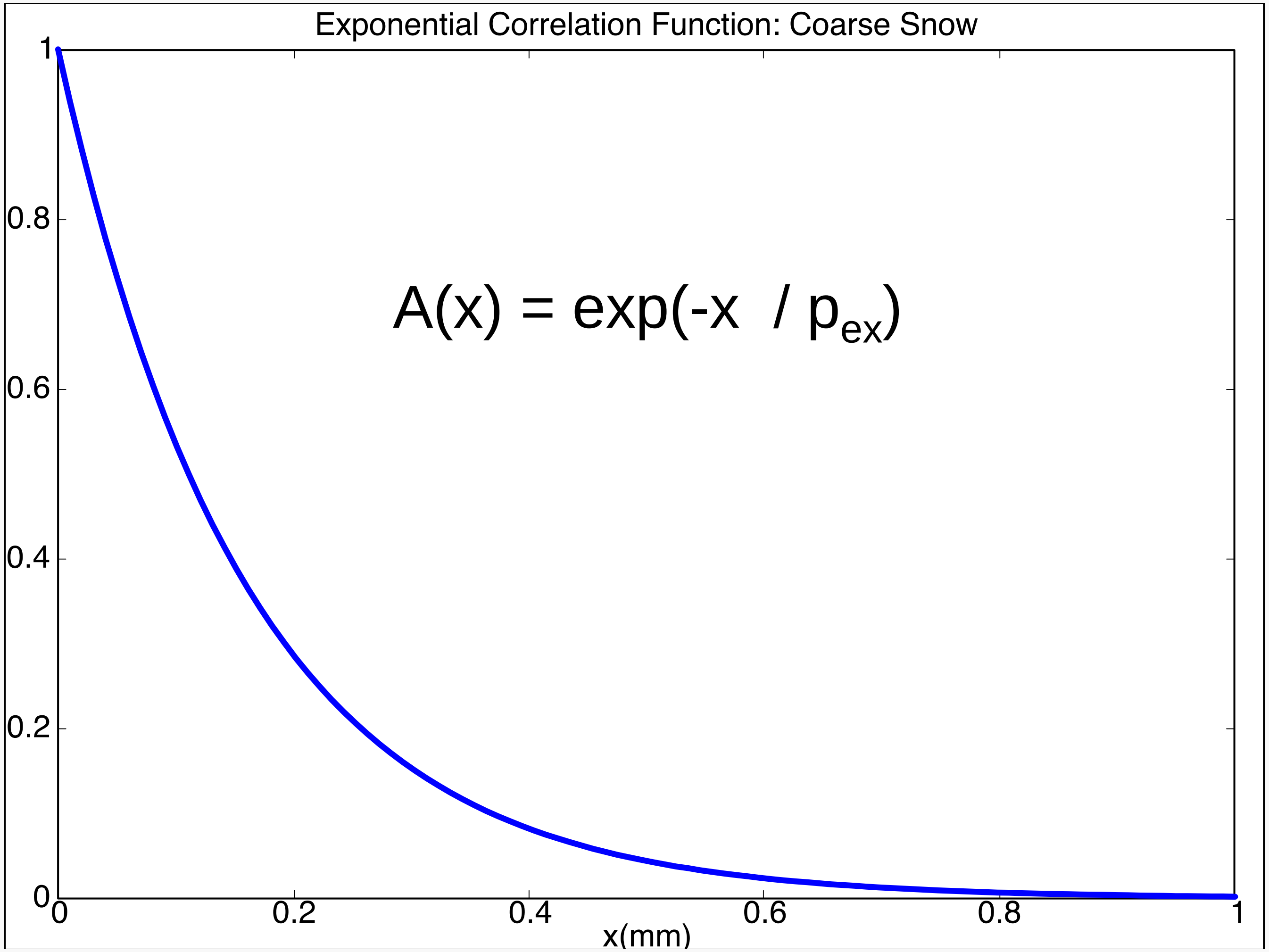
- What depth of snow is important and accuracy (c.f. 4% soil moisture)
- Spatial resolution
- Repeat cycle
- Melt state
- Regional or global

