Microwave Remote Sensing Group

Microwave Remote Sensing of snow cover

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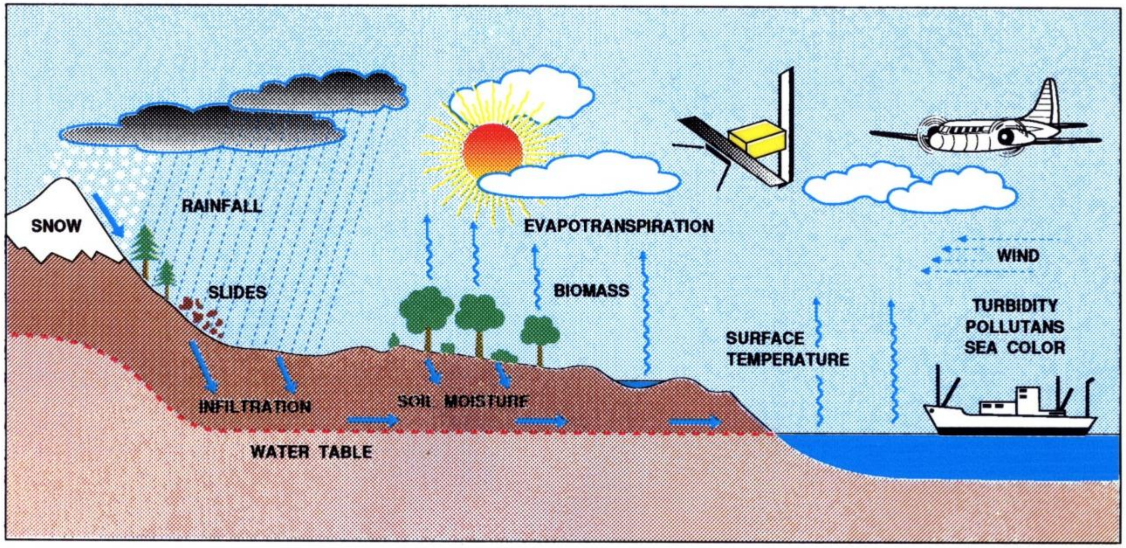
Outline

- Introduction & Motivations
- Characteristics of terrestrial snow
- Active/passive Microwave Remote Sensing: experimental results
- Model sensitivity analysis
- Generation of snow cover (snow depth) maps

The Hydrological cycle

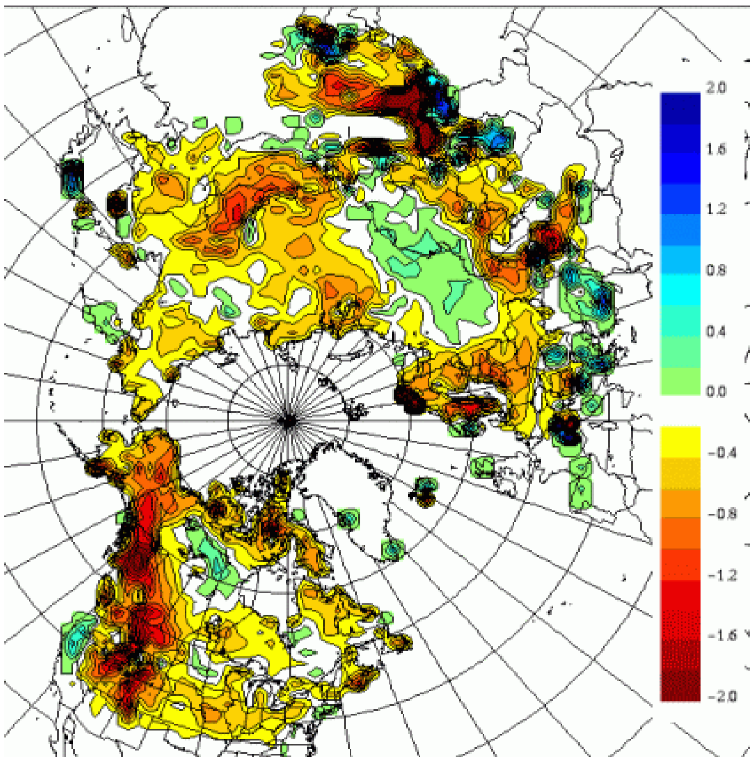


Snow is a major component of the cryosphere. It plays an important role in the global **water cycle** and **climate change.**

It has also a significant impact on some **economical factors**

Snow and climate

Du to its high albedo **Snow reflects 80 to 90% of the incoming sunlight and** helps Earth's energy balance, because it contributes to **cool the planet** (trees, plants, and soil reflect only 10 to 30%).



Snow cover trends serve as key indicators of climate change: ***Observations show a global-scale decline of snow and ice over many years, especially since 1980 and increasing during the past decade,***

Average change (days/yr) in snow cover duration over the period 1972-2000.
(Canadian Cryospheric Information Network)

http://www.socc.ca/cms/en/climateChange.aspx

Economical factors

Benefits

Water reservoirs: Greenland and Antarctica and contain ~70% of the world's freshwater - Glaciers and mountainous icecaps account for about 3%

Hydro-electrical power represents 19% of total world electricity production and is the most important and widely-used renewable source of energy.

Paraguay:	100 %
Norway:	98.81 %
Austria:	59.15 %
Canada:	56.98 %
Switzerland:	53.08 %
Sweden:	39.64 %
Finland:	17.56 %
Italy:	13.52 %
Spain:	11.39 %
France:	10.53 %
United States:	6.54 %
Germany:	3.46 %

Energy Information Administration

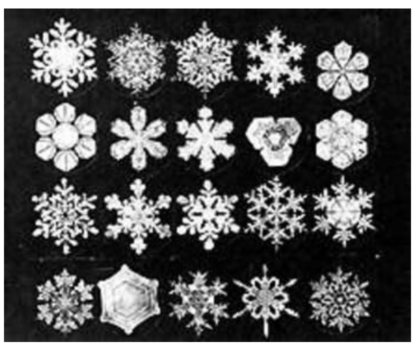
Disasters

Most major floods develop over a period of days after heavy winter or spring snow melting (*snowmelt flood*),

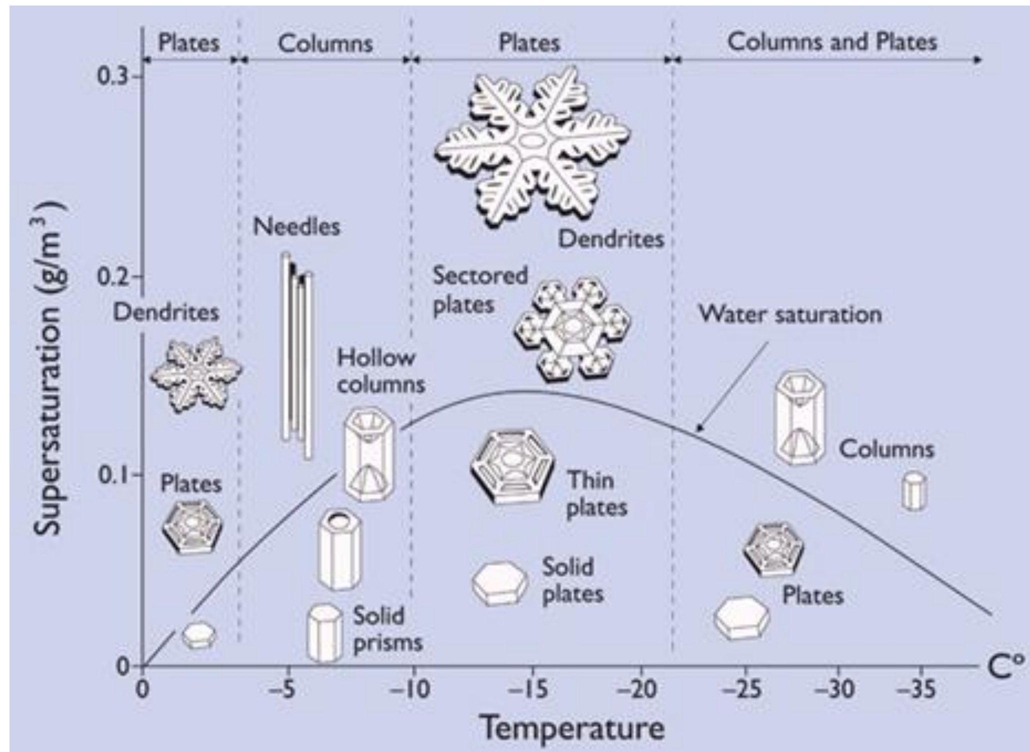
Avalanches: over 150 lives each year worldwide and hundreds more are injured France, Austria, Switzerland, and Italy experience the greatest number of avalanches and loss of life annually

http://geography.about.com/

Characteristics of falling snow



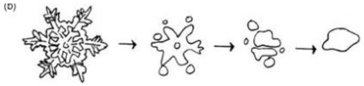
blogsnowflake_bentley.jpg
longstreet.typepad.com



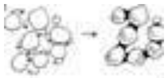
1.morphologydiagram.jpg
2.its.caltech.edu

Structure e metamorphism of terrestrial snow

DRY SNOW is a mixture of ice particles and air voids
After a snowfall, the shapes of the ice particles in dry snow are modified by metamorphism. Thermodinamically, the ice crystals seek equilibrium, for which the ratio of surface area to volume is minimum.

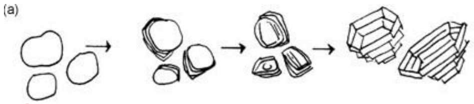


Destructive metamorphism



Sintering

The sharp pointed ends of crystals sublimate, and the resulting water vapour is deposited into the concave areas, changing the crystals into increasingly rounded forms. At the contact points between grains, water vapour is deposited creating strong bonds (sintering)



Constructive metamorphism

For large temperature gradients (> 1°C/10cm), water vapour is produced by sublimation at warm grain surfaces, and is deposited at colder surfaces. Rounded grains are transformed in facet like crystals

Parameters of terrestrial snow of practical interest

Depth

Density

Snow Water Equivalent (SWE)

Grain shape and size

Wetness

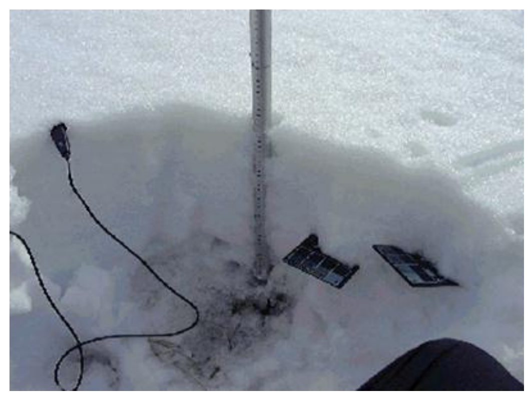
Dielectric constant

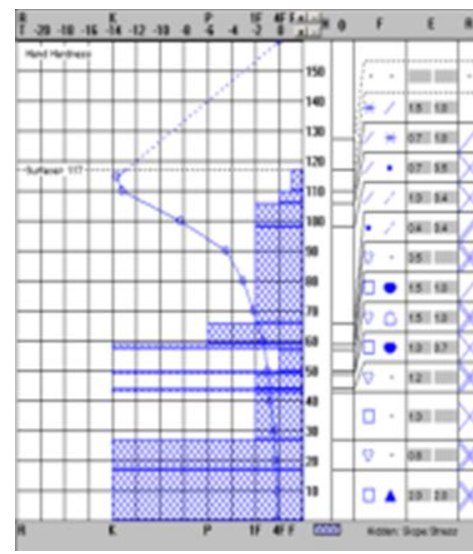
Surface roughness

Hardness

Layering

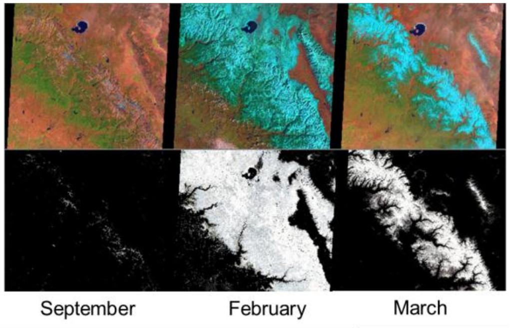
Ground measurements





Optical remote sensing of snowcover

❖Optical and near-infrared sensors can monitor the seasonal variations of snow cover in alpine areas in cloud free conditions.



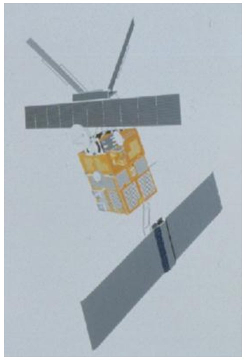
❖Only microwave sensors are able to acquire data independently of day light and weather conditions and to estimate snow water equivalent.

