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Advances in Microwave Emission Models for Snow and Ice

Christian Mätzler, Inst. Appl. Physics (IAP)
University of Bern, Sidlerstr.5, 3012 Bern, Switzerland
matzler@iap.unibe.ch, http://www.iap.unibe.ch

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- Lambertian Versus Specular Reflection
- MEMLS for Layered Snowpacks
- Direct Retrievals or Data Assimilation?
- Conclusions
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Motivation

Applications of microwave brightness temperature measurements in meteorology, hydrology,climatology etc. require quantitative understanding of microwave interactions with all media of relevance.

Knowledge has been accumulated over time, including

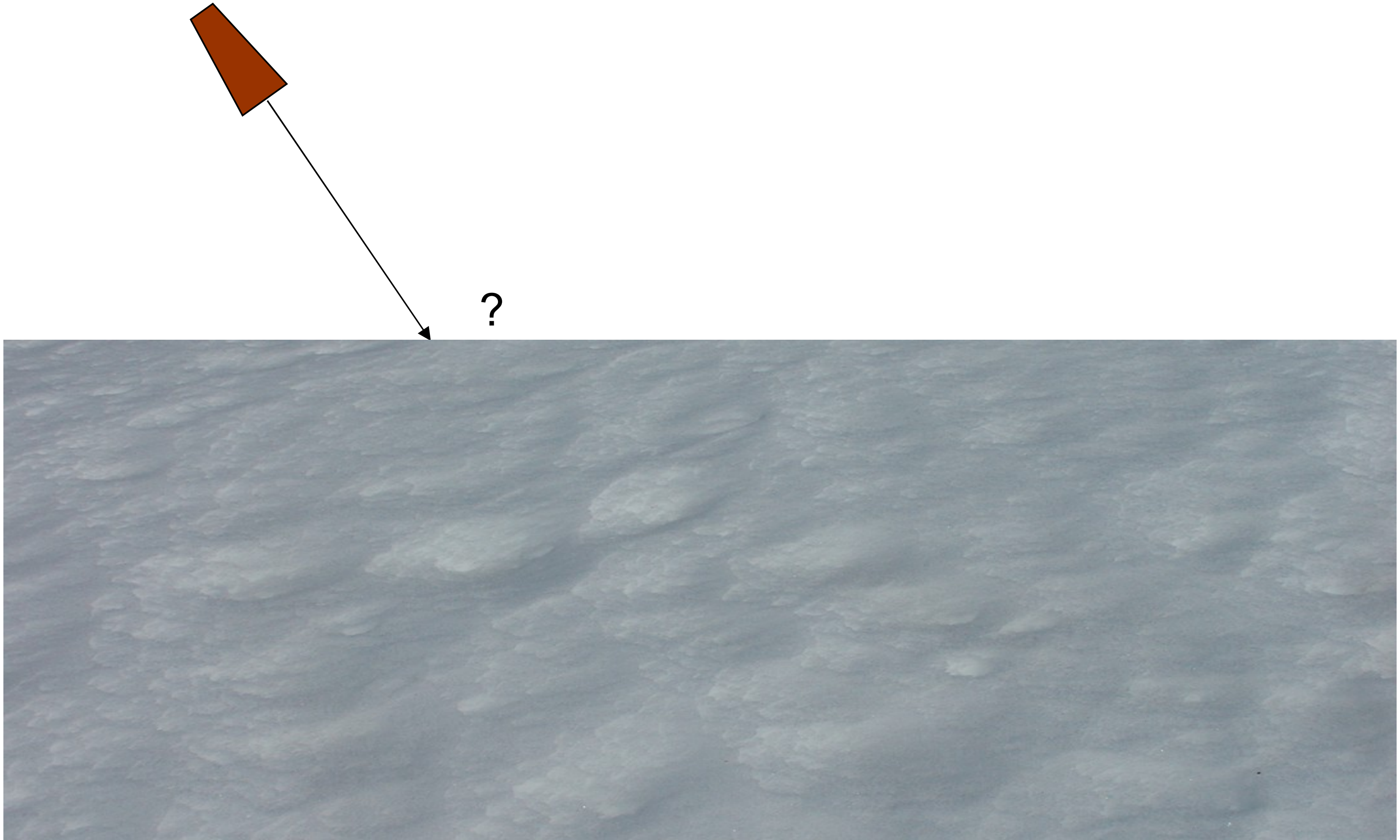
1) dielectric properties of components and mixtures
2) scattering and absorption in dense and in dilute media
3) radiative properties of the atmosphere
4) behaviour versus frequency, polarisation and incidence angle
5) empirical results observed in situ, from aircraft and satellites
6) relationship with other observations (radar, ir, vis)
7) potential for data assimilation

Present radiative models are not perfect, and the physical models of the Earth systems must be further advanced and better adapted to the radiometric requirements.

This contribution concentrates on the terrestrial snowcover due to the large signature variability

HPACK and a Surprise

Emission and backscatter model for a refractive half space with isotropic volume scattering, using the *H* function of Chandrasekhar (1950) to simulate active and passive microwave signatures of snowpacks and ice sheets (Mätzler 2000).

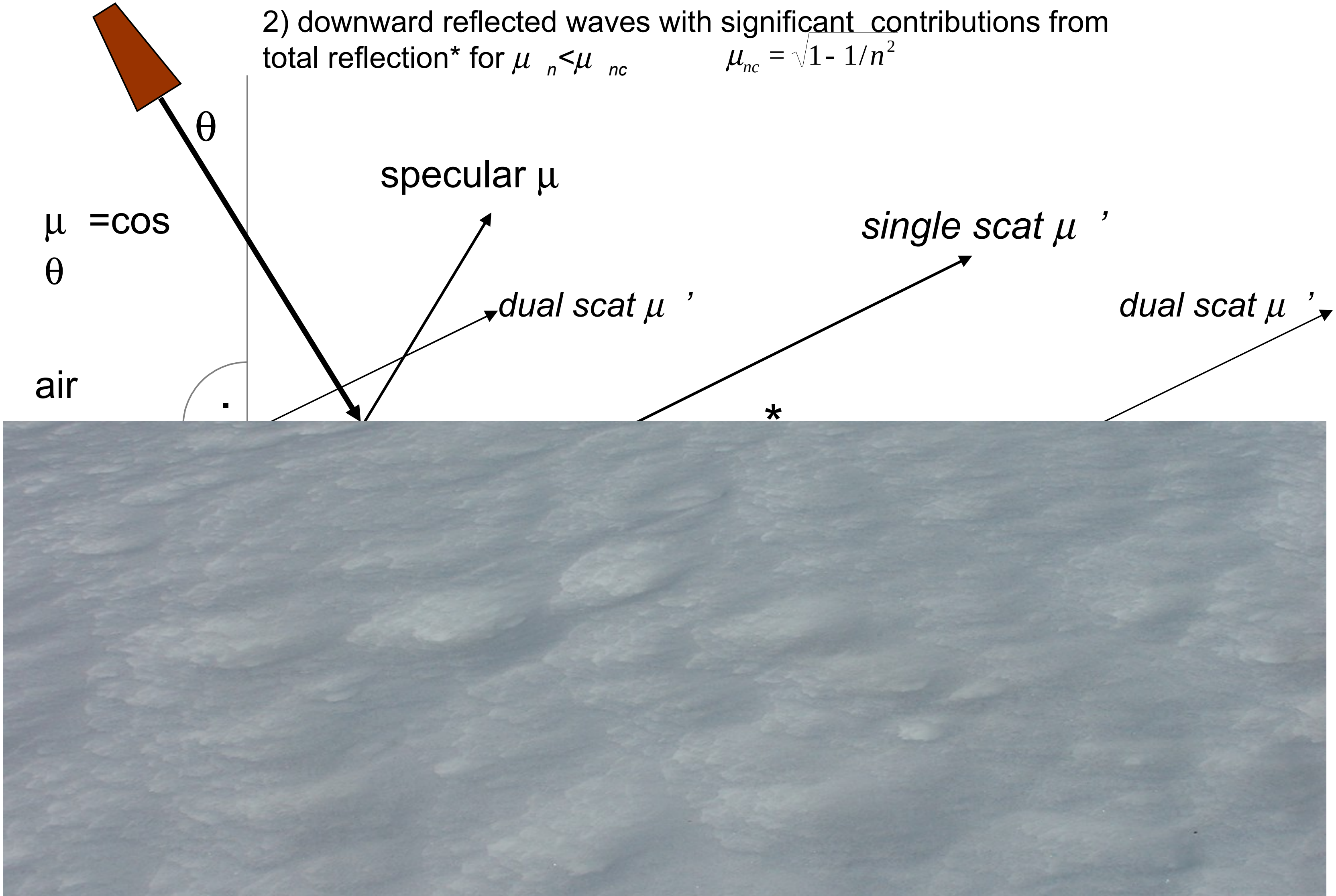


HPACK *Scattering at a Refractive Half Space*

The scattering half space with refractive index *n* is illuminated by

1) the refracted incident wave

2) downward reflected waves with significant contributions from total reflection* for $\mu_n < \mu_{nc}$ $\mu_{nc} = \sqrt{1 - 1/n^2}$



θ

specular μ

μ =cos θ

single scat μ'

dual scat μ'