Your opportunity – planning has started for next ESA / NASA mission concepts

Email me: m.j.sandells@reading.ac.uk

Airborne Snow Observatory

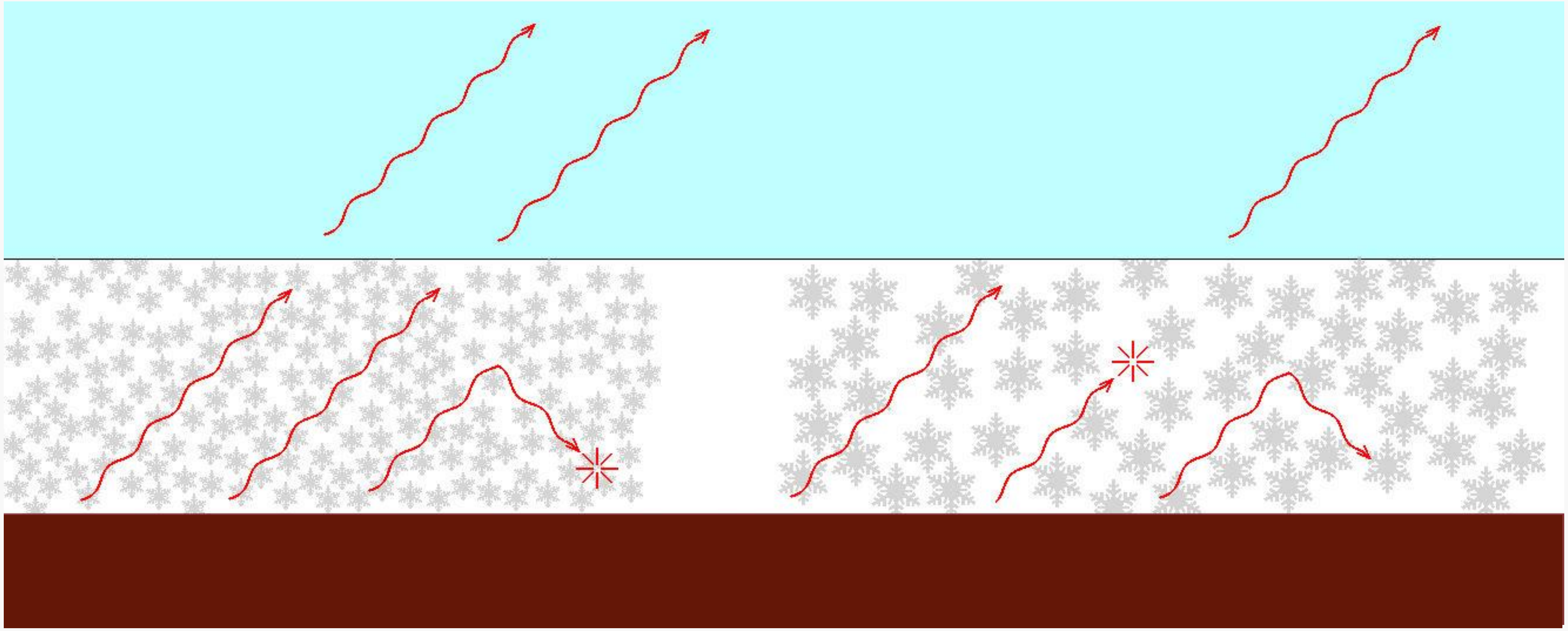
Correlation function



Get rid of empirical corrections!