Microwave Remote Sensing of snow

Multifrequency Radiometers

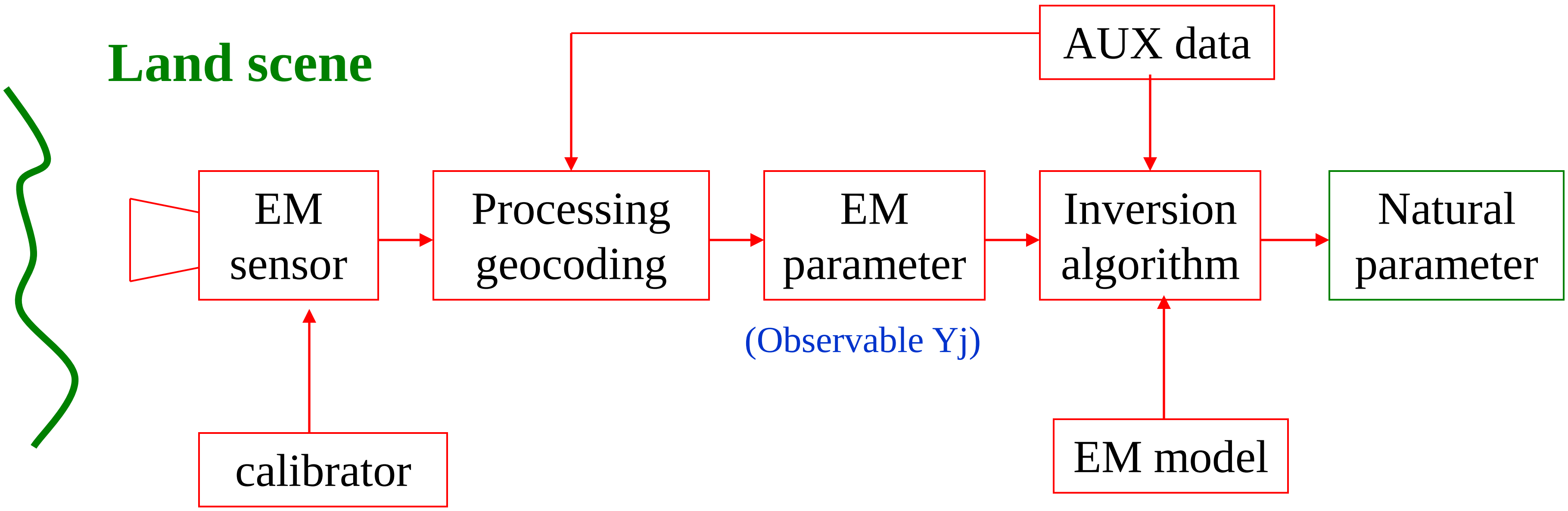
Multifrequency 7 – 90 GHz
Global observation
Low ground resolution (40 – 3 Km)

Synthetic Aperture Radar (SAR)



Single Frequency L, C, X bands
High ground resolution (up to 1 m)
Global to regional observations

Scheme of a MW RS system



Problem: To retrieve biophysical and geometrical characteristics of the observed medium from the measured EM parameter

Electromagnetic characteristics of snow

DRY SNOW

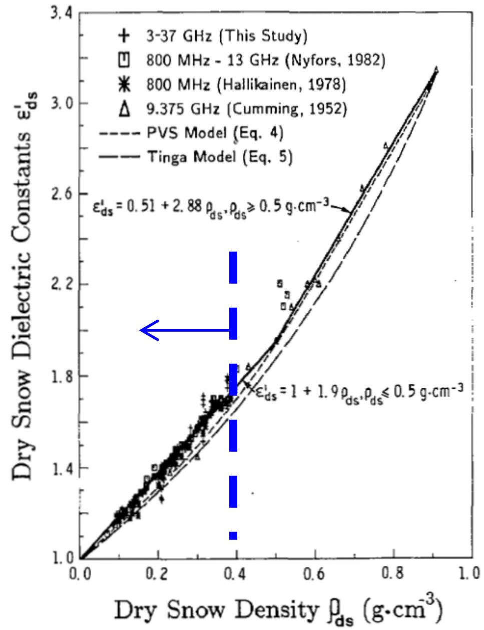
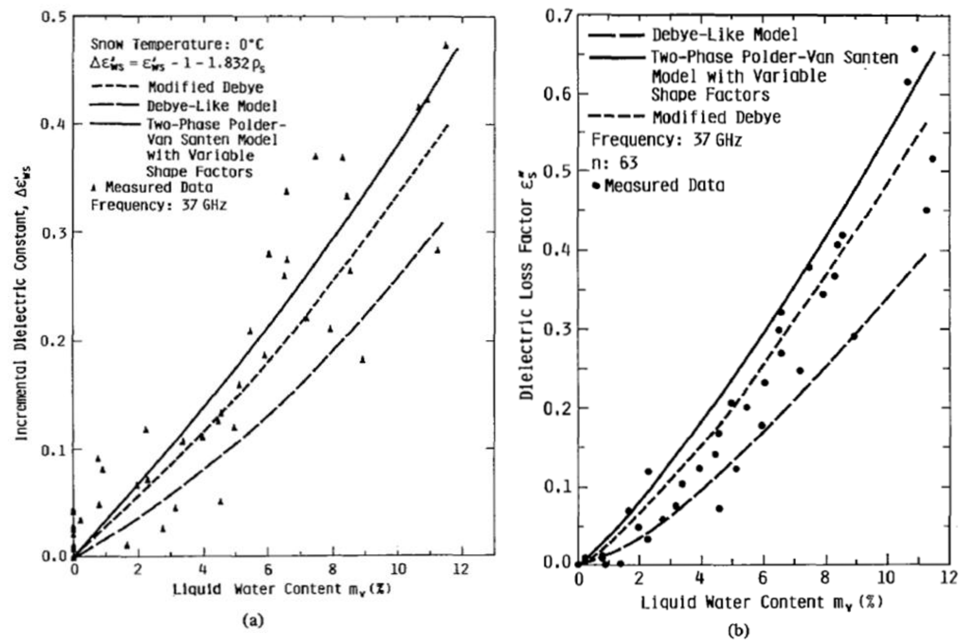
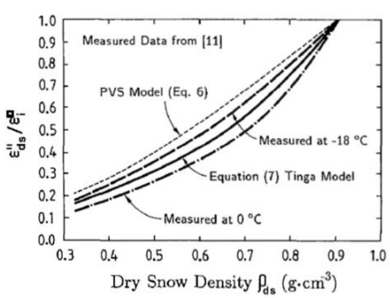


Fig. 4. Variation of ϵ'_{ds} with ρ_{ds}.

