The Development and Validation of a Multi-layer Multi-scattering Snow Model

Jiancheng Shi[1,2] , Jinyang Du[2]

1. Institute for Computational Earth System Science, University of California, Santa Barbara, U.S.A
shi@icess.ucsb.edu
2. Institute of Remote Sensing Applications, CAS, Beijing, China
djy@irsa.ac.cn

Workshop on Cold Regions Hydrology
April 28-30,2010 Innsbruck, Austria

Outline

- Basic Considerations
- Model Description
- Model Validation
- Comparisons and Analysis
  - Model Comparisons
  - Shape Effects
  - Snow Stratification
- Conclusion

Basic Considerations

- *To study natural snowpack which can be highly heterogeneous, we need to answer*
  - *Under what condition will ice particle shapes affect radar observations?*
  - *Can we describe multiple-layer snow by single-layer snow model?*

Non-spherical
ice particles

Snow stratification
(*Mark W. Williams*)

- *Multiple scattering effects also need to be considered*

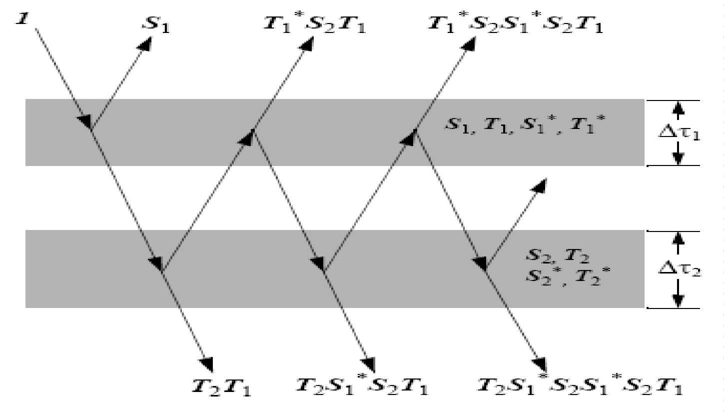
Model Description

- snow pack is divided into several layers along the vertical profile

- Matrix Doubling Algorithm calculates multiple scattering within each layer and the total phase matrix for the snow pack

$$S = S_1 + T_1 S_2 (I - S_1 S_2)^{-1} T_1$$

$$T = T_2 (I - S_1 S_2)^{-1} T_1$$

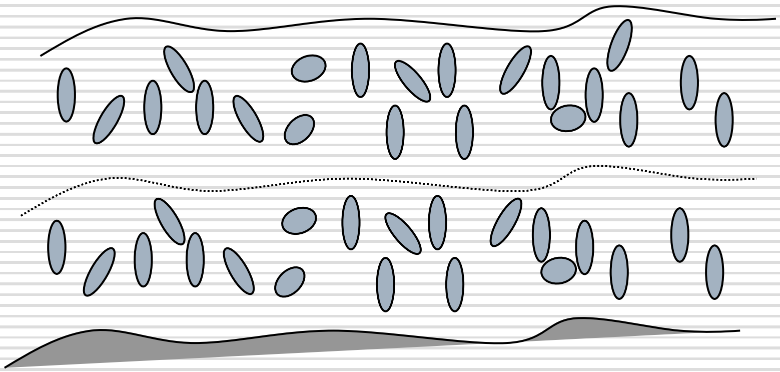


Matrix Doubling

Model Description

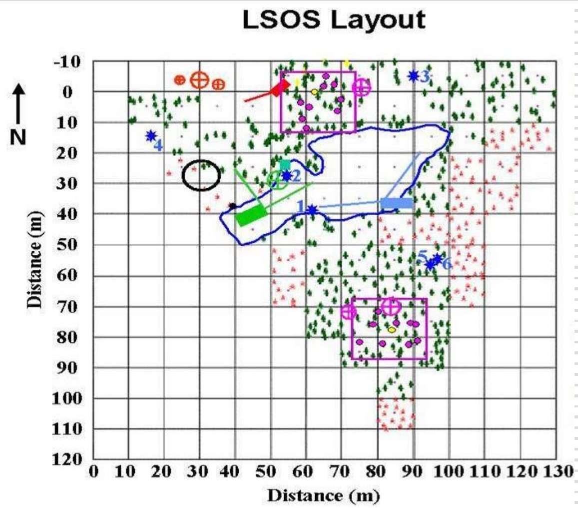
- ❖ellipsoid is adopted to account for the irregularity of the ice particles in natural snow and Rayleigh Approximation is used

- ❖AIEM is incorporated to describe the direct backscattering from soil surface and bi-static scattering from the boundaries