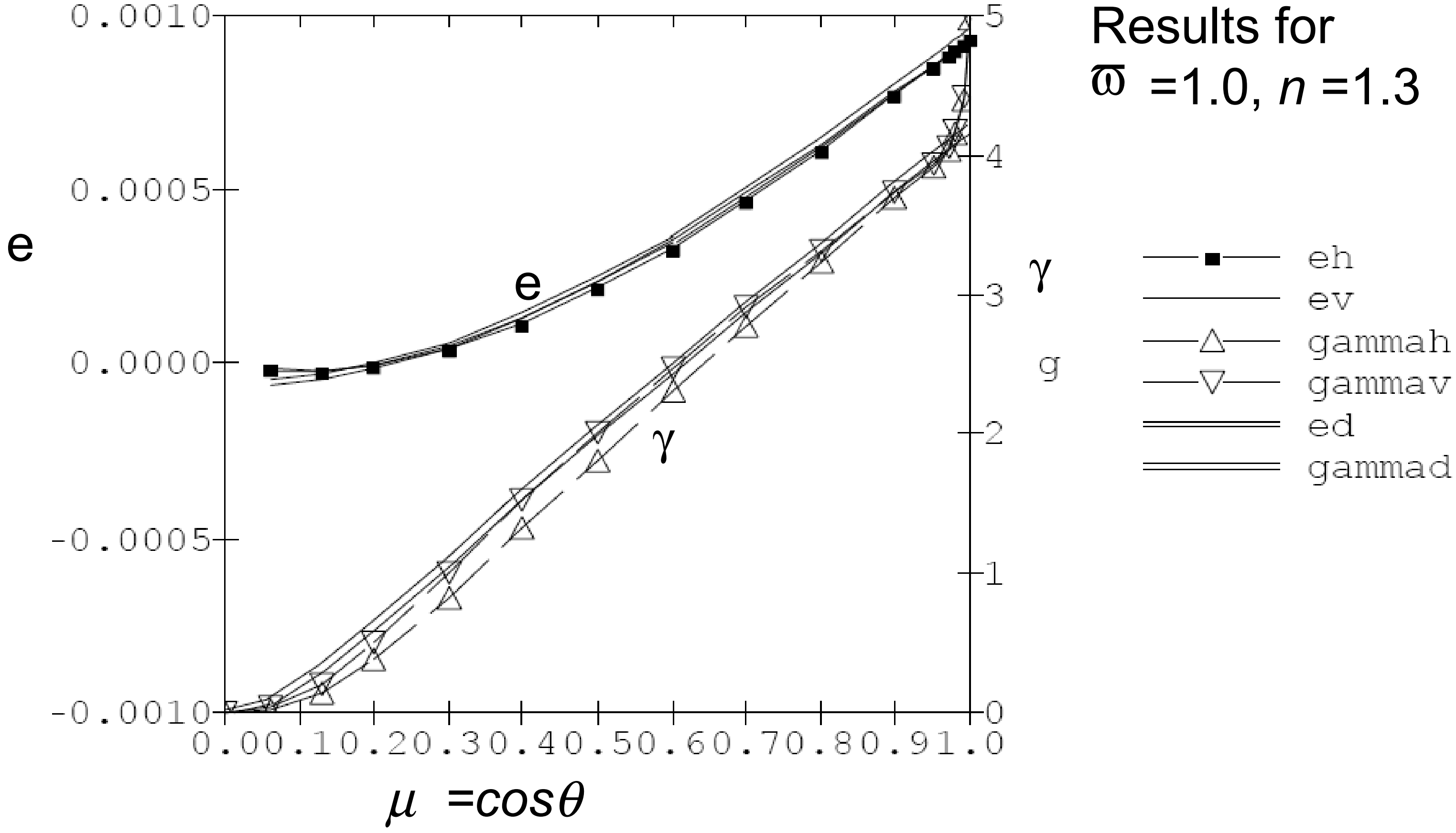
dual scat μ'

air

*

HPACK - surprise

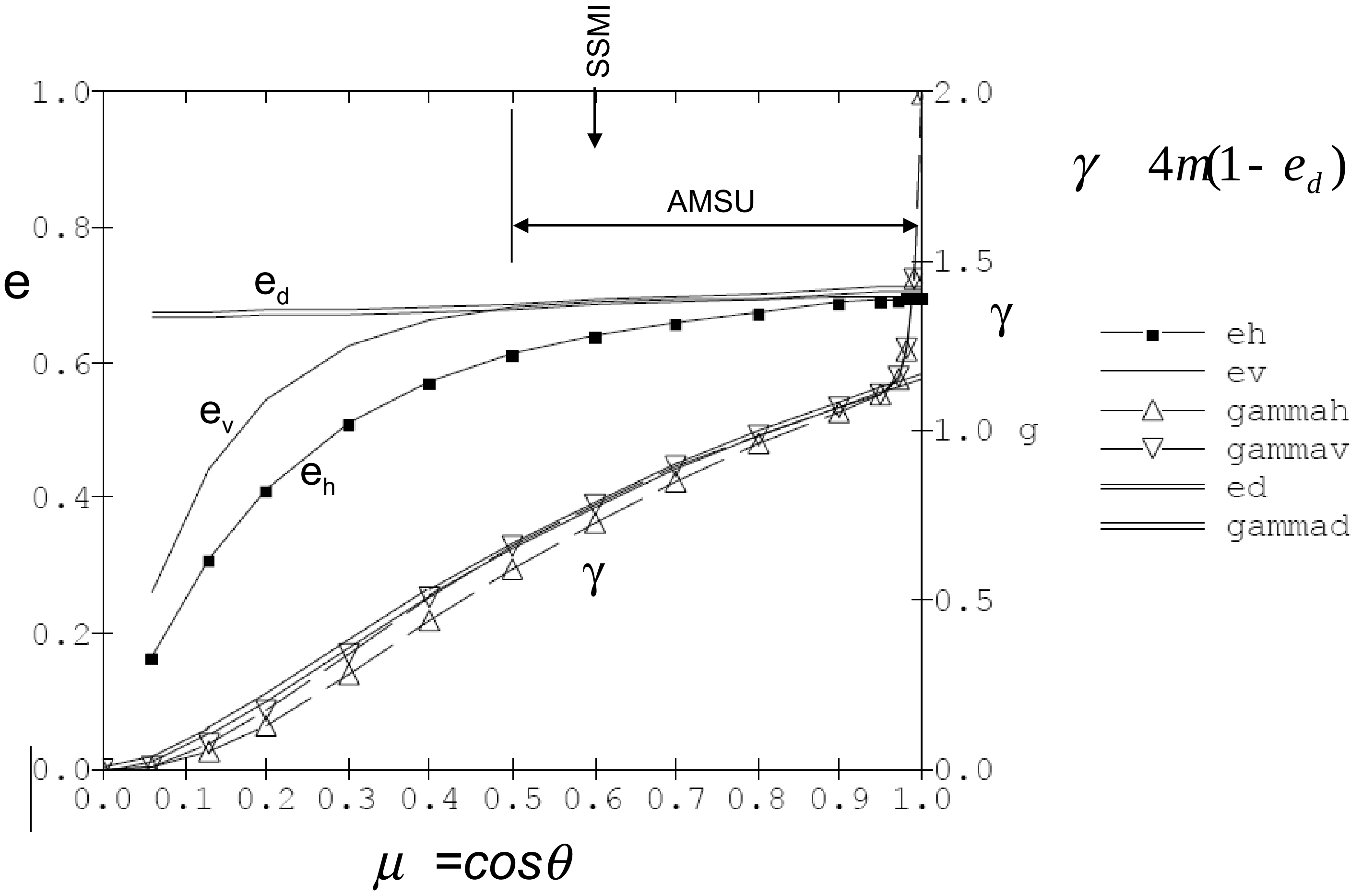
The result of the modified illumination is a bistatic scattering very close to Lambert Scattering:
(1) Emissivity *e* independent of μ , (2) backscatter coefficient $\gamma = 4m(1- e)$



Results for
ϖ =1.0, *n* =1.3

HPACK - for snowpack

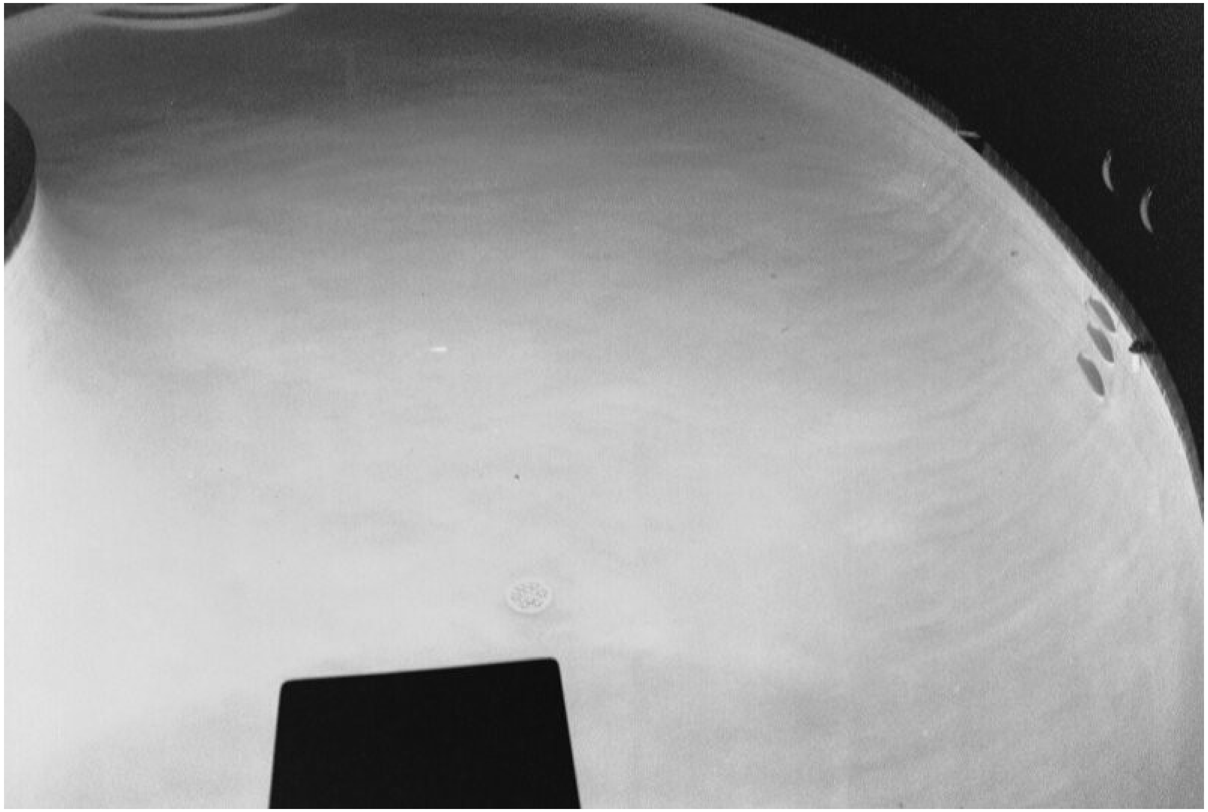
Similar result for realistic parameters of a snowpack: ϖ = 0.9, *n* = 1.3



$$\gamma \quad 4m(1- e_d)$$

HPACK and swimming pool

Comparison with visible range: Swimming pool by night (illumination below water surface): A single lamp produces a Lambert-like radiance