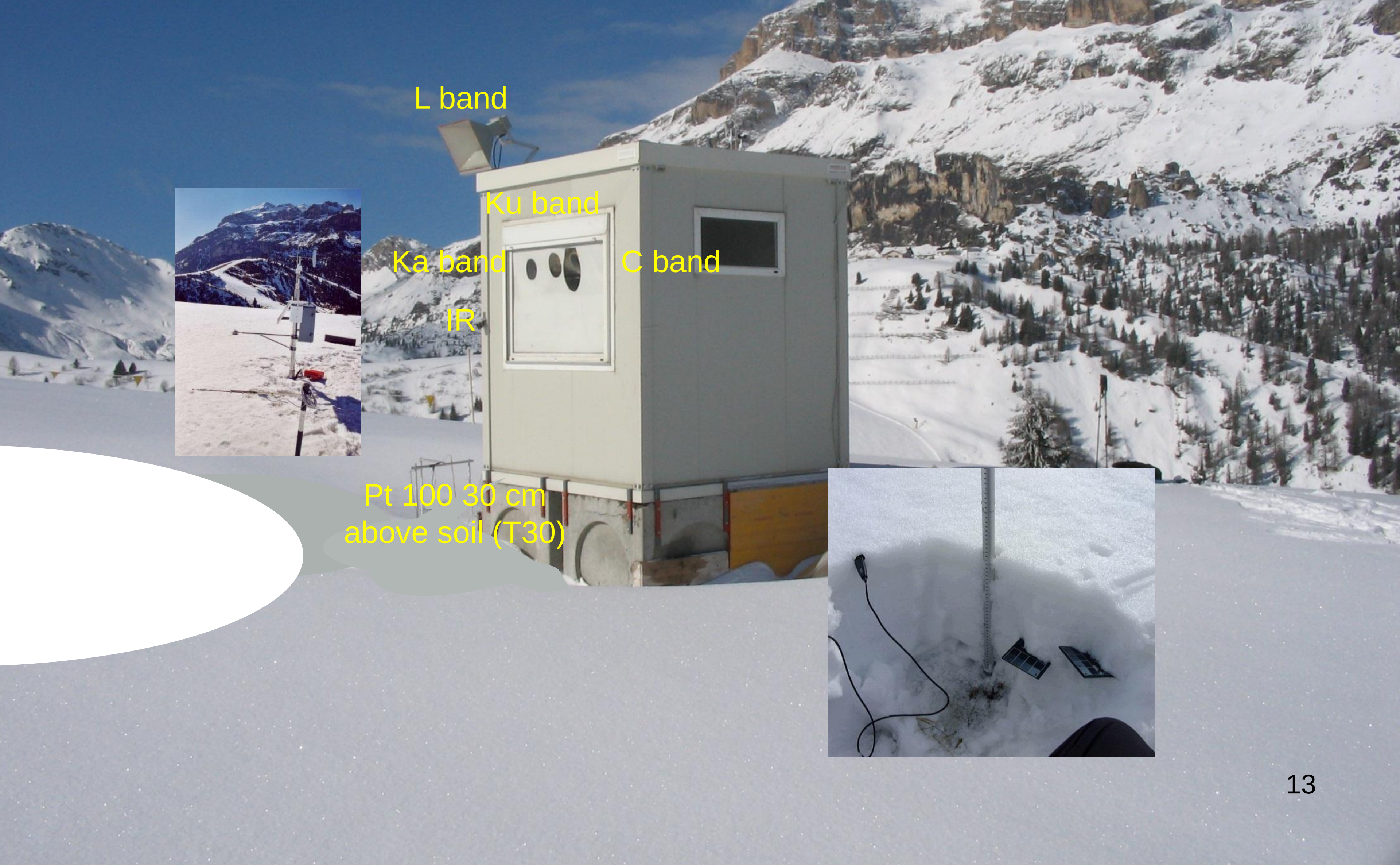
WET SNOW



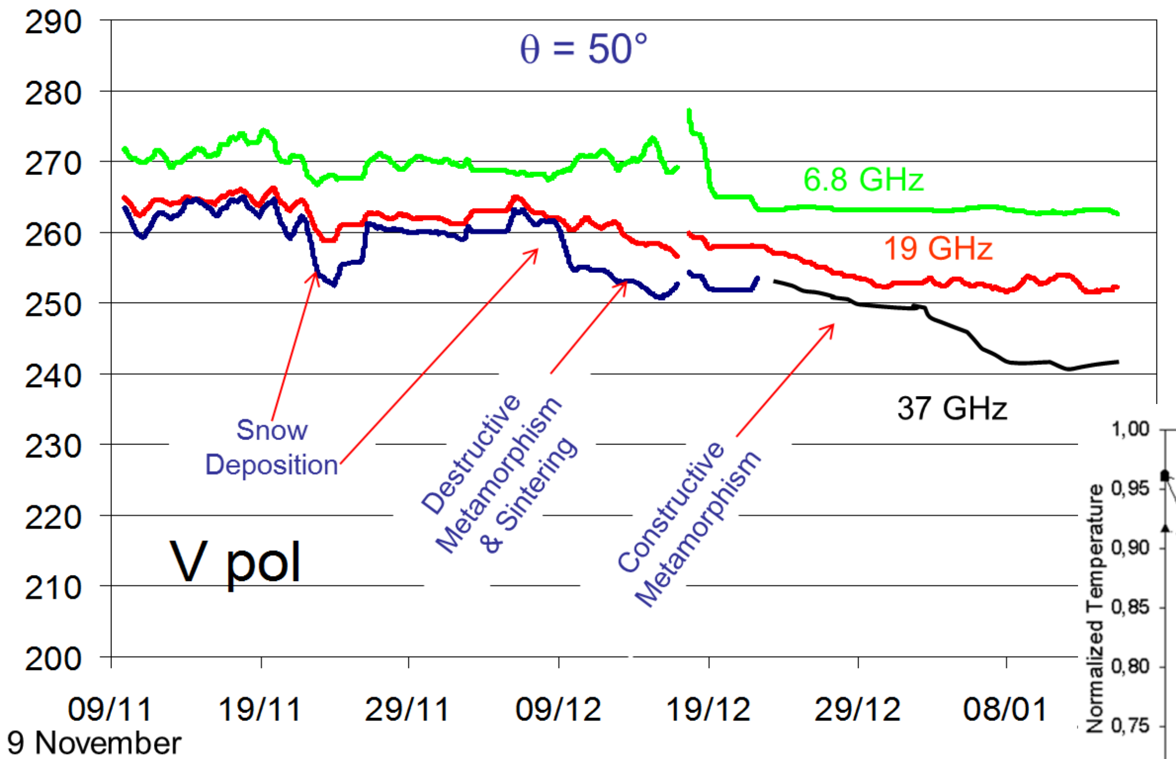


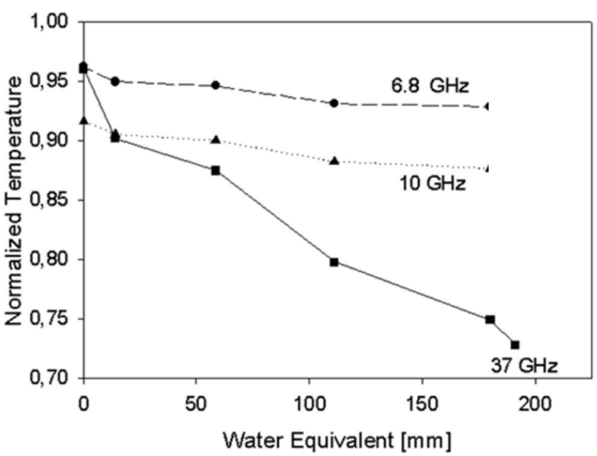
Hallikainen et. al. IEEE Trans AP 1986

Microwave radiometry: experiments



MW radiometry: Experimental Results: snow deposition

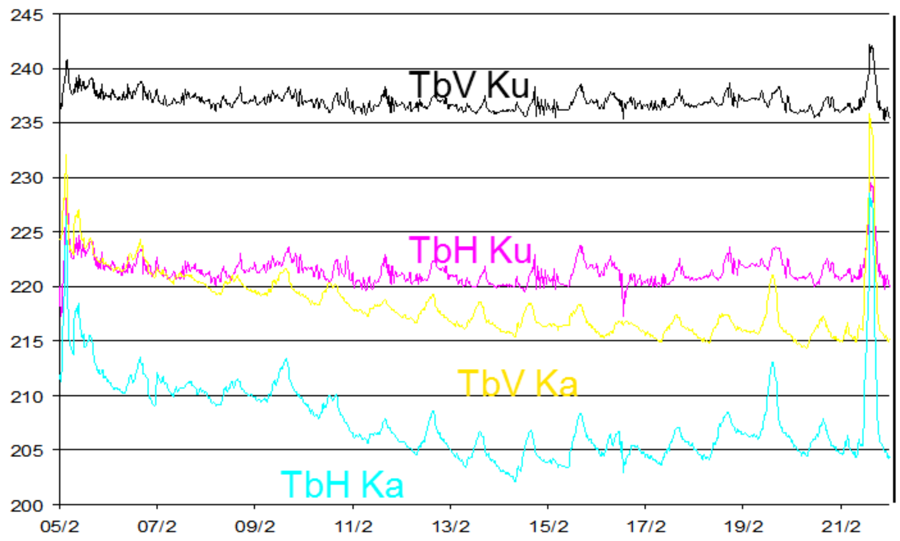




Brogioni et al. *IEEE TGRS*, 2009.

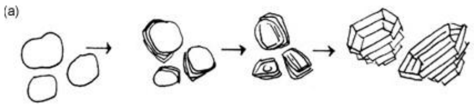
MW radiometry: Experimental Results: constructive methamorphosis

February 6

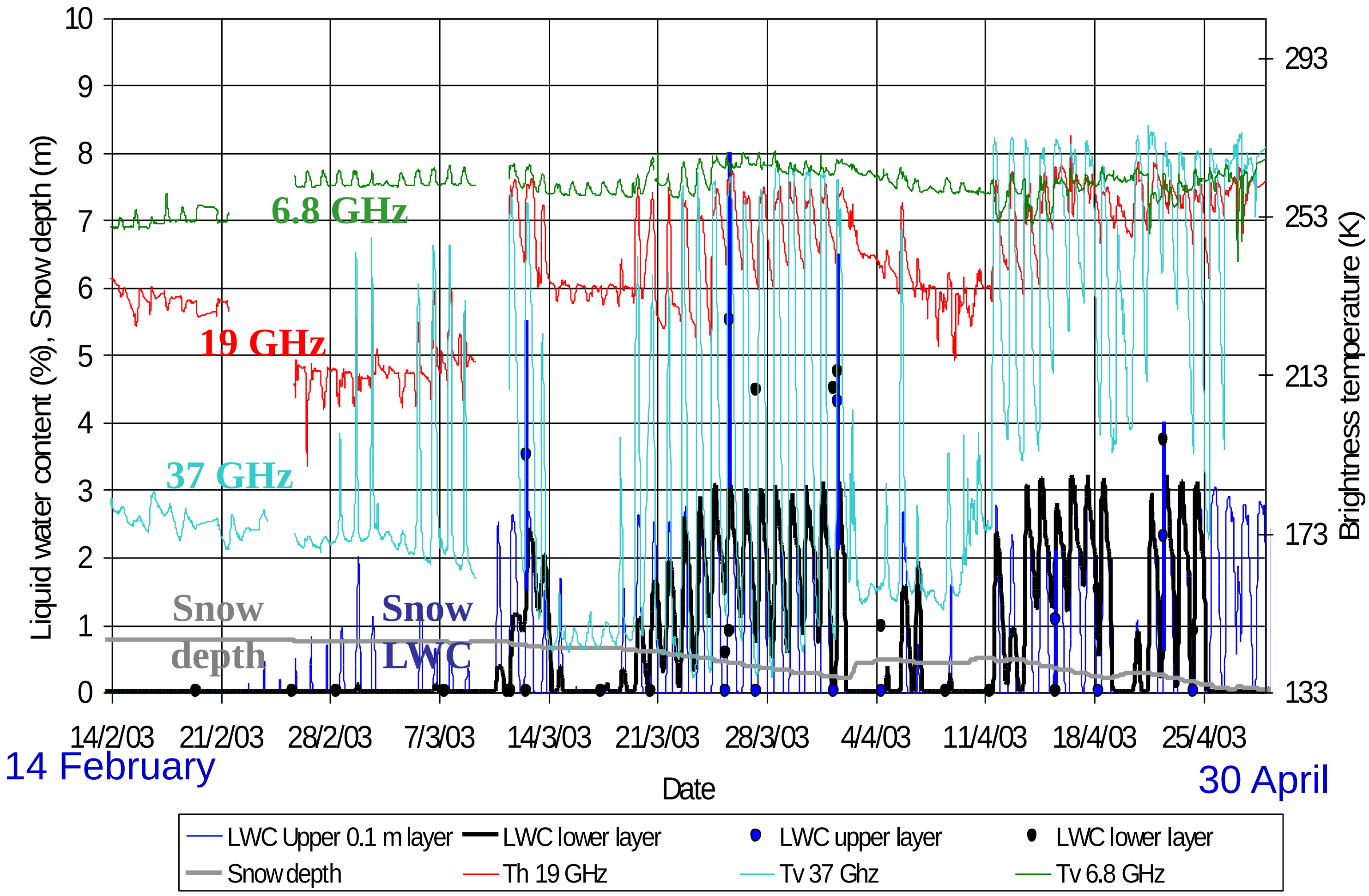


February 20

Increase of crystal dimensions

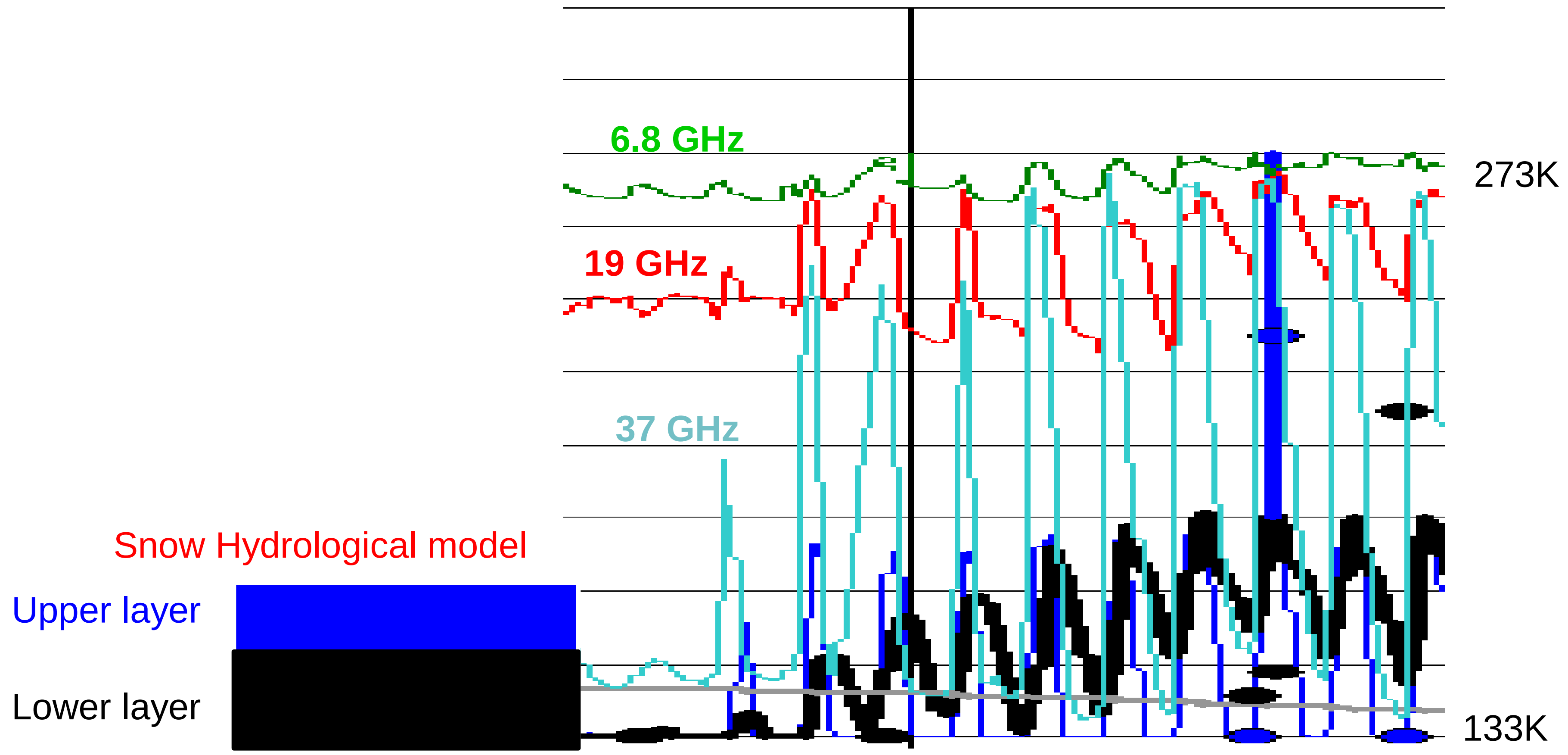


Microwave Radiometry: Melting refreezing cycles



Macelloni et al. *IEEE TGRS*, 2005.

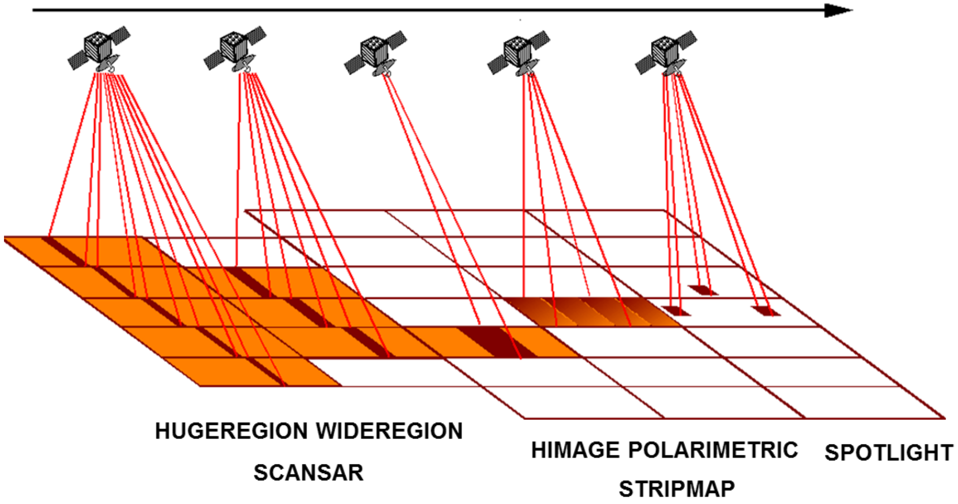
Melting refreezing cycles



SAR Observation: The ASI/Cosmo-Skymed mission

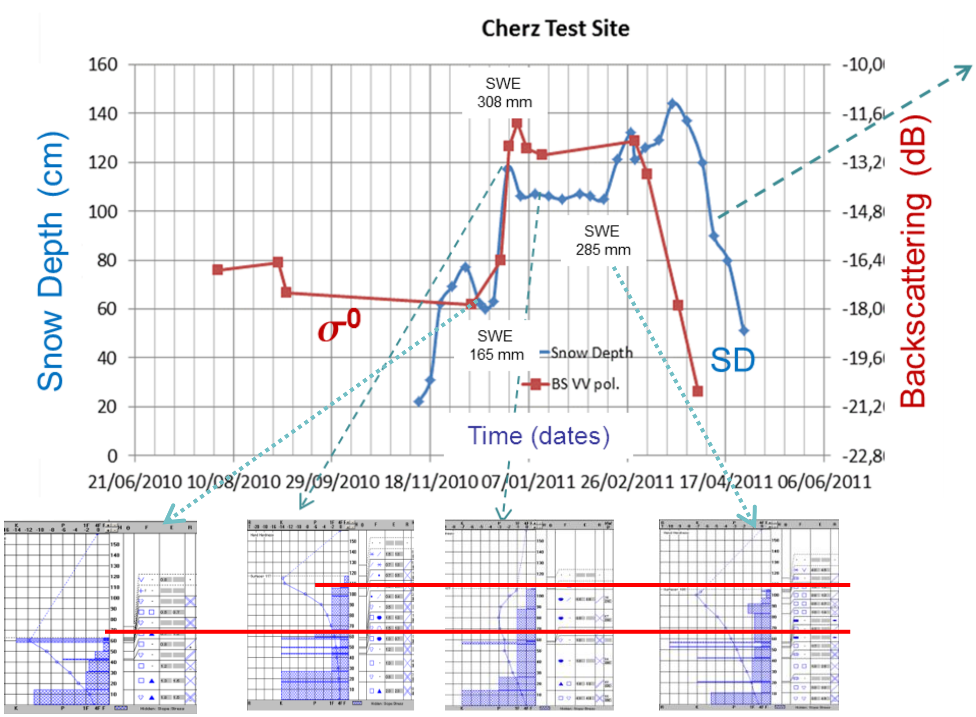
4 medium-size satellites, equipped with an X-band SAR HH, VV, HV, VH pol
sun-synchronous orbit at ~620km height