Autocorrelation function may be a different shape

Absorption and Scattering Within Snow



- Sensitive to the snow grain size (and density)
- Scattering mostly in the forward direction (96%)
- Wet snow highly absorptive, near blackbody

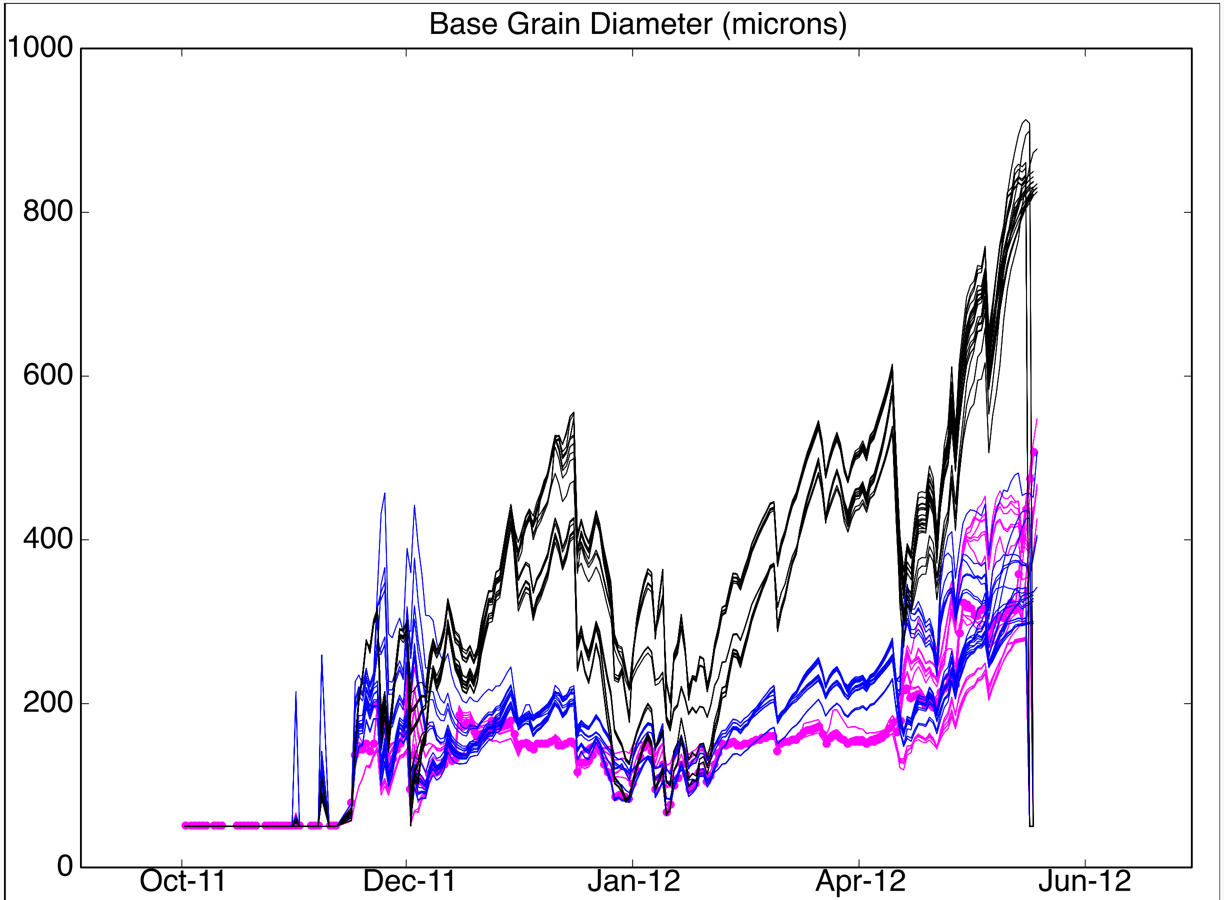
Capabilities

- Evaluate against time series of microstructure and temperature profiles, and temporal TB
- Use other microwave models, and examine microstructure metric relationships
- Can we go further?