Again: *n* =1.3

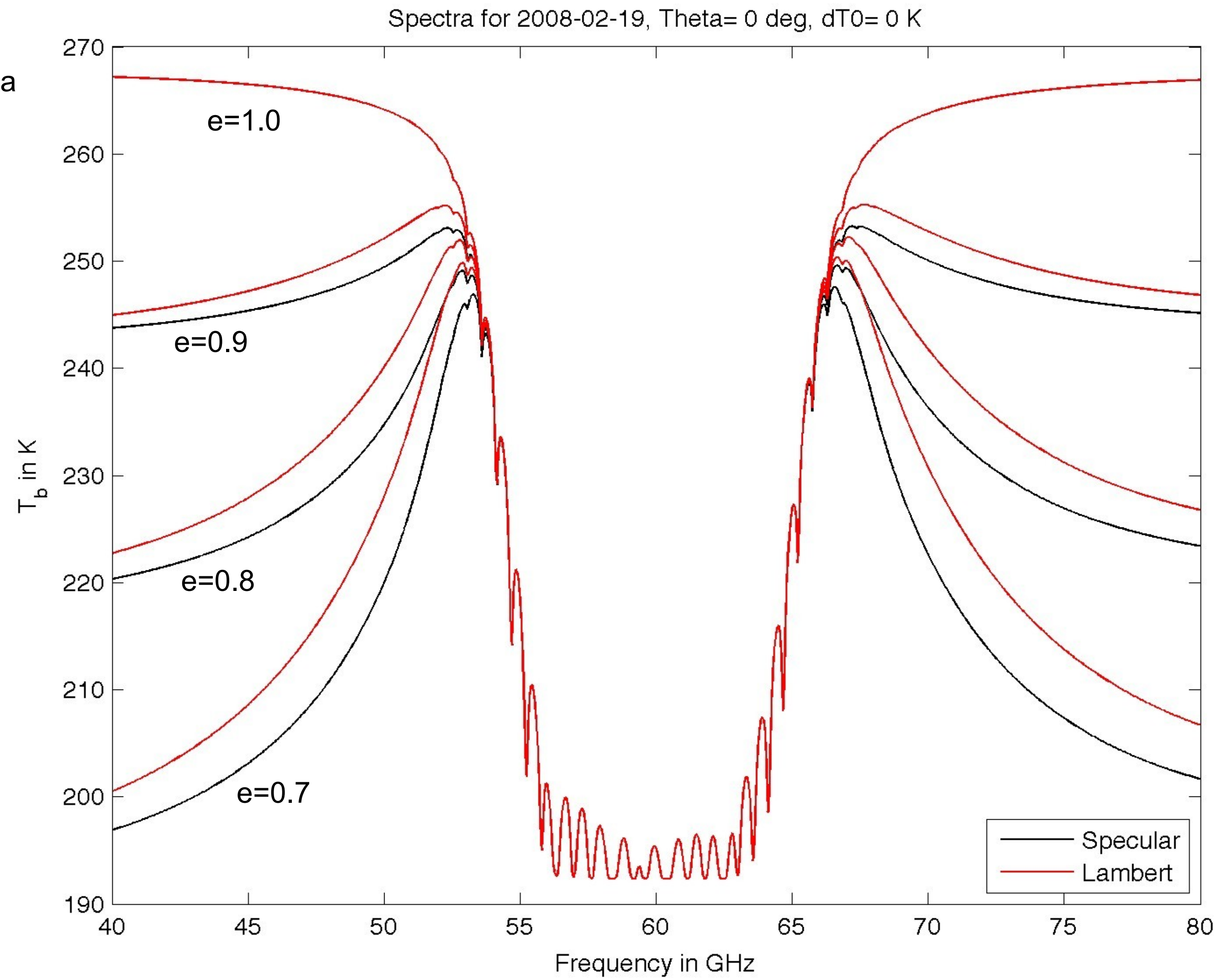
Lambertian Versus Specular Reflection

Difference in upwelling brightness is largest for vertical incidence and limited to window frequencies. Simulations with Rosenkranz (1998) model, using radiosonde data.

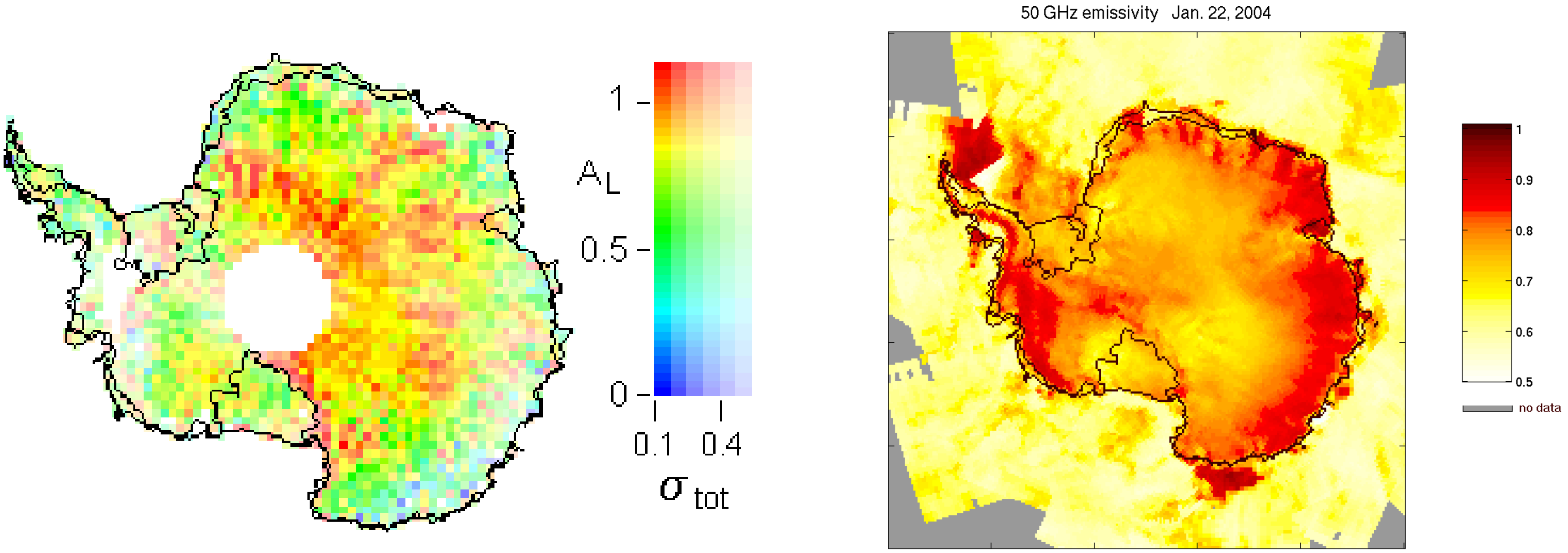
Simulation of upwelling brightness

RS92 Radiosonde data
Thun, Switzerland

Dry situation
IWV = 3.3 kg/m^2



Test of reflection properties in Antarctica



Mean A_L=0.84
1- 6 Aug 2005

Lambertivity A_L and its uncertainty σ_{tot} (left), and emissivity (right) of Antarctica at 50 to 53 GHz, advancements with AMSU-A Data since 2006: Rosenkranz & Matzler (2008)

Test of snowcover reflection type

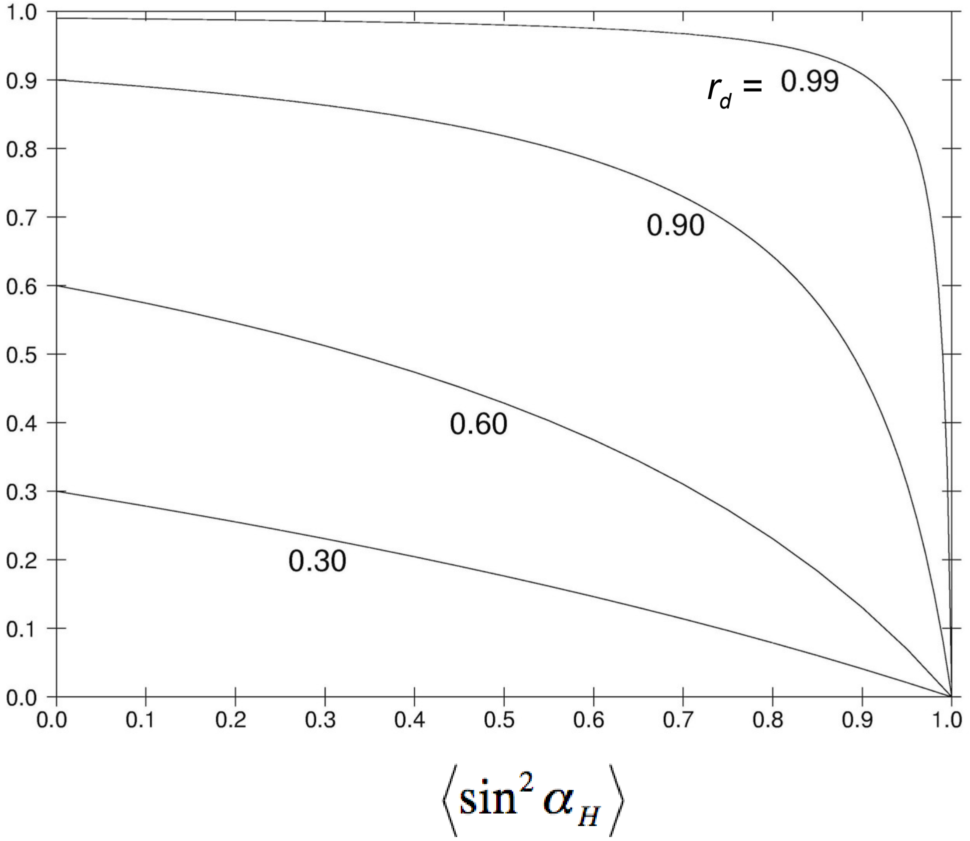
Lambertian-like behaviour was noted by Harlow (2009) for snow-covered land and sea-ice surfaces from airborne surveys (89 - 183 GHz) in Alaska. More on this work will follow in the next talk by Chawn H.