Full constellation
revisit time : 12 h

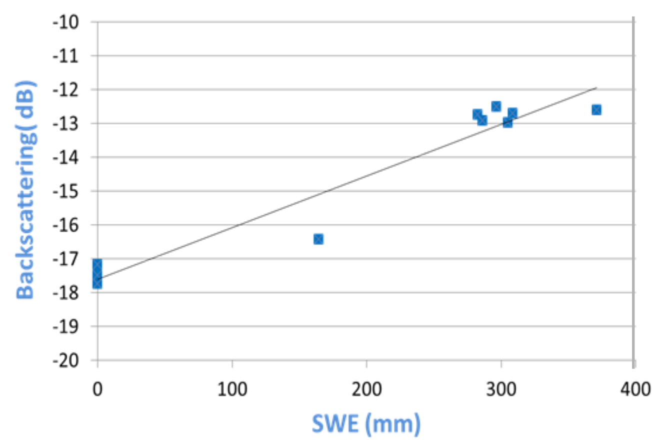


- 1 Spotlight mode, for metric resolutions over small images
- 2 Stripmap modes, for metric resolutions over tenth of km images; one mode is polarimetric with images acquired in two polarizations
- 2 ScanSAR for medium to coarse (100 m) resolution over large swath

Sensitivity of X-band backscattering to SWE:
experimental data on natural land covers(Cosmo Skymed)



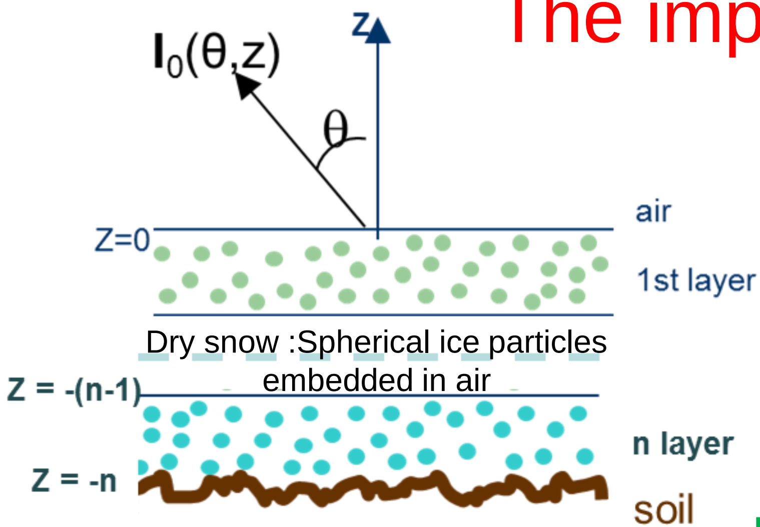
Wet snow

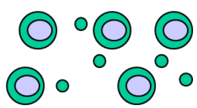


Pampaloni et. al. Proc. IGARSS 2011

Model analysis for emission and backscattering

The implemented Model

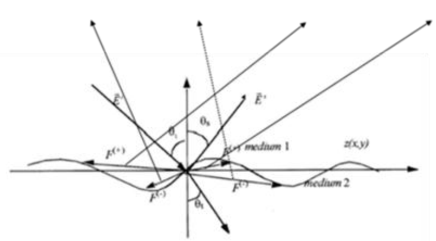




Wet snow

Soil
Co-pol: AIEM (*Chen et al. 2003)*
X-pol: Oh et al. model

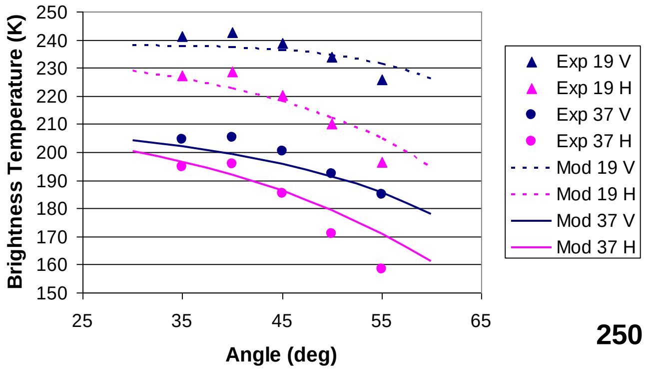
$$\sigma^o_{qp}(S)=\sigma^k_{qp}(S)+\sigma^{kc}_{qp}(S)+\sigma^c_{qp}(S)$$

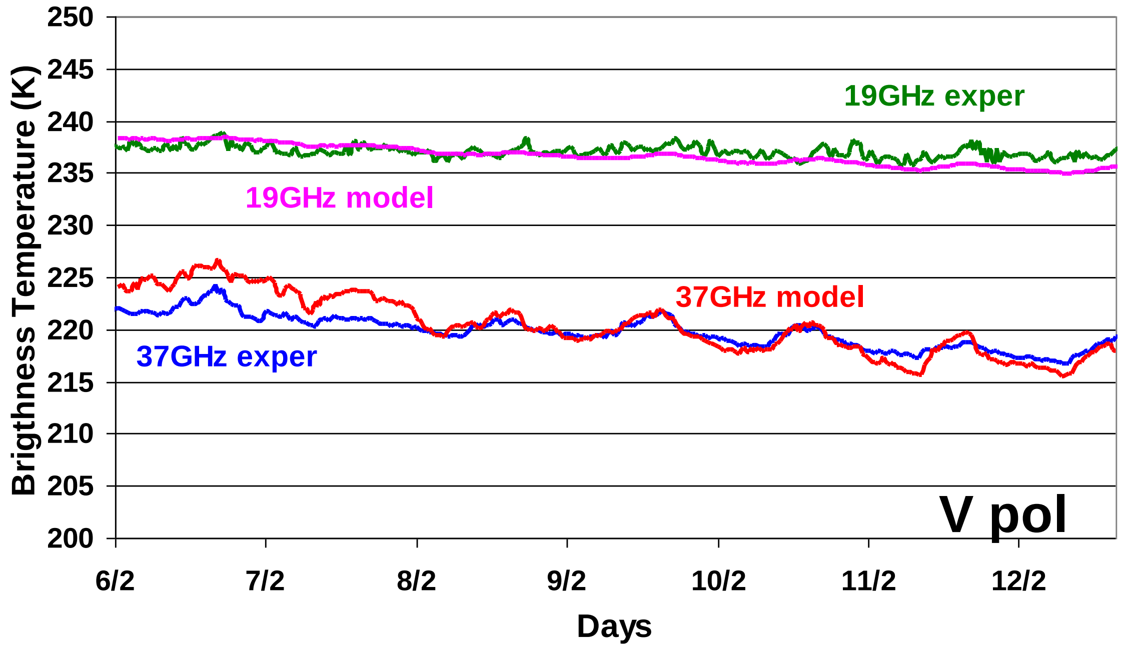


Snow: DMRT–QCA (Dense Medium Radiative Transfer Model, Quasi Crystalline Approximation) (*Tsang et al. 2007*)

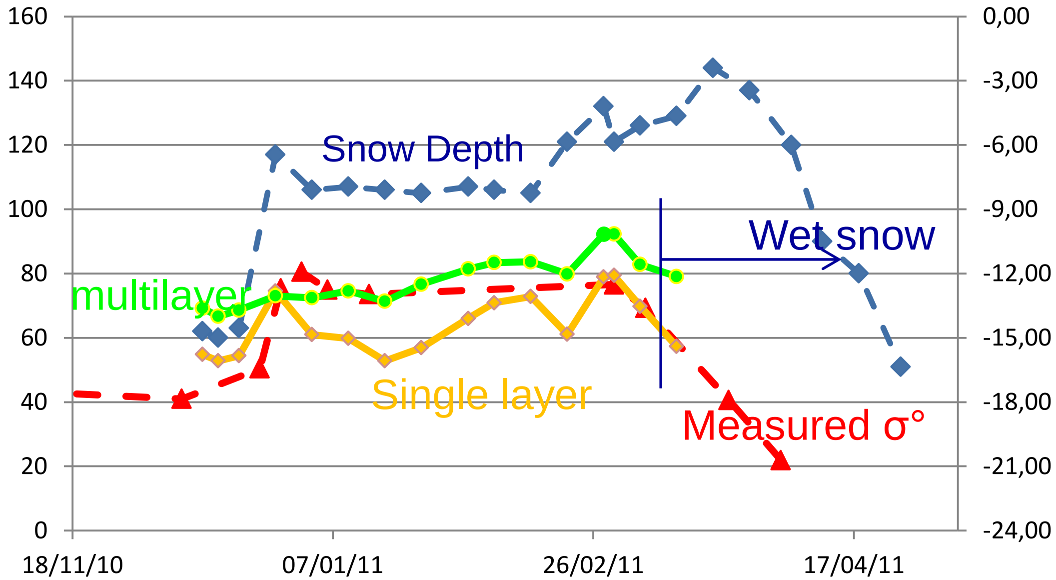
- The DMRT describes the scattering in a medium with particle fractional volume >10% (independent scattering is not valid)
- DMRT equations are derived from Dyson's equation under the QCA approx. and from the Bethe Salpeter eq. under the ladder approx. of correlated scatterers
- The correlation of particle position described by the pair distribution function of the Percus–Yevick approximation
- The physical input parameters are: size, density, and stickiness of particles, number and depth of layers, wetness, and soil permittivity and roughness parameters.
- No particle size distribution is used in this work.

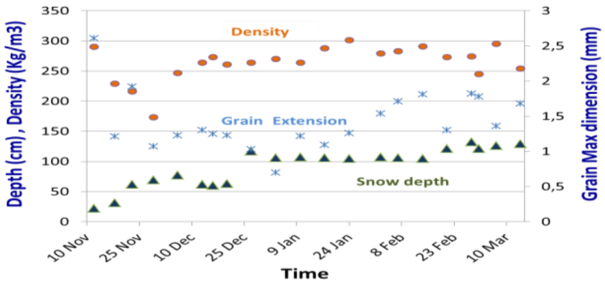
Model validation: Brightness temperature





Model validation backscattering coefficient





Grain **size**

Single layer: averaged and weighted by the layer thickness.

Multi-layer: Scaled as

$$\mathrm{Deff} = 1.5(1 - \exp(-1.5 \cdot \mathrm{Dobs}))$$

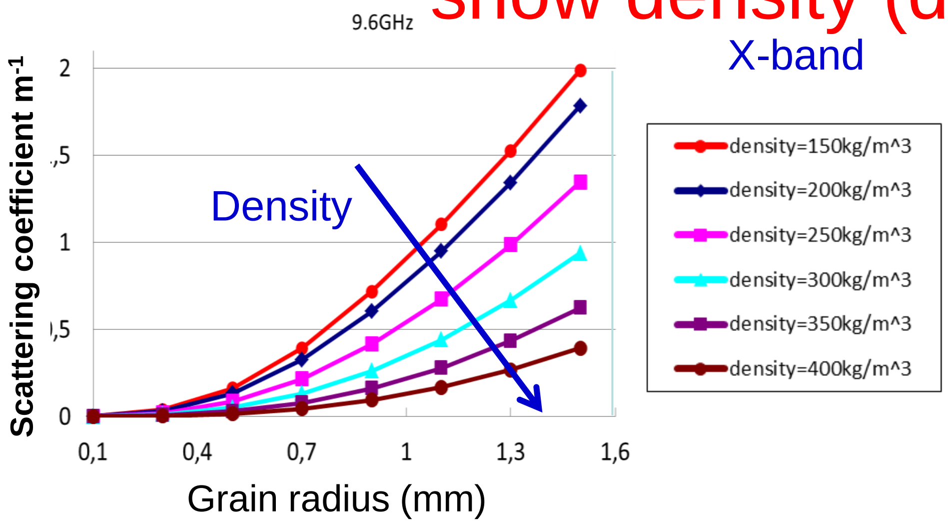
(Kontu and Pulliainen 2010)