JIM

- Contains all major snow parameterisations
- 1701 Unique model combinations
- 63 model subset:
  - Compaction parameterisation (3)
  - Thermal conductivity (3)
  - Fresh snow density (3)
  - Snow hydrology (3)
- This has now been coupled with 3 of 5 microstructure evolution functions: MOSES, SNICAR, SNTHERM

JIM subset: Sodankylä



$$\hat{S}(t) = \hat{S}_0 \left(\frac{\tau}{t+\tau} \right)^{(1/\kappa)}$$

MOSES

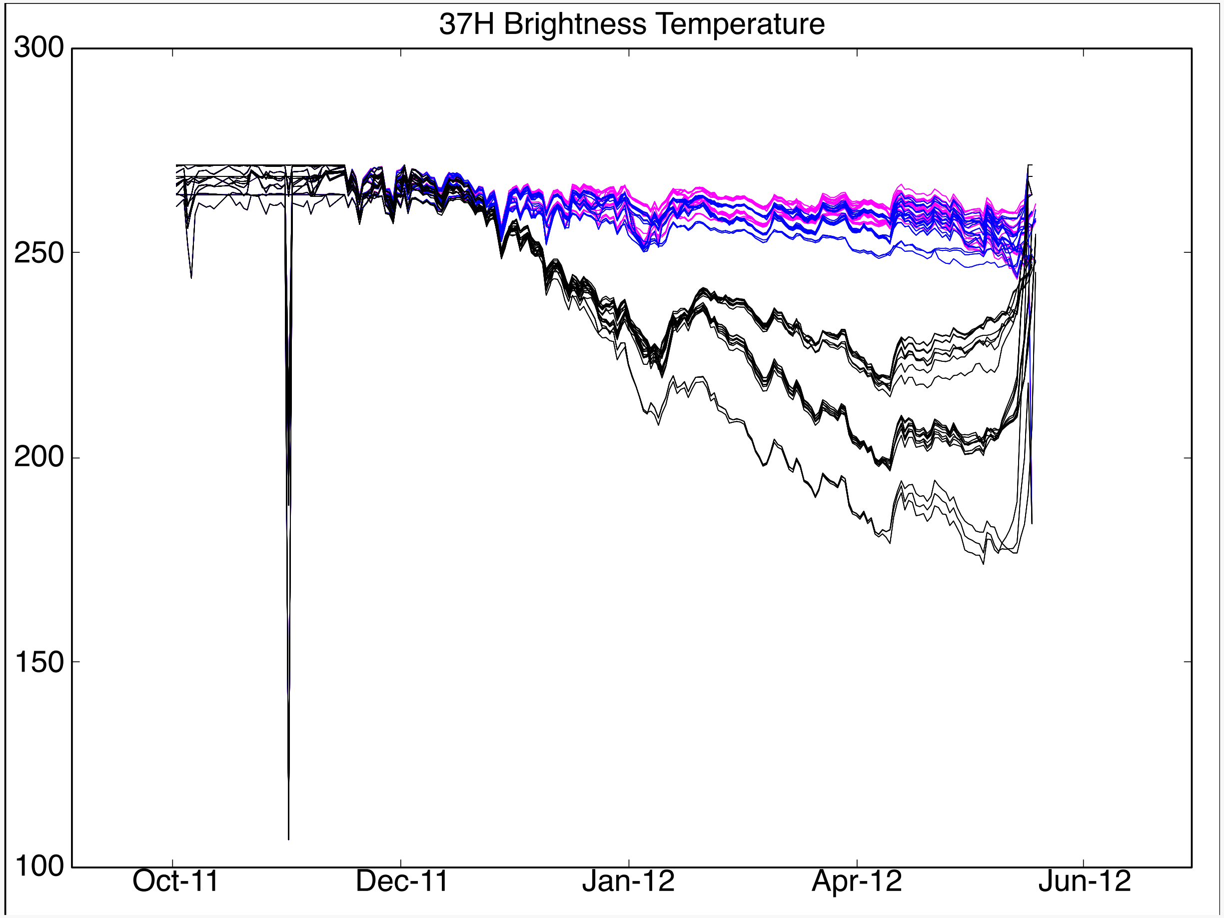
SNICAR

SNTHERM

$$r(t+\delta t) = \left[r(t)^2 + \frac{G_r}{\pi} \delta t \right]^{1/2} - [r(t) - r_0] \frac{S_f \delta t}{d_0}$$

$$\frac{\partial d}{\partial t} = \frac{4.6 \times 10^{-11}}{d} \left(\frac{T}{273.15} \right)^6 C_{kT} \left| \frac{\partial T}{\partial z} \right|$$