Relief increases the emissivity

The effective landscape emissivity e_{ff} increases with increasing ruggedness of the terrain, i.e. with increasing elevation angle α_H of the horizon
(r_d =1-e_d is the local Lambertian reflectivity)

$$e_{eff} = \frac{e_d}{1 - r_d \left\langle \sin^2 a_H \right\rangle}$$

$$r_{eff} = 1 - e_{eff}$$



MEMLS for Layered Snowpacks

Microwave Emission Model of Layered Snowpacks (MEMLS) to simulate microwave radiation of snow-covered land (Wiesmann & Mätzler 1999), and sea ice (Tonboe et al. 2006). MEMLS considers refractive and layering effects, but simplifies volume scattering by a six-flux radiative transfer model.

MEMLS - together with the HUT snow emission model - originated from an ESA study (Pulliainen et al. 1998), and is available in MATLAB from IAP.

MEMLS can be driven by a snow-physical model (e.g. CROCUS, SNTHERM, SNOWPACK), which is fed with standard meteorological data.

The input parameters of MEMLS are derived from vertical profiles of the snowpack

- temperature
- density
- correlation length (or specific surface)
- liquid-water content (if T=0°C)
- salinity (optional since Version 3)

These profiles are then approximated by a finite number of homogeneous layers to obtain the reflectivities at each layer interface, and the propagation parameters within each layer.

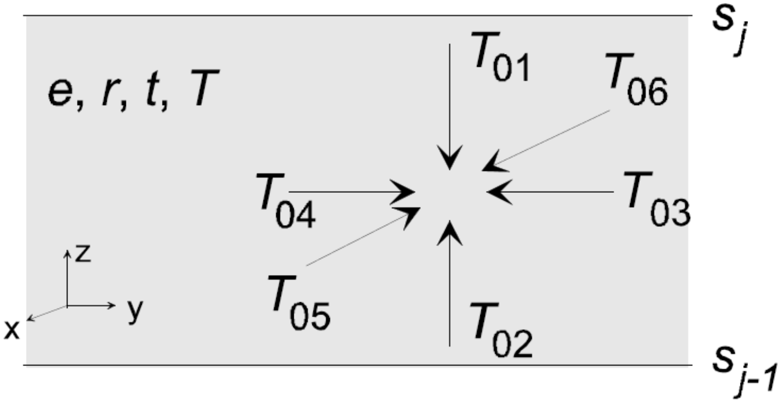
Furthermore the reflectivity at the snow-ground interface has to be given.

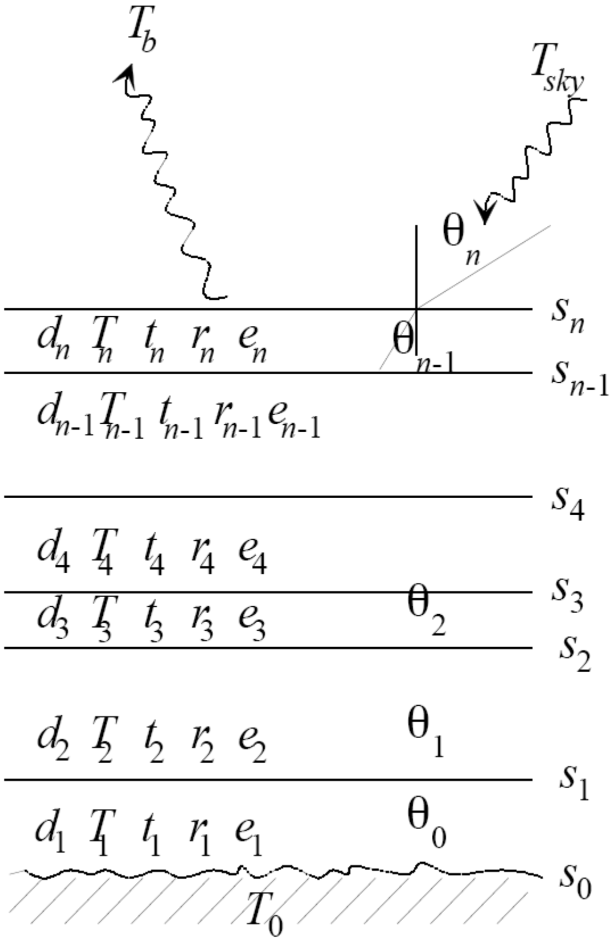
Interaction with a forest canopy, with a relief, and with the atmosphere can be accomplished.

MEMLS fluxes and layers

Radiative transfer within each layer is described by a 6-flux model with given absorption and (isotropic) scattering coefficient.

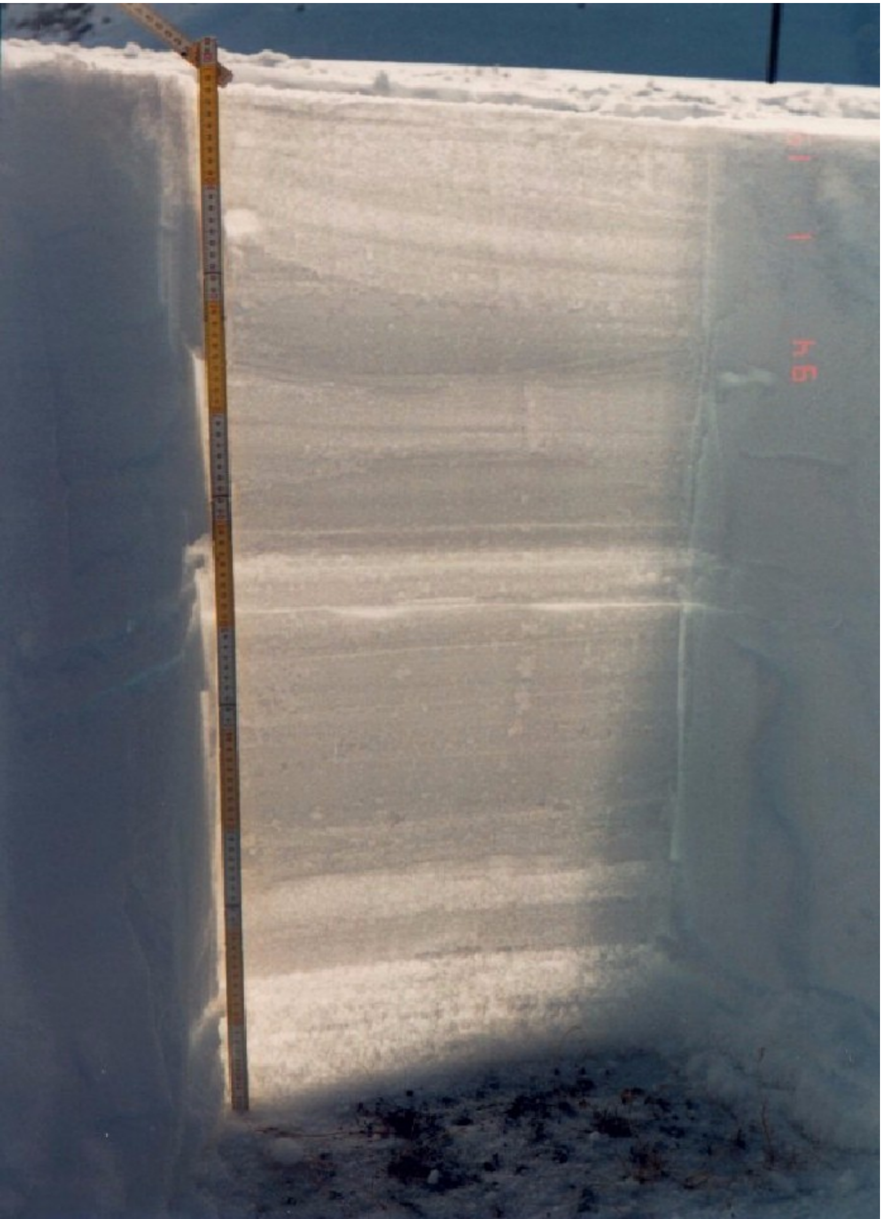
Boundary conditions at the layer interfaces link the vertical fluxes