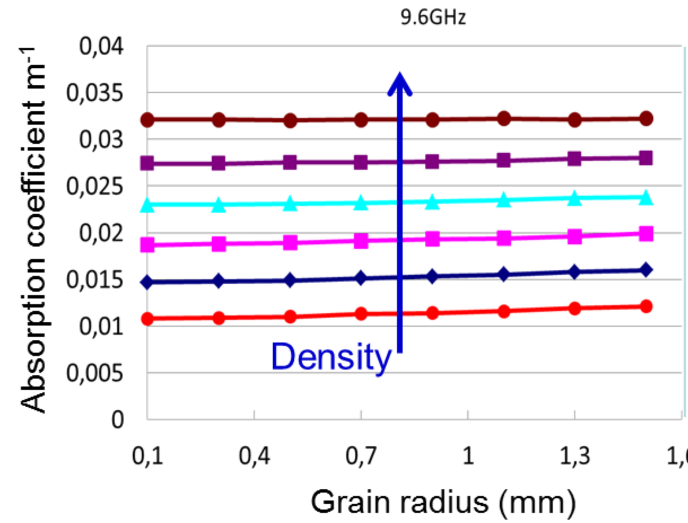
Pampaloni et. al. Proc. IGARSS 2012

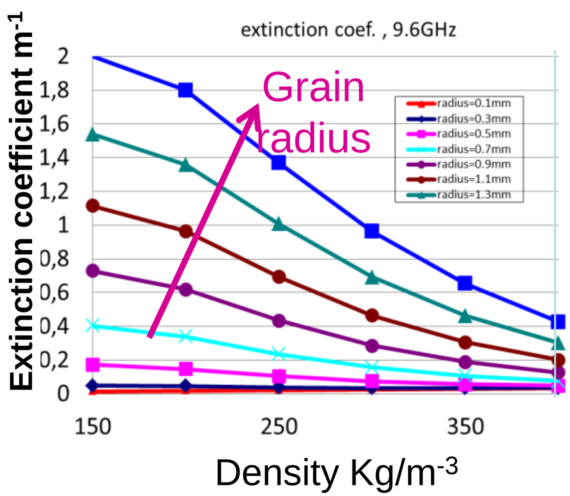
Sensitivity analysis

Sensitivity of em parameters to grain radius and snow density (dry snow)

X-band







Penetration in dry snow is a function of snow density and grain size

5 GHz: 3 - 10 m

10 GHz: 1-2 m

19 GHz: 1 m

37 GHz: 0.5 m

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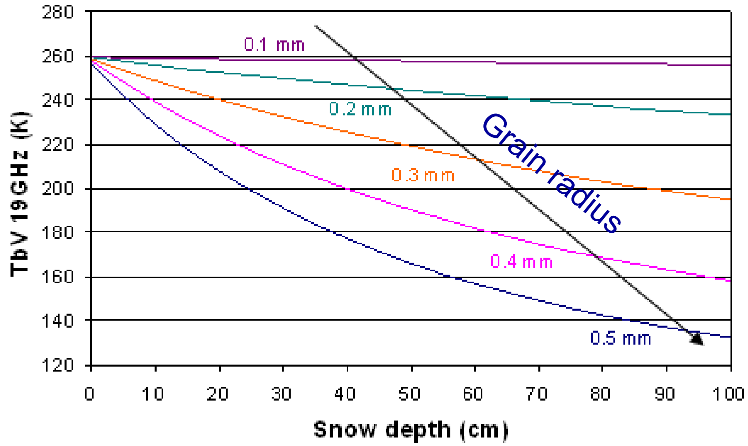
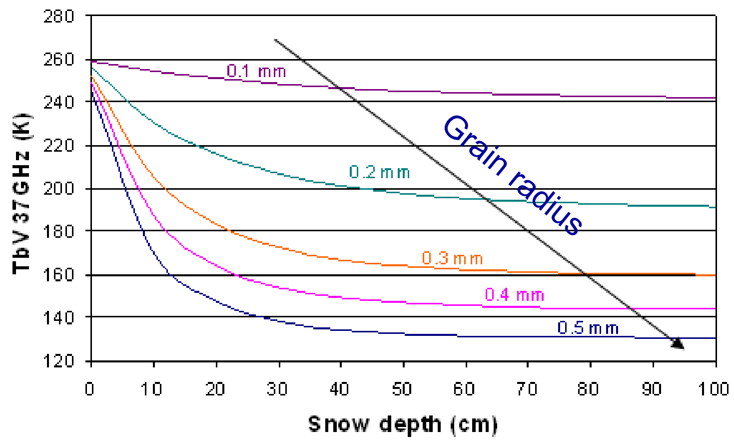
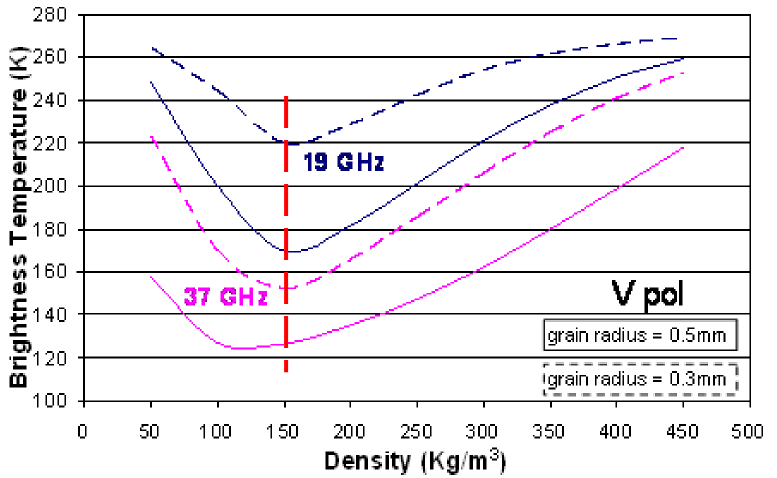
Sensitivity of Brightness Temperature to dry snow parameters

Snow depth



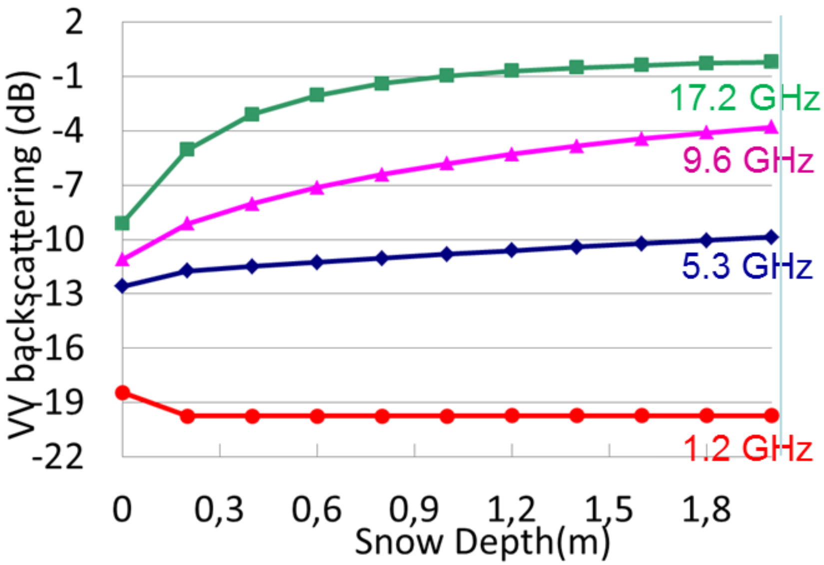


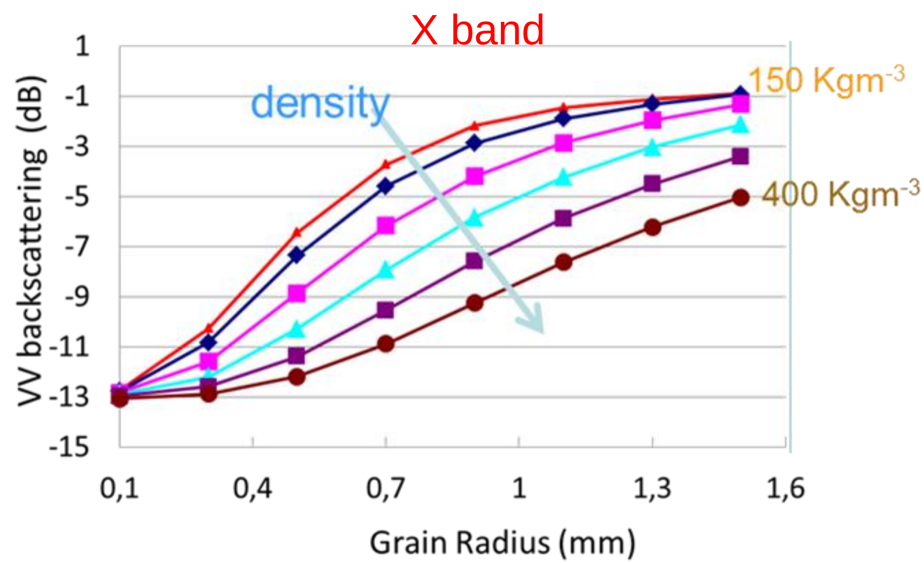
Snow density



Backscattering sensitivity to Snow Dept, Density and grain size (dry snow)

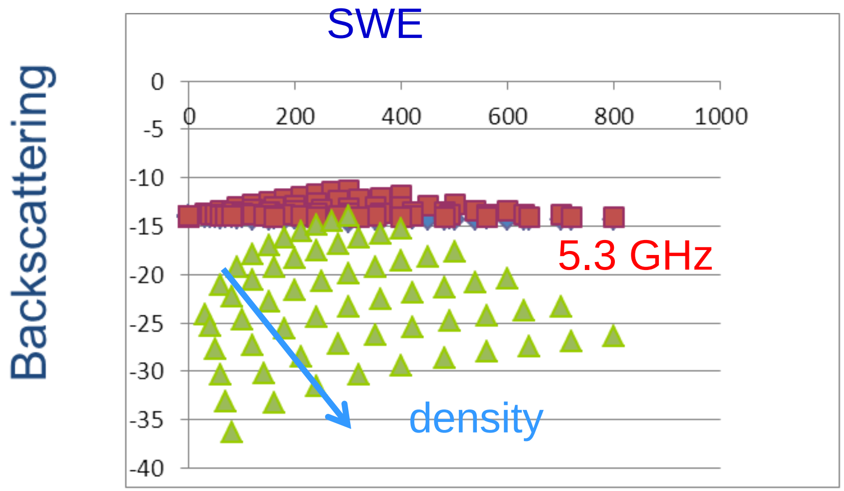
Θ =35° soil HStD=0.5cm, L=, 6cm

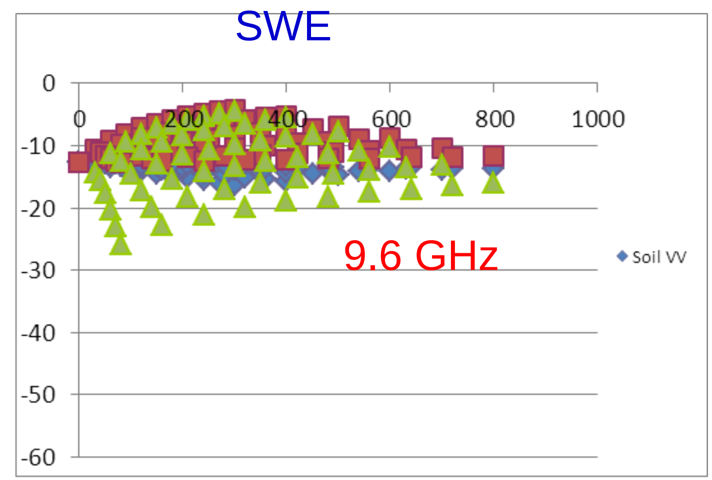


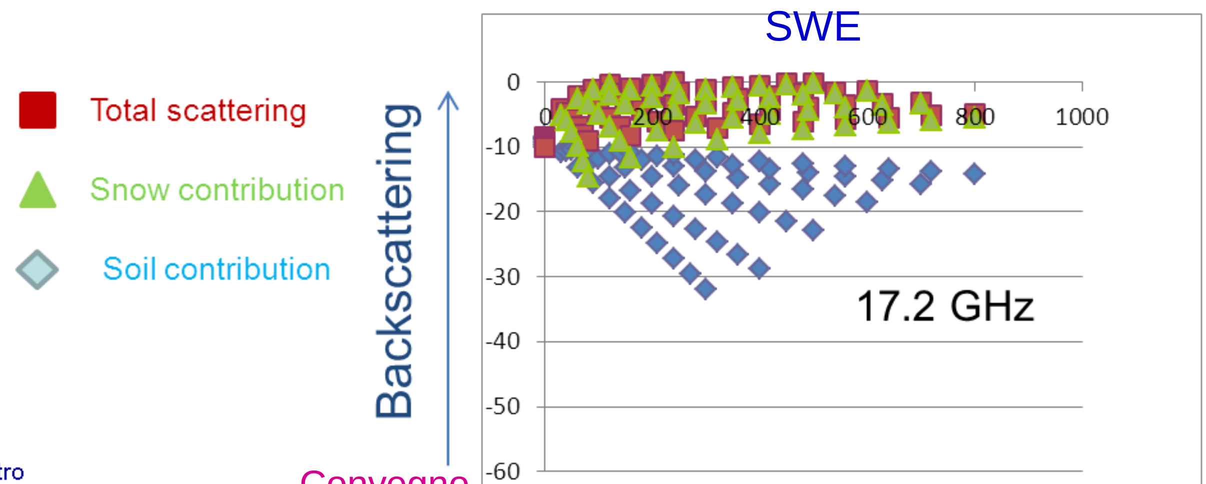


Density =250 kg m^{-3},
soil HStD=0.5cm, L=, 6cm

Sensitivity of backscattering to dry snow SWE



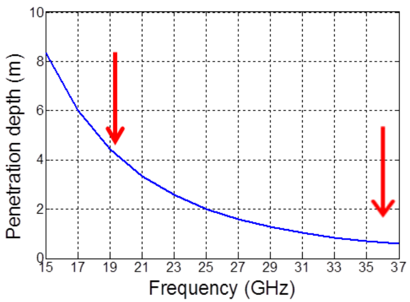




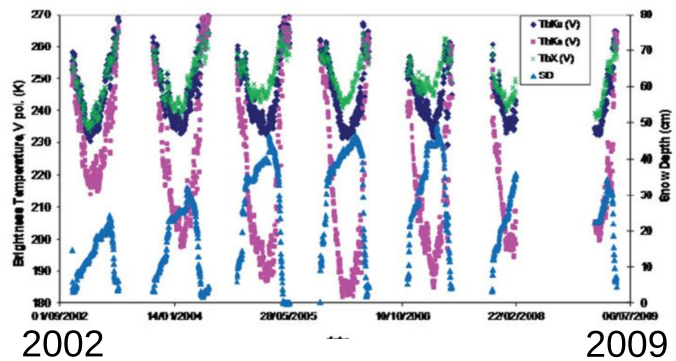
Xtal radius: 0.5 mm
Incidence angle: 35°