JIM subset: DMRTML

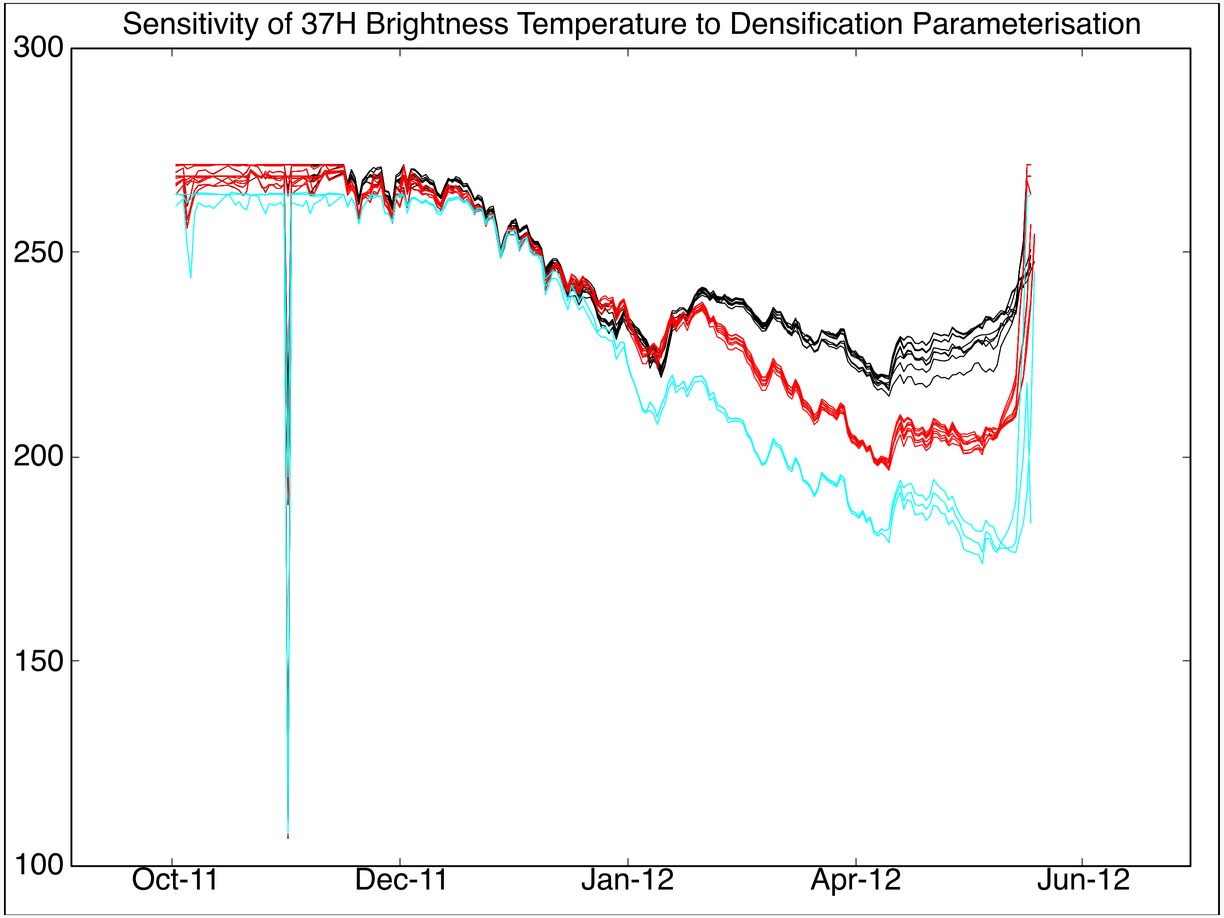


MOSES

SNICAR

SNTHERM

JIM subset: DMRTML-SNTHERM



Physical
Empirical
None