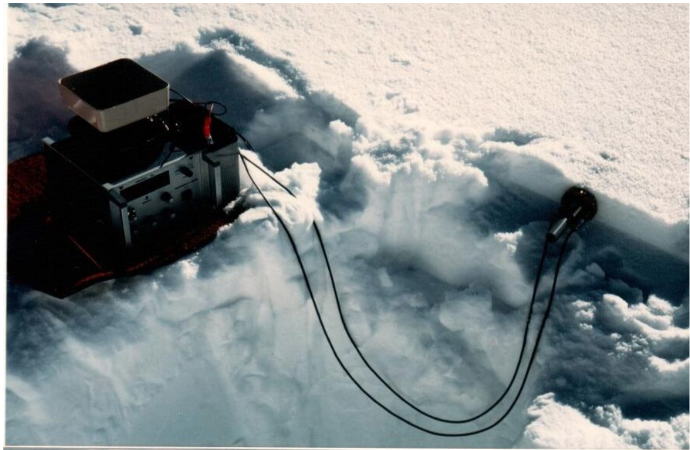


The 6 fluxes (above) separated at the critical angle θ_c, and the system of snow layers above ground (on right)

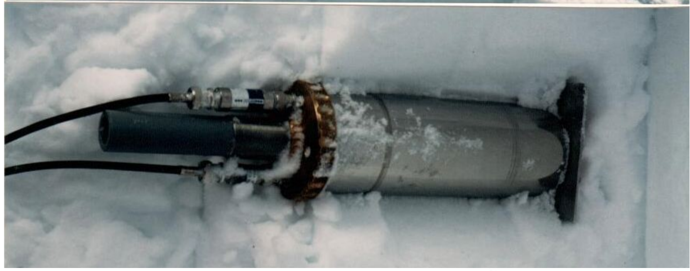
MEMLS experimental studies 1

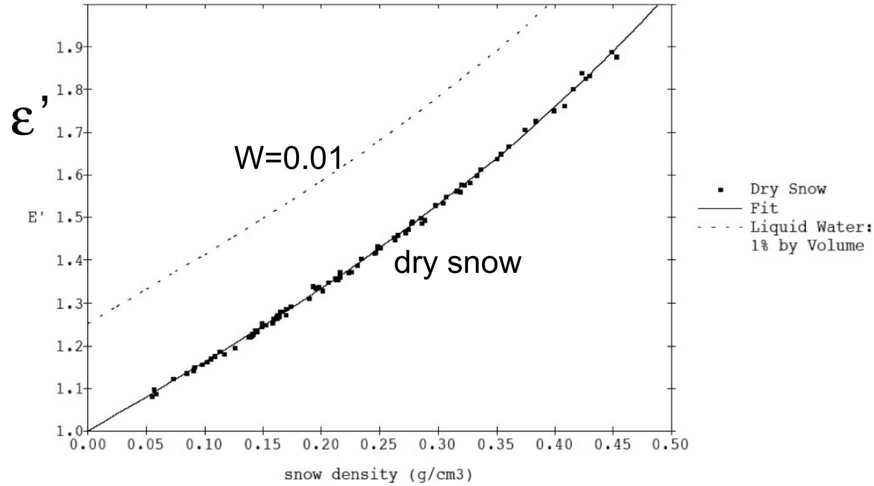


Layered snowpack structure



Measurement of dielectric properties



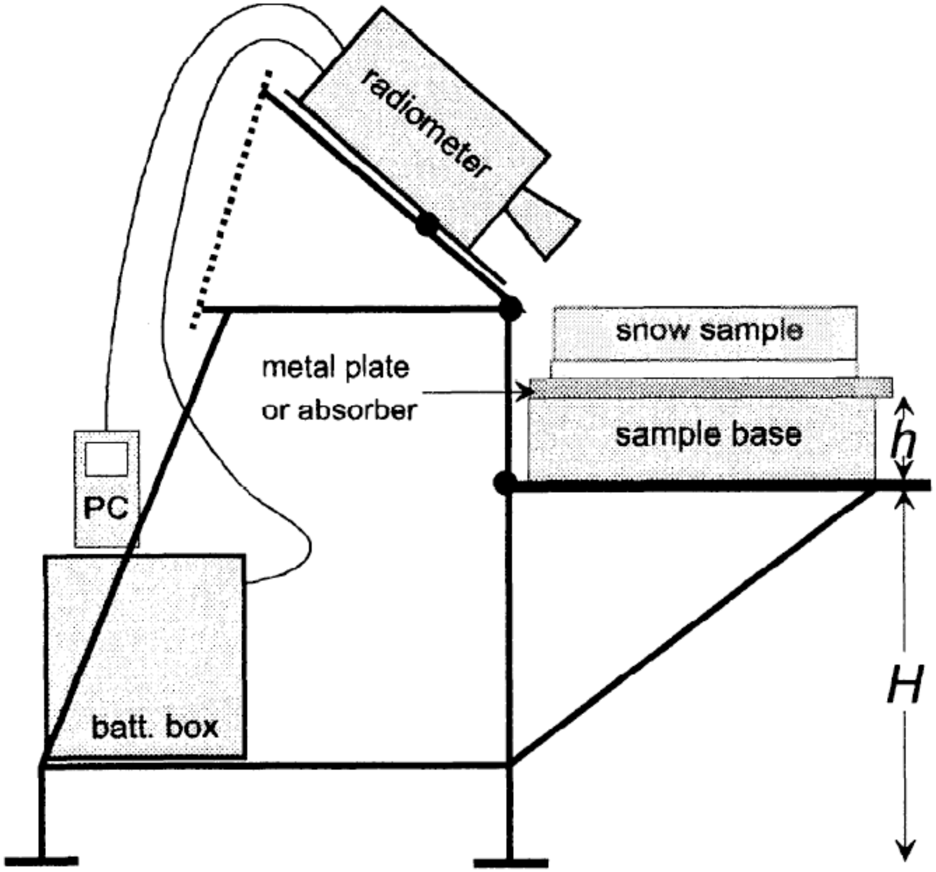


MEMLS experimental studies 2

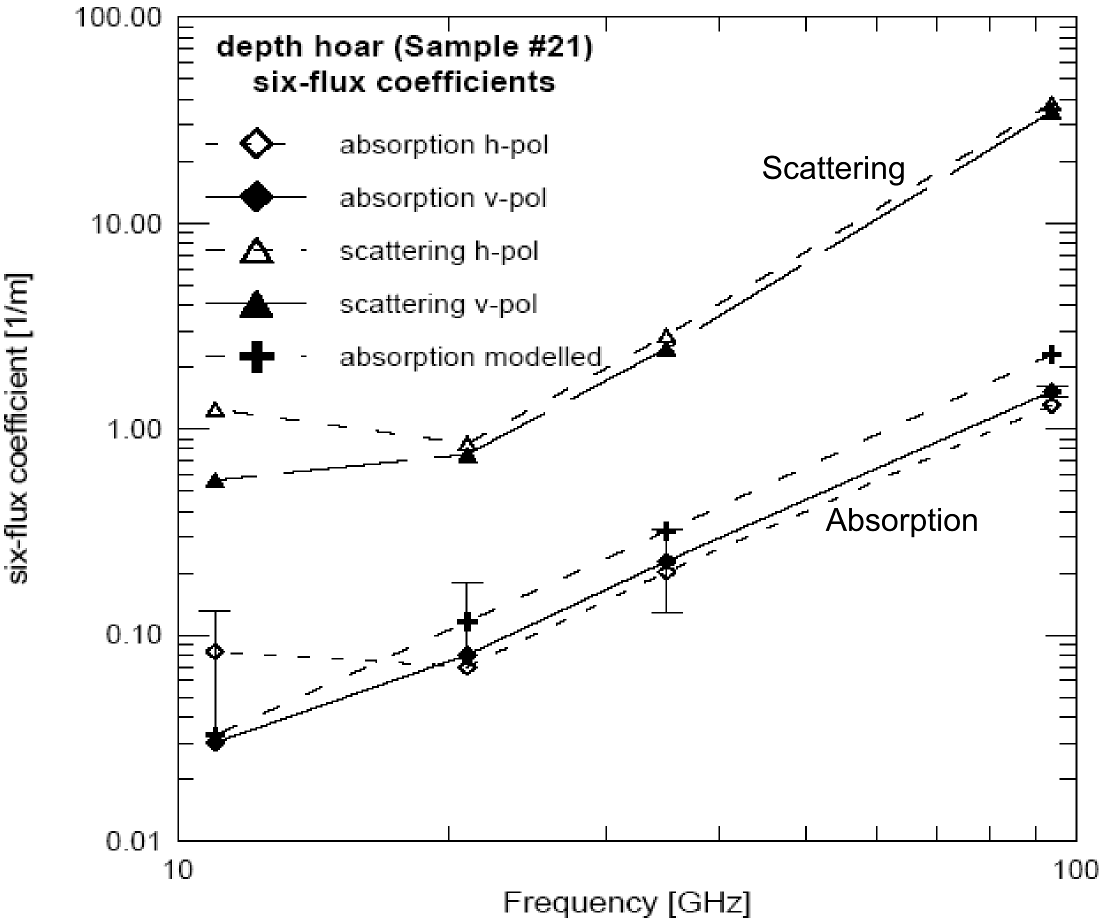
Setup for radiometric measurements of well-controlled samples

size 60 cm x 60 cm

d = 8 - 16 cm



MEMLS experimental studies 3



Results:

1) Scattering coefficient increases with frequency by less than power 4 in agreement with DMRT (Liang et al. 2008).

2) Absorption coefficient is in agreement with physical dielectric mixing model and dielectric model of ice.