Generation of snow cover maps from radiometric data

Retrieval of snow depth from microwave multifrequency radiometer (AMSR-E)



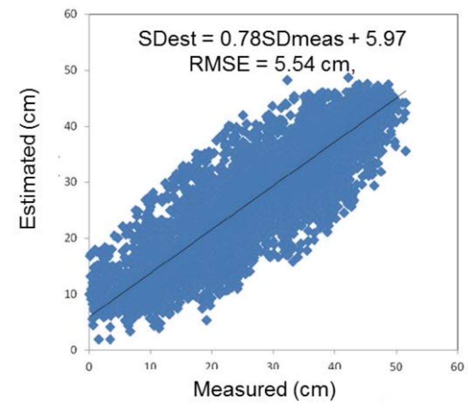
Siberian data set 13 000 data



Inversion: Threshold + ANN

$$FI = [(Tbv(19) - Tbv(37) + (TbH(19) - TbH(37)]/2 \begin{cases} \geq 4K & \text{snow} \\ < 4K & \text{no snow} \end{cases}$$

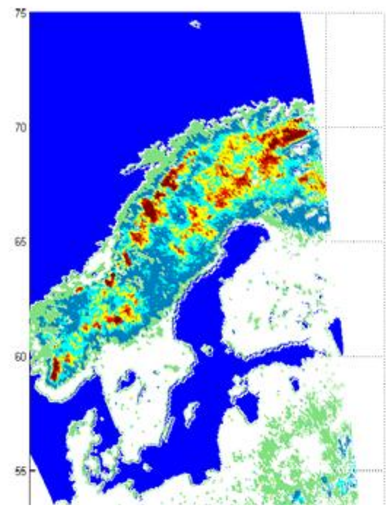
$$\left.\begin{aligned} Tb10V &= -0.499SD + 149.34\ (R2 = 0.067) \\ Tb19V &= -0.4432SD + 256.55\ (R2 = 0.3505) \\ Tb37V &= -1.4379\ SD + 255.86\ (R2 = 0.6944) \end{aligned}\right\} \boxed{\text{ANN}} \rightarrow \boxed{\text{Snow depth}}$$

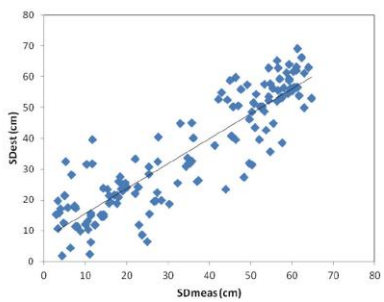


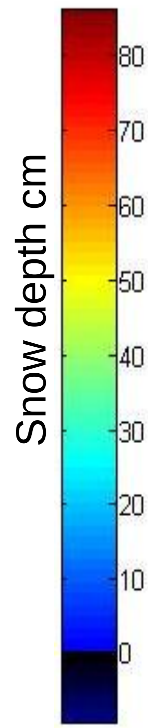
Santi et al. HESS 2012.

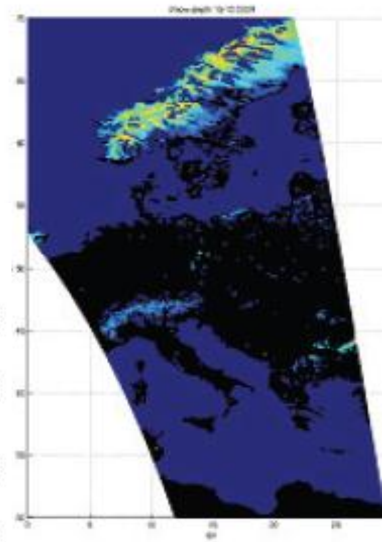
Snow depth from Multifrequency Radiometer

- Water
- Wet snow
- Soil
- 10-30cm
- 30-50cm
- 50-70cm
- >70cm

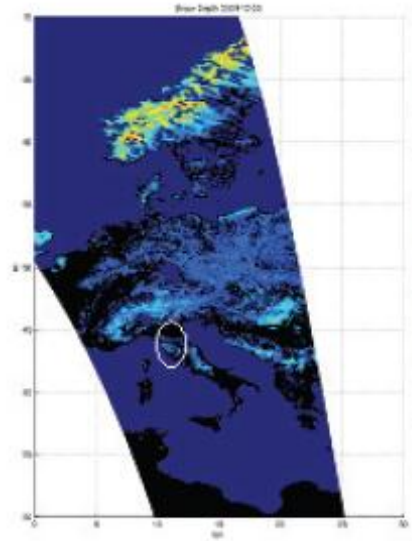




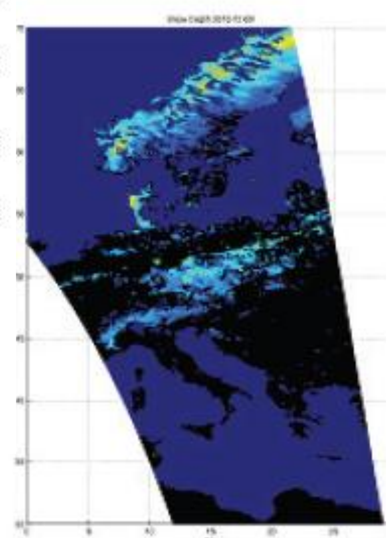


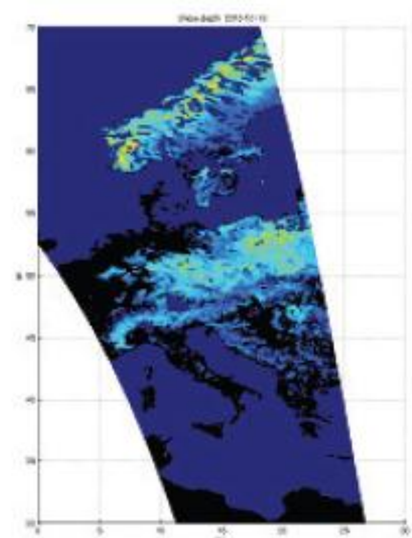


15 December 2009



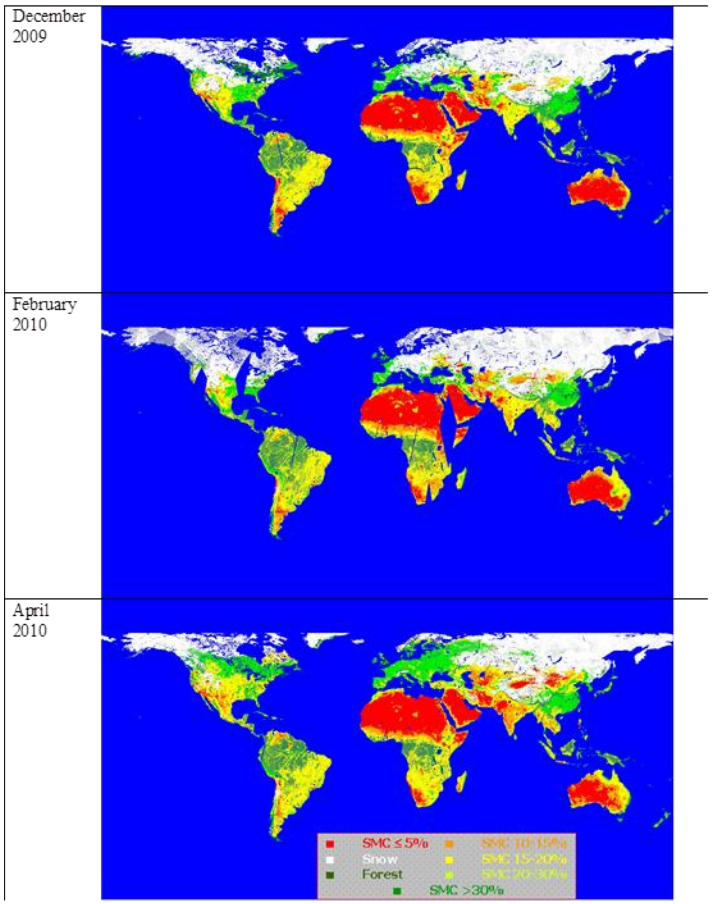
20 December, 2009

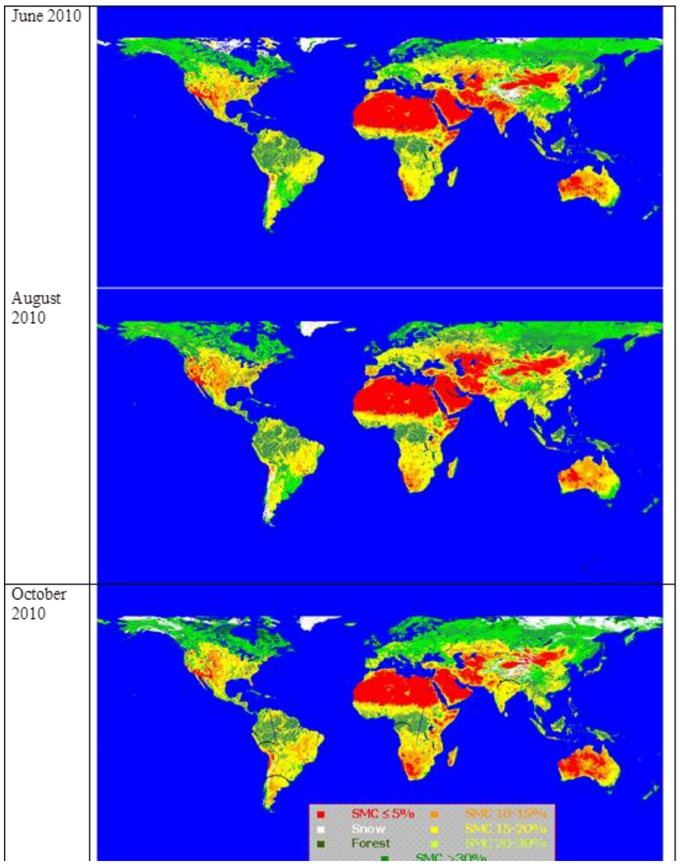




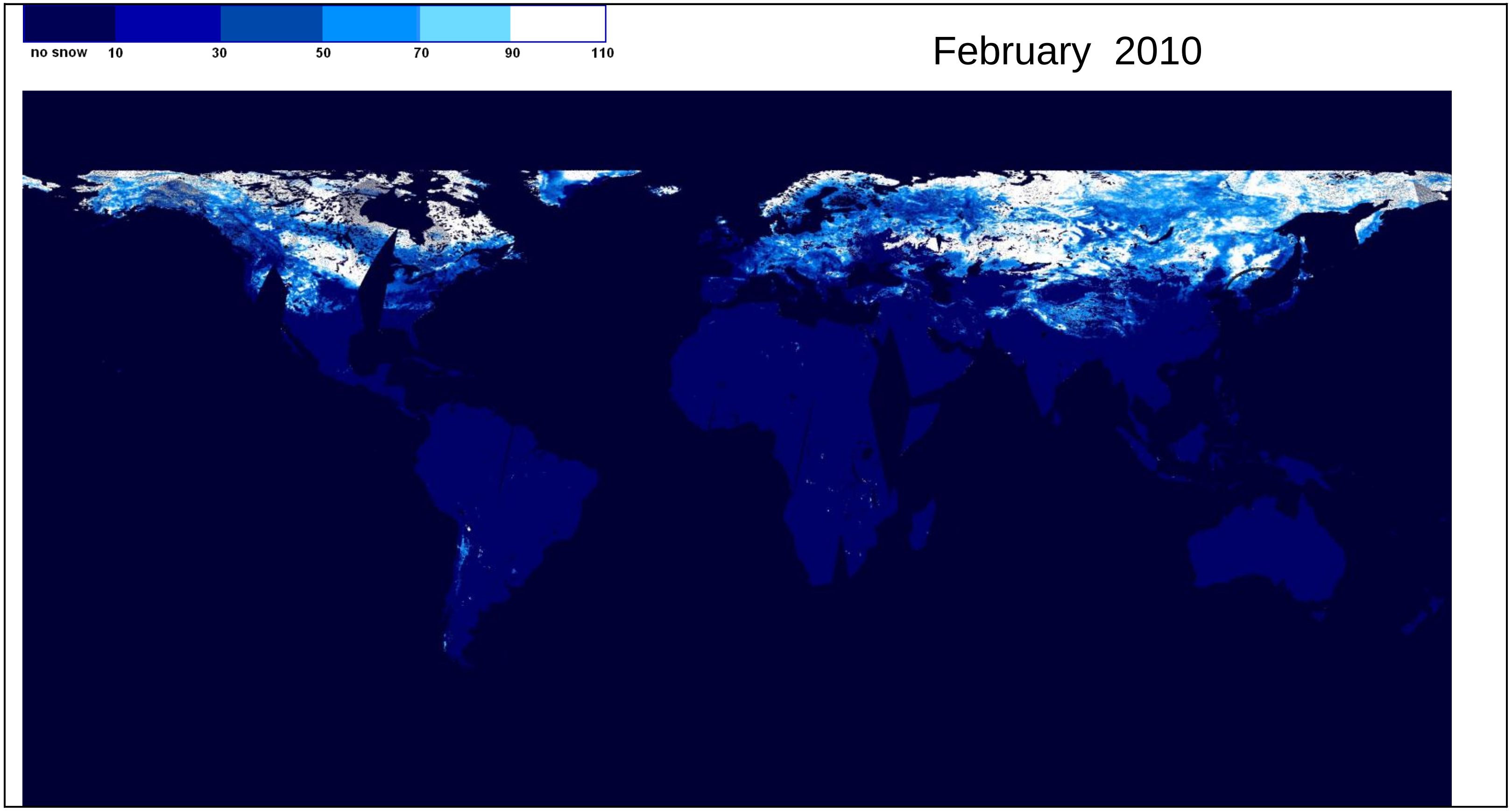
December 2010

Snow cover maps from Multifraquency Radiometer (AMSR-E)





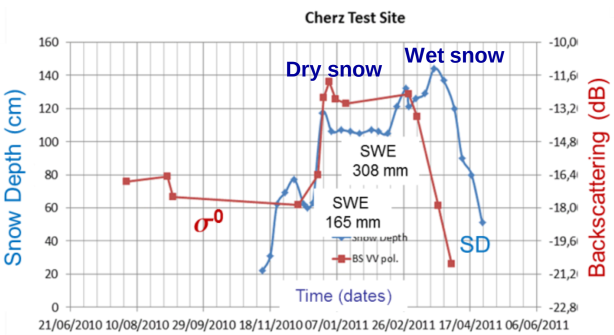
Global map of Snow Depth



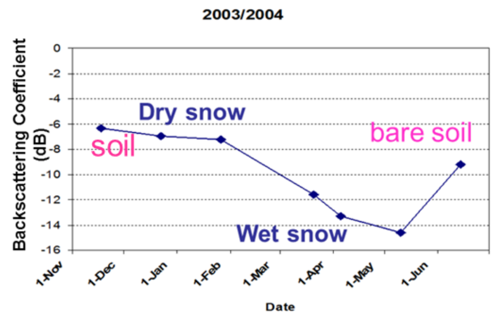
Generation of Snow Cover/SWE maps from SAR Data

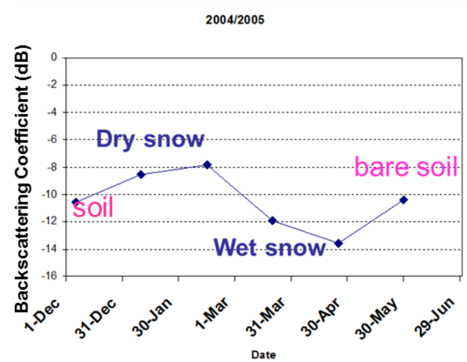
Temporal variation of backscattering coefficient

Experiments



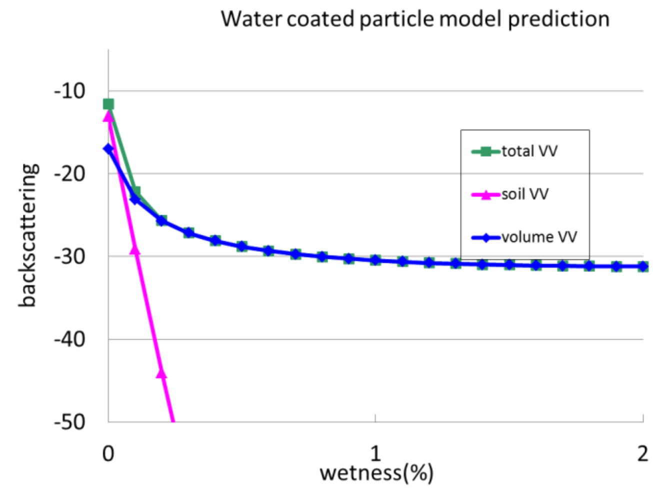
X-band



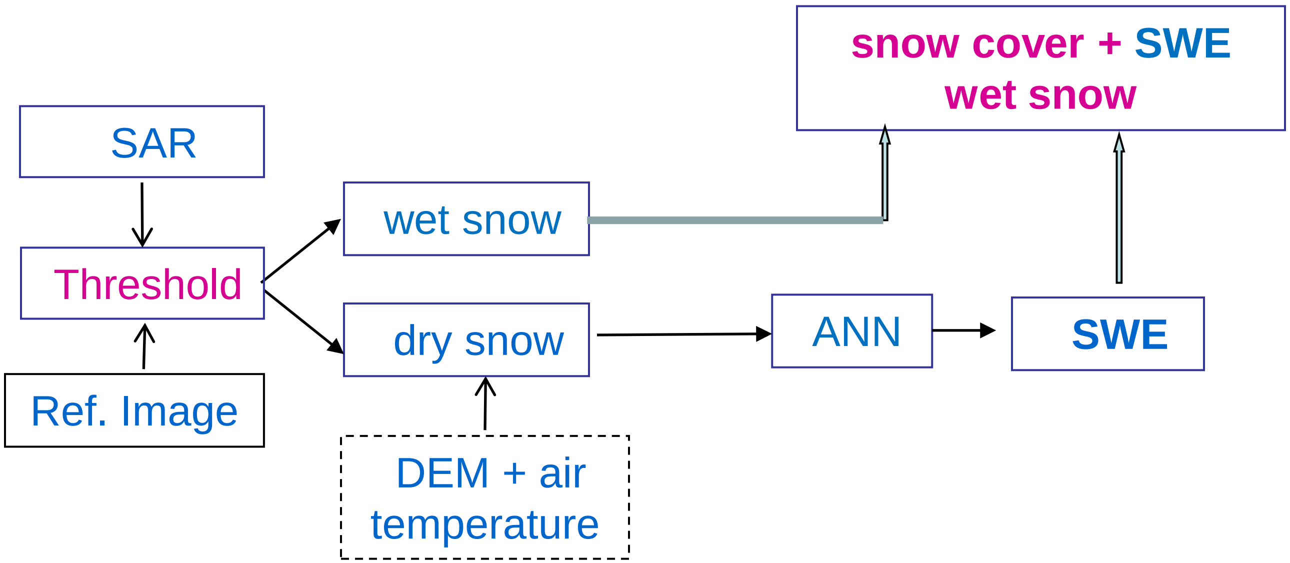


C- band

Model

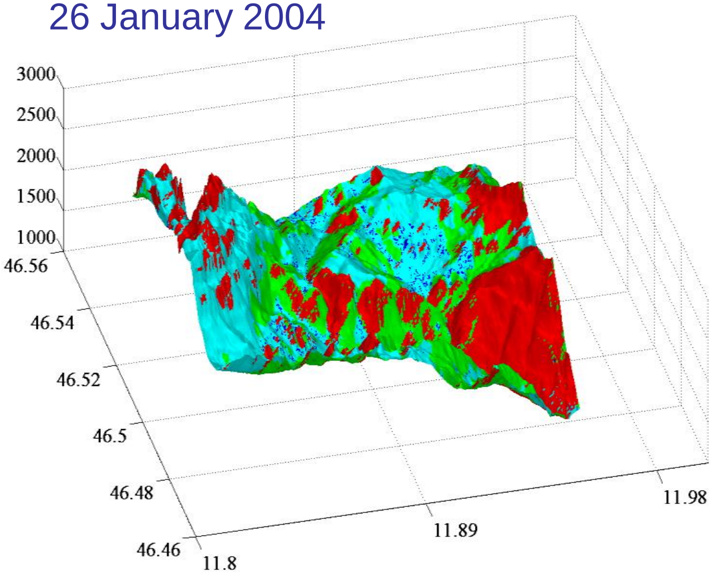


Generation of snow cover SWE maps from Backscattering Data: Principle of the algorithm



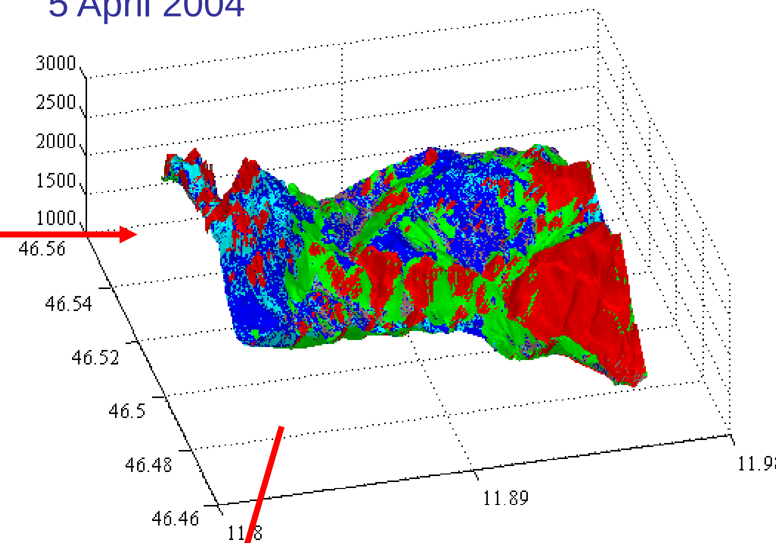
Snow cover maps - 2004

26 January 2004

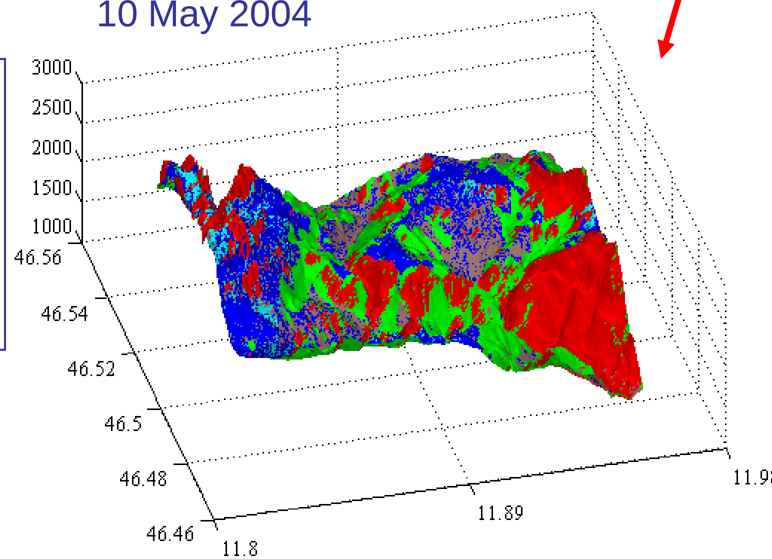


C-band
ASAR

5 April 2004



10 May 2004

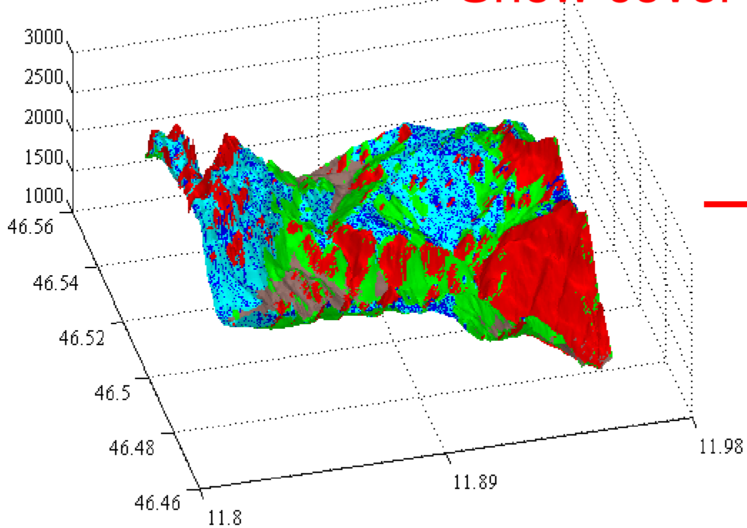


Light blue: dry-snow
Blue: wet snow
Green: forests
Brown: bare soil
Red: layover and
shadow areas