MEMLS experimental studies 4

Example:
emissivity and
structure
of dry-snow
slabs

(Wiesmann
et al. 1998)

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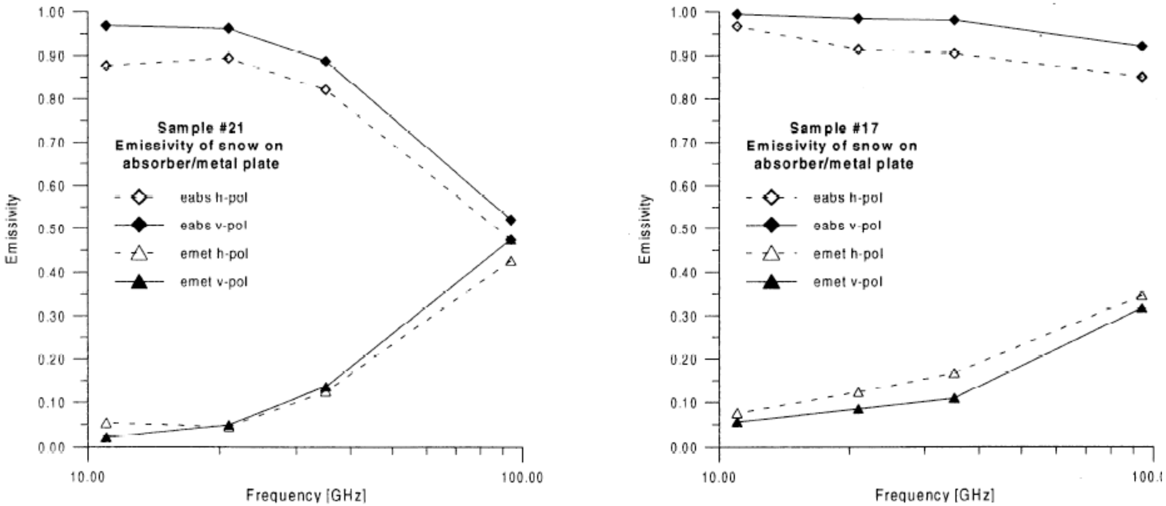


Snow on
absorber

Snow on
reflector

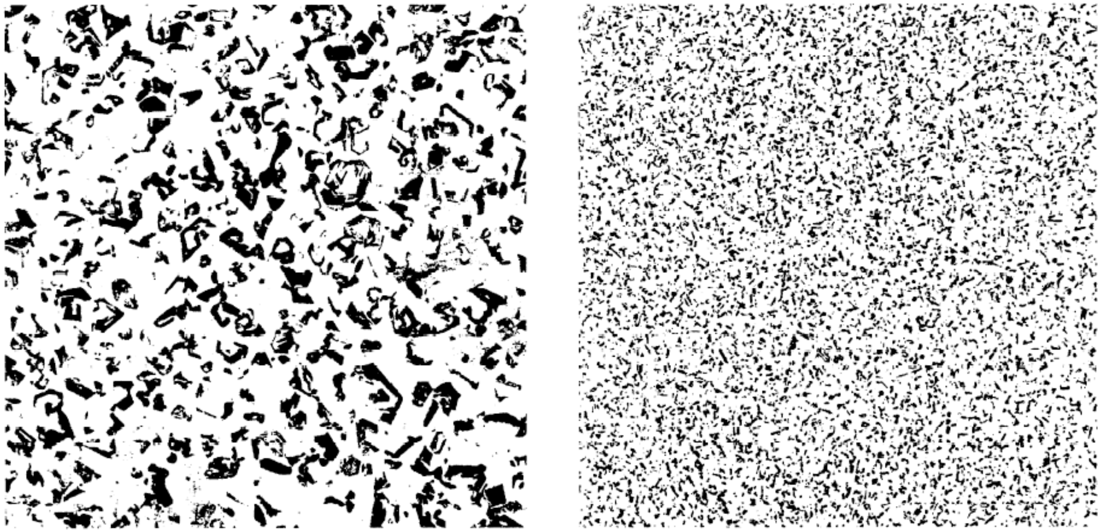
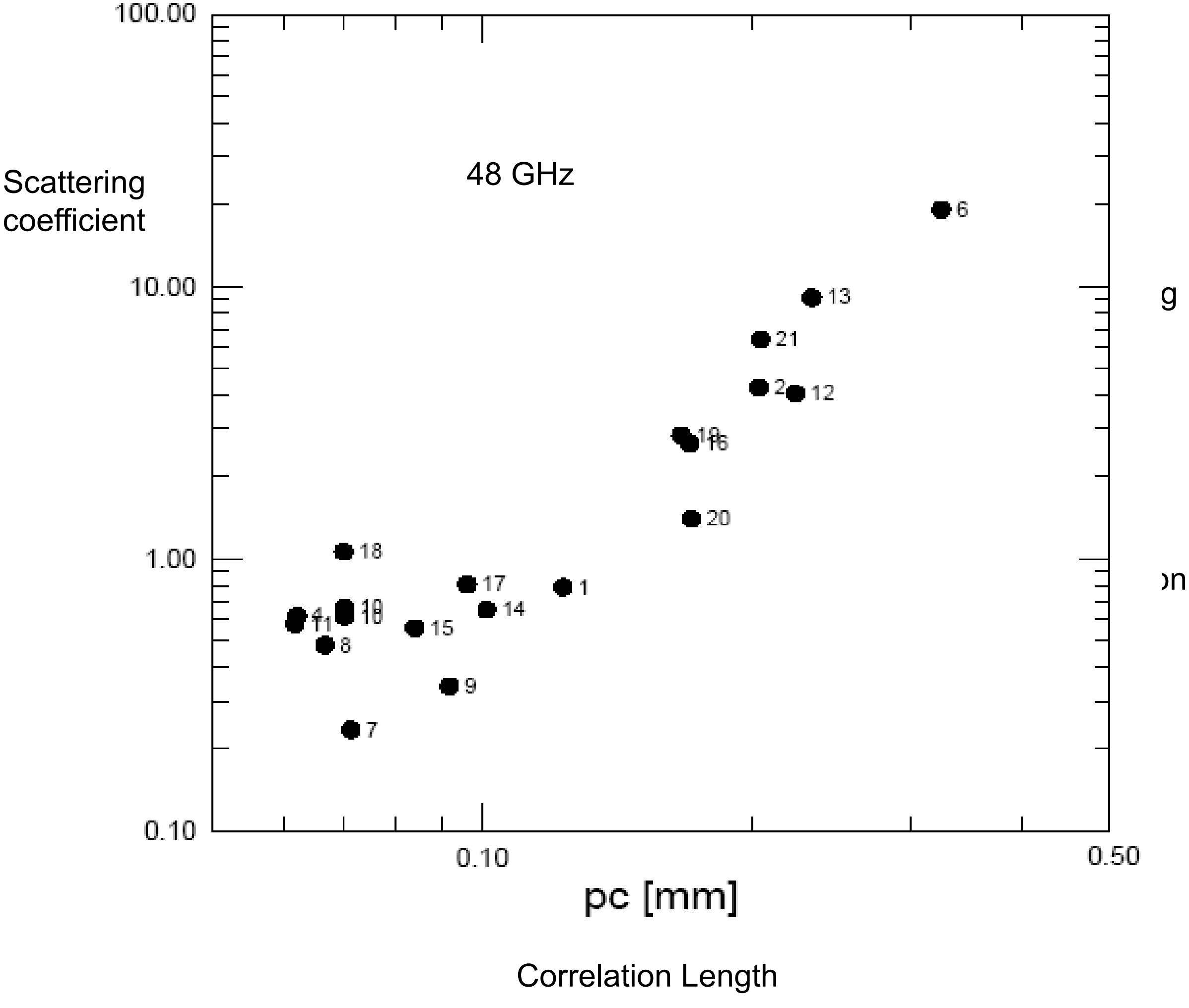


Figure 3. Binary snow sections (3 cm × 3 cm). (Left) Coarse-grained sample 21. (Right) Fine-grained sample 17. Ice grains are black.

MEMLS experimental studies 5



MEMLS validation 1

Example of a full snowpack approximated by 4 layers

Date/ layer No.	T_{snow} [K]	W [%]	ρ [kg/m^3]	d [cm]	p_{ec} [mm]
21.12.95					
1	273.0	0.00	259.0	25.0	0.1702
2	272.0	0.00	177.0	15.0	0.0961
3	266.5	0.00	400.0	0.3	0.0000
4	271.4	0.00	109.0	20.0	0.0701

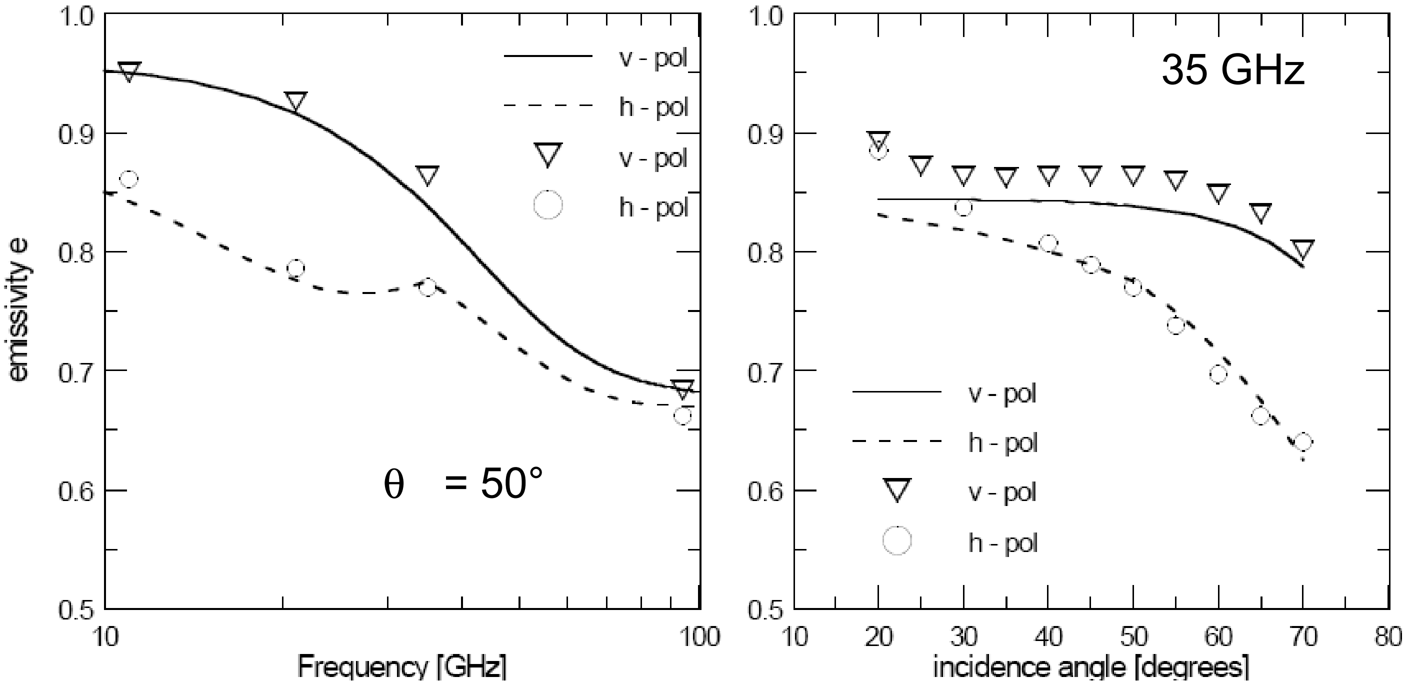
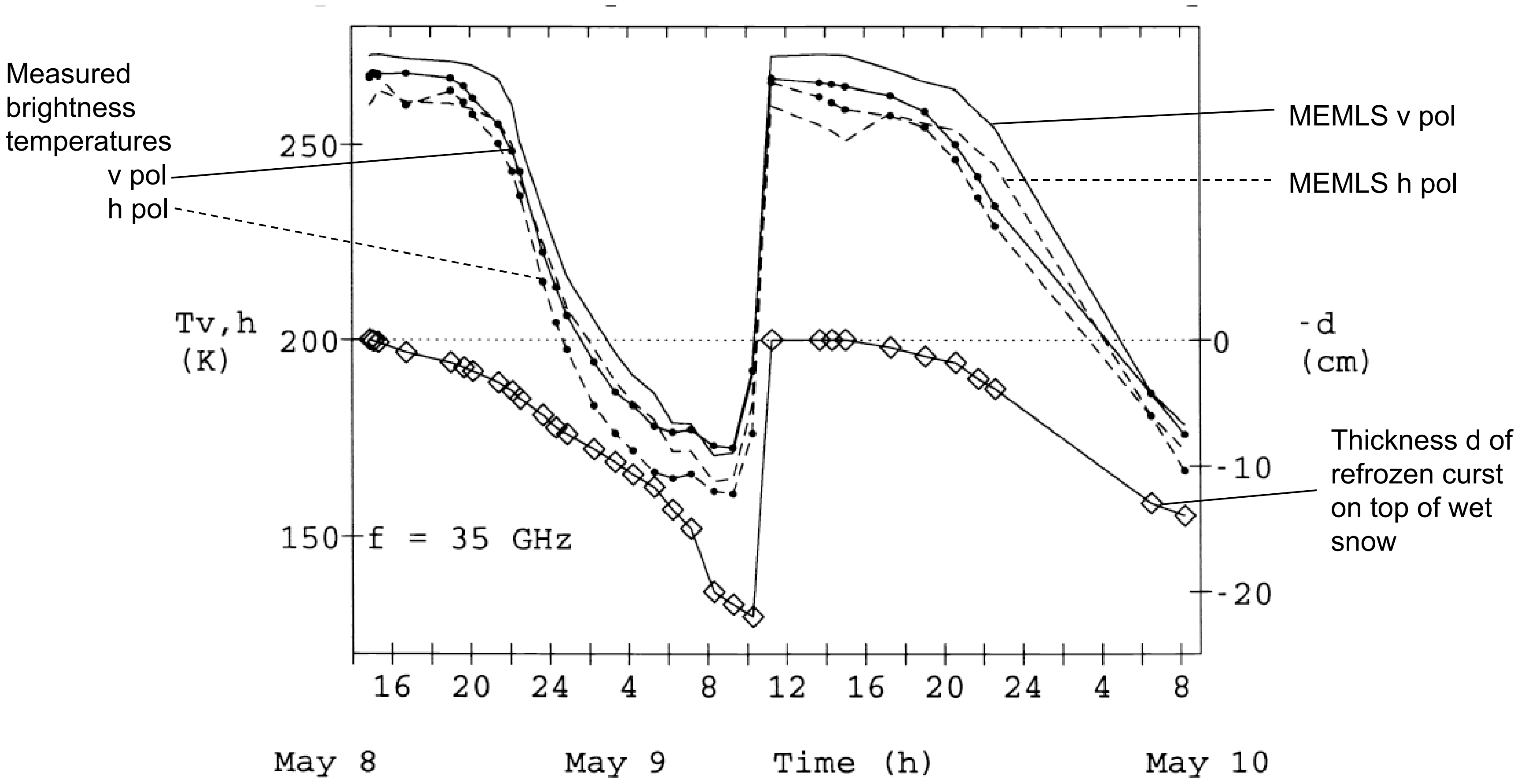


Figure 6: *Left: Emissivity versus frequency of the modified winter snow pack on 21 Dec. 1995. Right: Emissivity versus incidence angle of the same snow pack.*

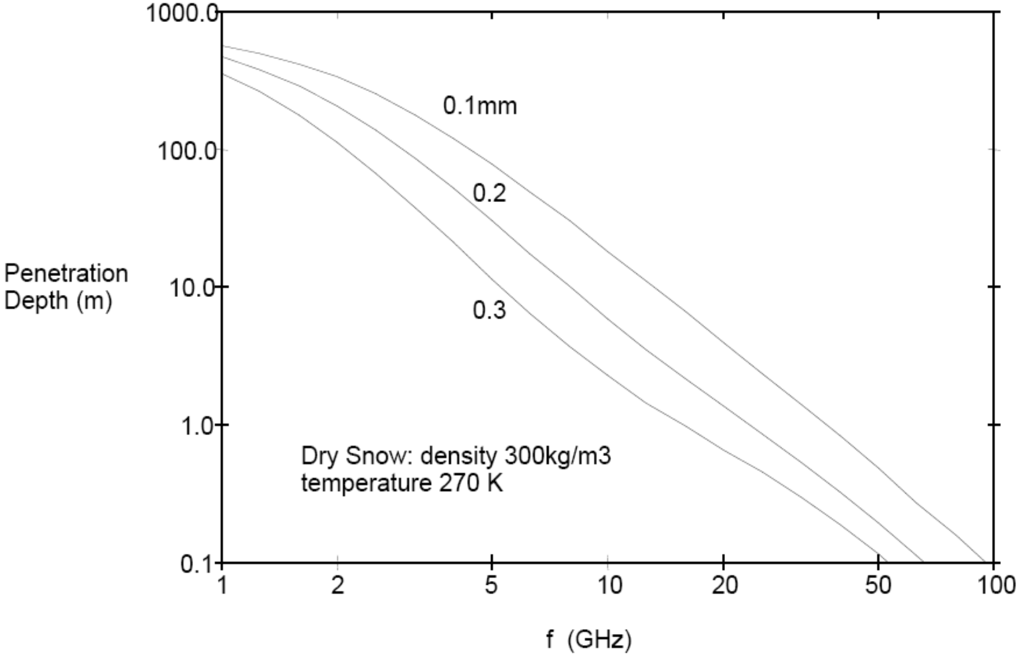
MEMLS validation 2

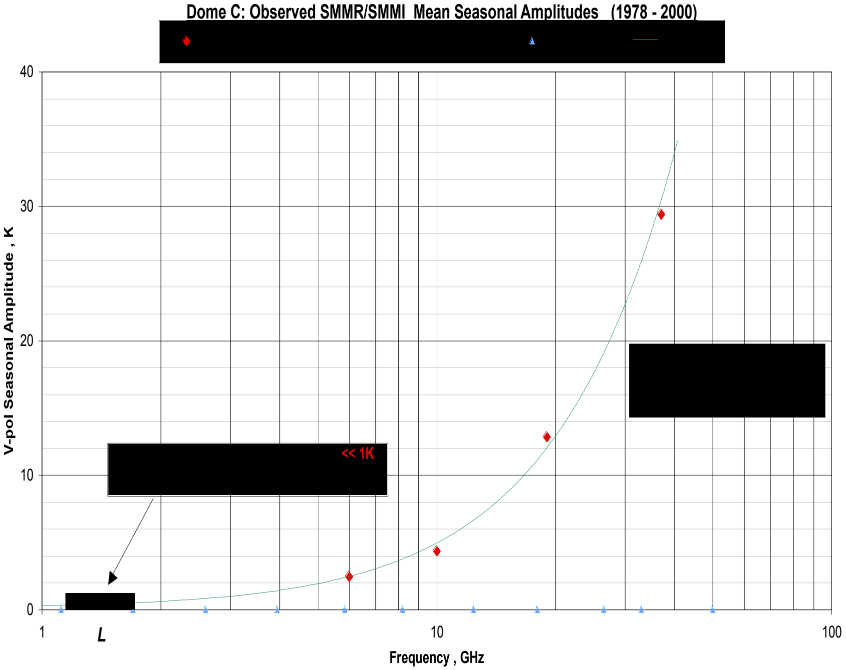
Example of MEMLS applied to a freeze - thaw cycle in spring snow (here at 35 GHz) from Matzler and Wiesmann (1999)