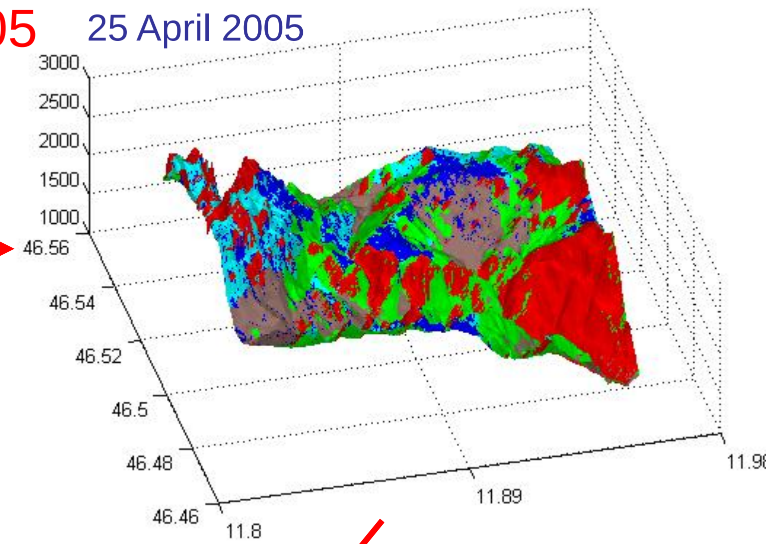
Snow cover maps - 2005

C-band
ASAR

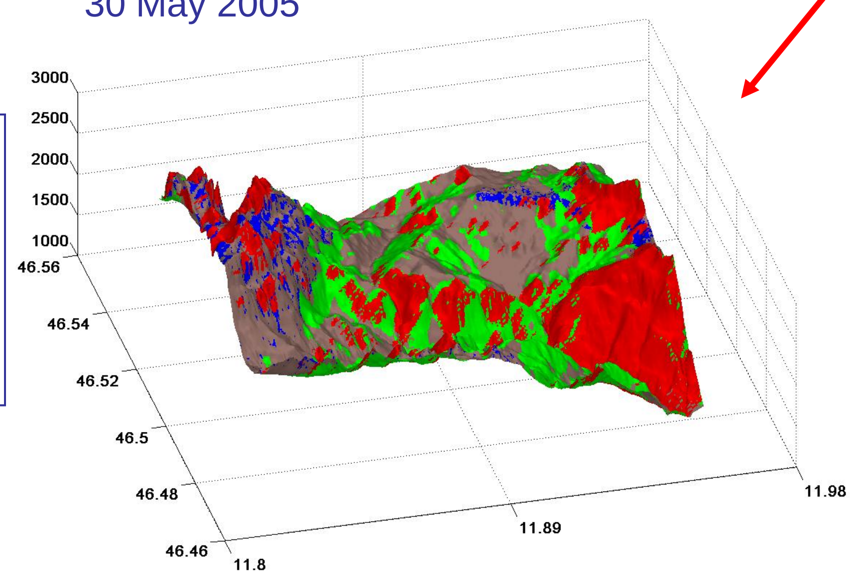
21 March 2005



25 April 2005



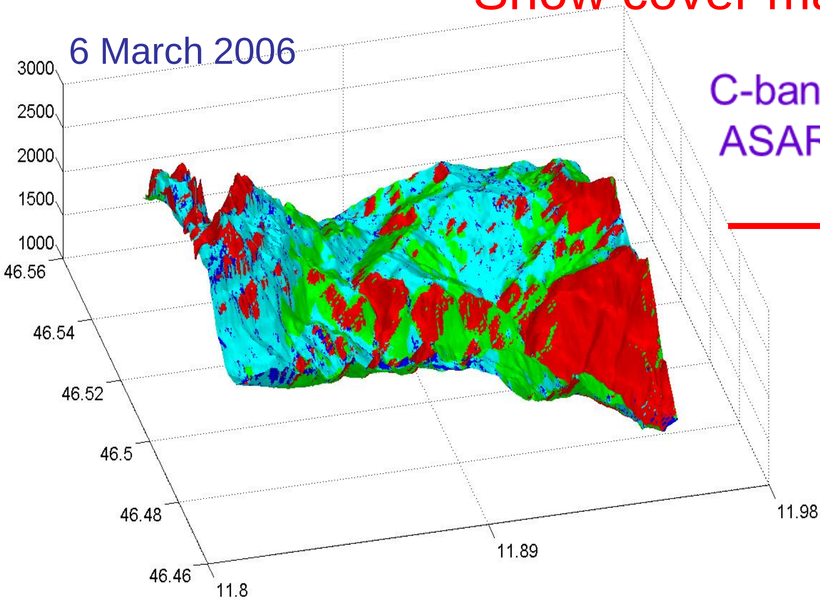
30 May 2005



Light blue: dry-snow
Blue: wet snow
Green: forests
Brown: bare soil
Red: layover and
shadow areas

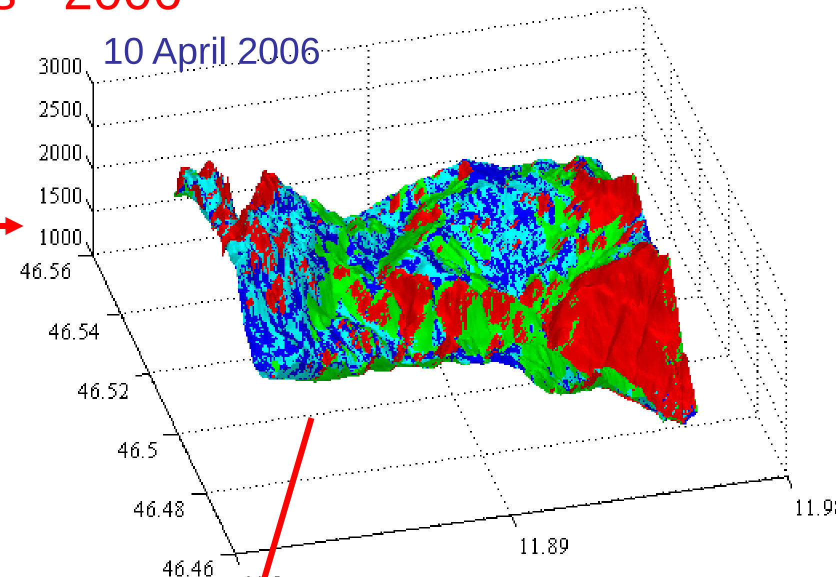
Snow cover maps - 2006

6 March 2006

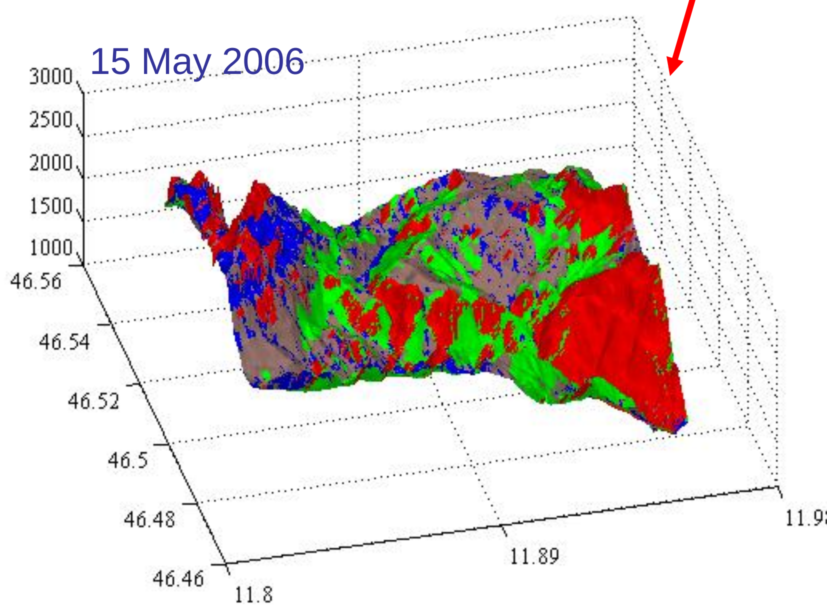


C-band ASAR

10 April 2006

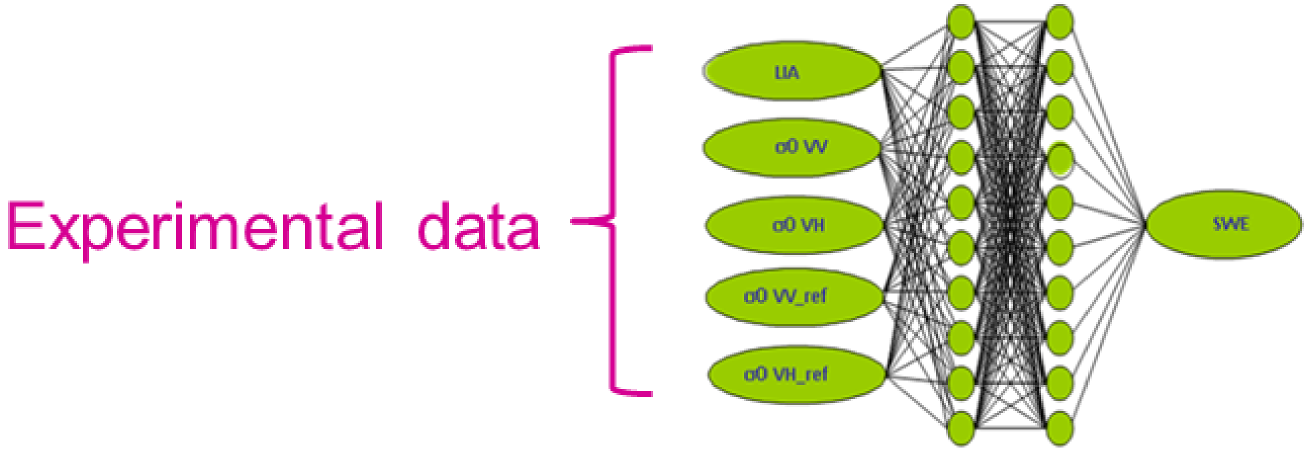


15 May 2006



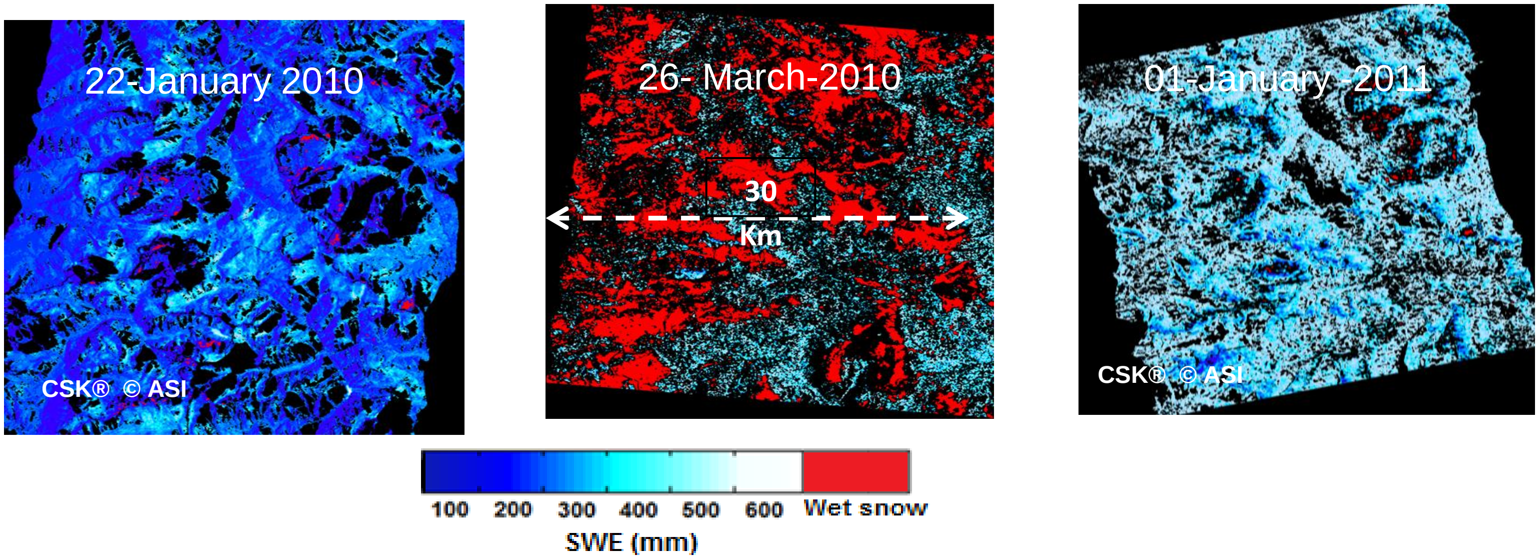
Light blue: dry-snow
Blue: wet snow
Green: forests
Brown: bare soil
Red: layover and shadow areas

Maps of Snow Water Equivalent from X-band Cosmo Skymed data

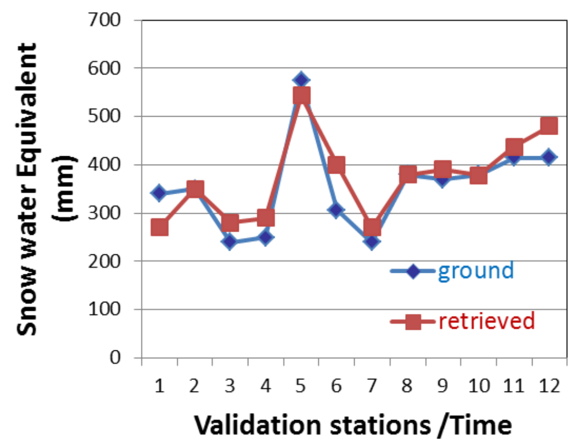


Pettinato et. al. IEEE GRSL 2013.

Example of Snow Cover maps



Validation



Conclusions

- Multi-frequency microwave radiometers can produce daily maps of snow water equivalent at global scale
- X-band SAR can add significant information on restricted areas provided snow depth is higher than about 50-60 cm
- Significant improvements are expected by the Ku band (17GHz) SAR (ESA COREH2O Mission)


Thanks
for the attention