MEMLS simulates microwave penetration: dry snow

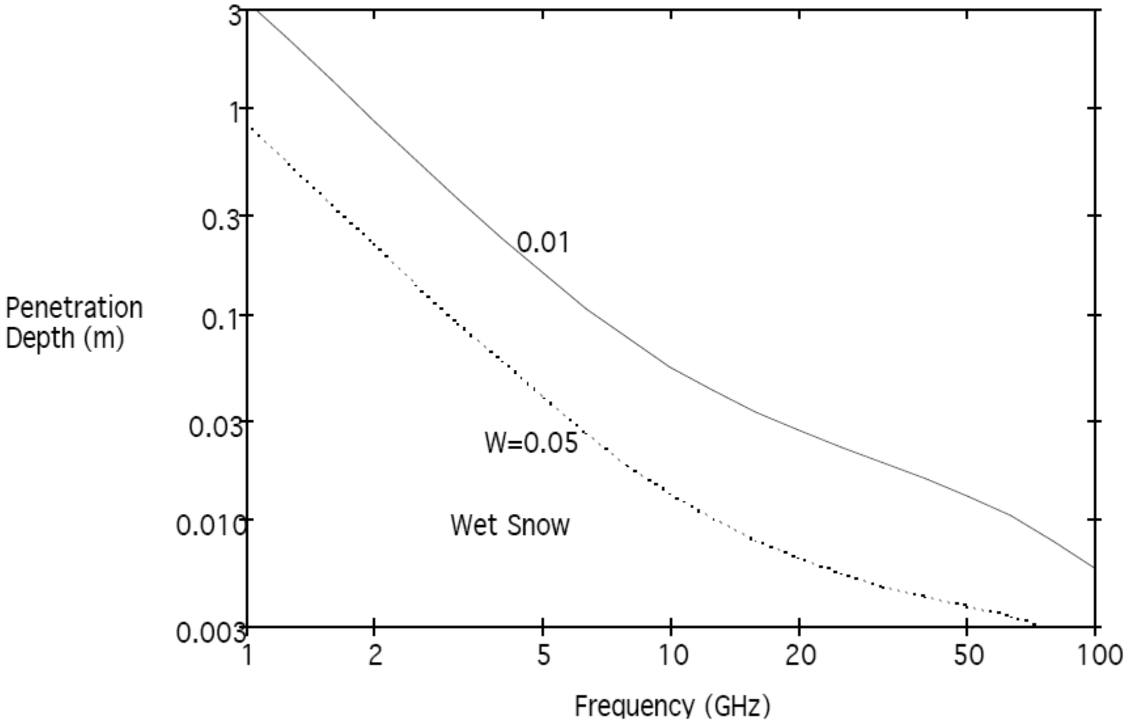
Example of penetration-depth computation versus frequency for different correlation lengths of dry snow - in accordance with seasonal $T_{b\,v}$ amplitude measured at Dome C, Antarctica





MEMLS simulates microwave penetration: wet snow

Example of penetration-depth computation versus frequency for wet snow, vol. liq. water content 1% and 5%, respectively



Direct Retrievals or Data Assimilation?

Direct retrievals do not account for information from the past, which is inherently present in snowpacks.

Kalman Filters can include this information, thereby improving the quality of products by an order of magnitude. The method builds on observed changes.

First simulation results for Snow Water Equivalent (SWE) and other parameters - using Ensemble Kalman Filtering - were found by Durand and Margulis (2006) for SSMI and AMSR frequencies from a 3-layer snowpack model coupled with MEMLS.

TABLE 1. The bias and rmse of the SWE estimate for assimilating different synthetic observations and for the open-loop simulation.

	Bias (cm)	Rmse (cm)
Open loop	25	27.1
SSM/I	3.36	4.0
AMSR-E	2.04	3.16
AMSR-E and MODIS	1.20	2.60

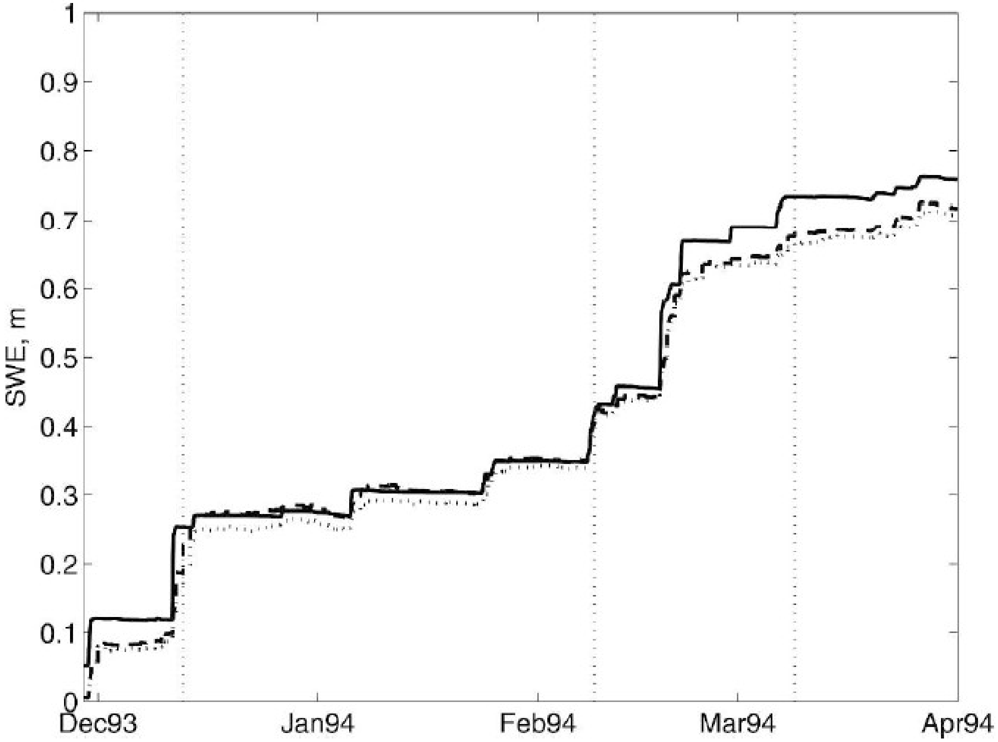
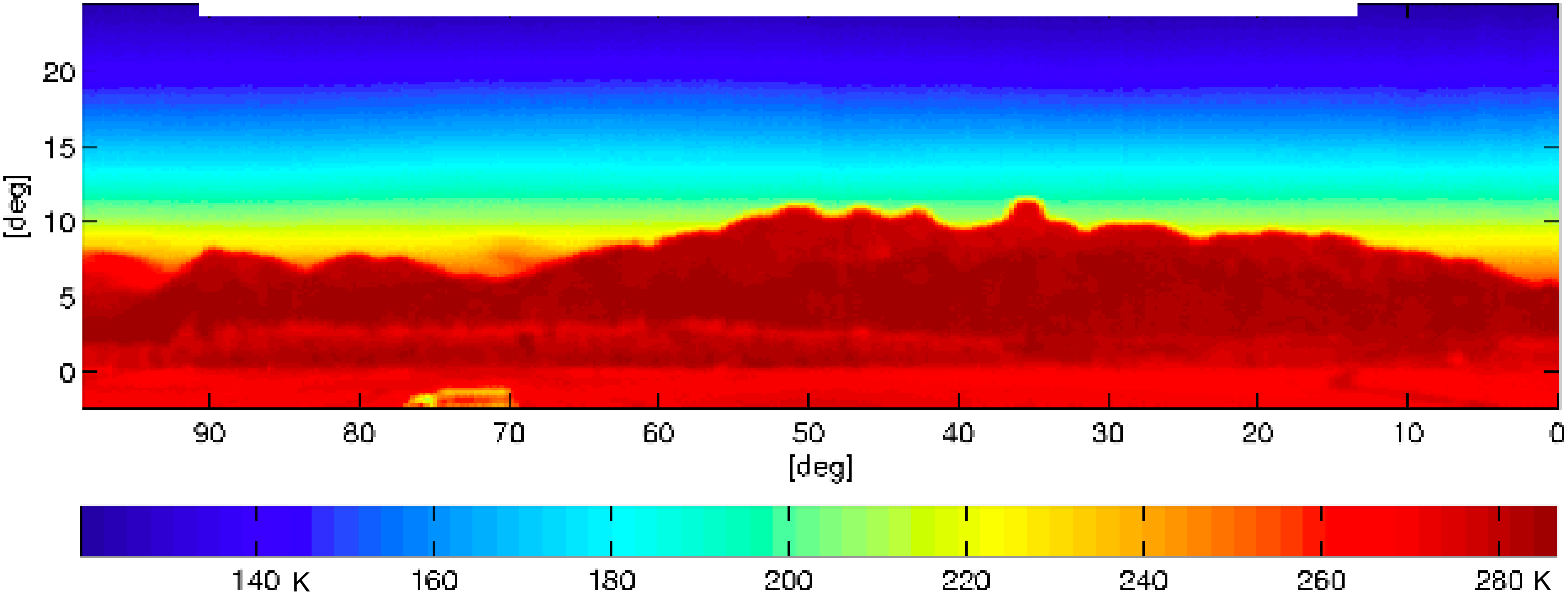


FIG. 9. Snow water equivalent estimates obtained by assimilating different subsets of passive microwave frequencies. The truth is the solid line, the result using SSM/I is the dotted line, and the result using AMSR-E is the dash–dot line. The vertical lines show the update times on 13 December, 9 February, and 9 March, which are discussed in detail.

Conclusions

1) There exists significant empirical and physical knowledge about microwave interaction with and emission from snowpacks, landscapes, vegetation and atmosphere.
2) Further improvements are needed. This applies also to snow metamorphism and the formation of the layered snowpack structure.
3) Modelling efforts and observations have contributed to the question on bistatic scattering, indicating that Lambert-like scattering is significant.
4) Satellite data assimilation together with coupled snow-physical and snow-emission models is far better than direct retrievals of snowpack parameters.

Snow-free landscape seen at 91 GHz: *Stockhorn Range, Switzerland*, from Stähli (2009)



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Simulation of upwelling brightness

RS92 Radiosonde data
Thun, Switzerland

Humid situation
e = 0.9
IWV = 32 kg/m²