Modeled Snowpack

Model Validation- using CLPX datasets

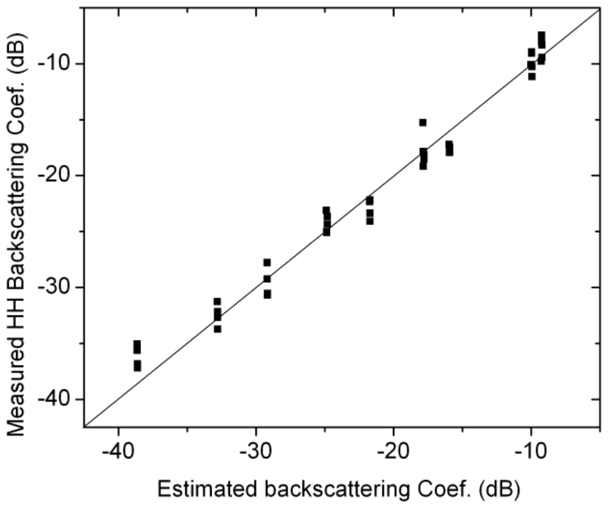


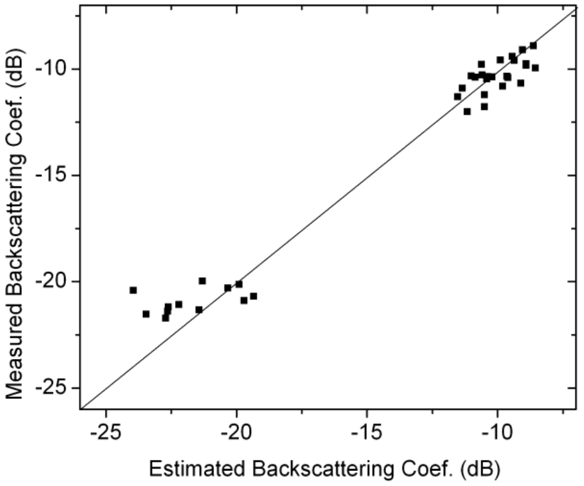
- University of Michigan truck-mounted scatterometers
  - Incident Angles: 20, 35,50 degrees
  - Frequencies: 1.25GHz and 15.5GHz
- Location: Local Scale Observation Site (LSOS) test site, is located within the CLPX Fraser Intensive Study Area
- Date: IOP3 (February 19 -25, 2003)

Model Validation- Input Parameters

- The **lower layer** is from 0 cm to 58 cm for all the days
- The **upper layer** is from 59 cm to the top of the snow pack.
- A fixed axis ratio 0.3 has been assumed
- Snow density of each layer is calculated from snow-pit measurements
- The retrieved surface roughness parameters: RMS-height 0.7 cm and correlation length 14 cm
- Volumetric soil moisture 18%
- The selected radii are 0.3 mm (upper layer) and 0.5 mm (lower layer)

Model Validation - Results





❑ L-Band Data were used to estimate ground parameters (Left figure)

(RMSE 1.5 dB, 1.1 dB and 1.8 dB for VV, HH and HV polarizations)

❑ Ku-Band Data were used to examine the model (right figure)

(Root MSEs 0.8 dB, 0.6 dB and 1.5 dB for VV, HH and HV polarizations)

Model Validation – Using SARALPS-2007 datasets

- SARALPS-2007 Campaign supported by ESA
  - Supporting CoReH2O satellite mission
  - Collecting experimental data on X- and Ku- band backscattering of snow-covered ground using a ground-based SAR (GB-SAR)
- Location: Kühtai / Untere Issalm and Leutasch in the Austria’s Alps
- Duration: Jan. 2007 ~ Mar. 2007

Model Validation- Input Parameters

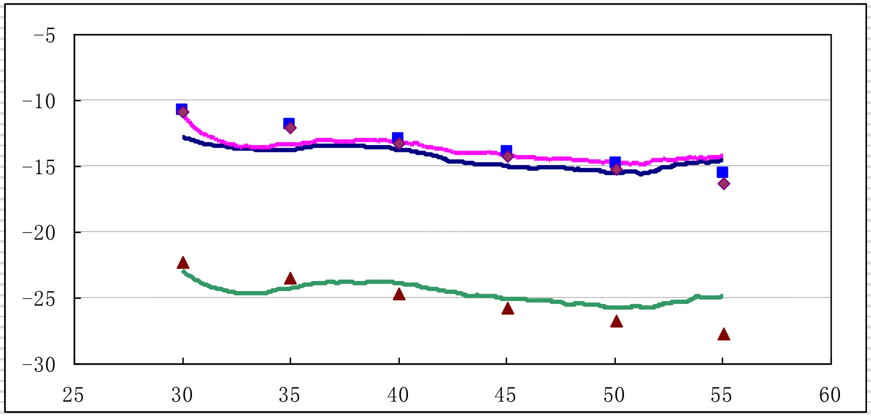
- Surface roughness, snow density and depth are directly from field measurements
- Short cylinder with an aspect ratio 0.5 is assumed to represent ice particle
- Particle size is the best-fitting value that is within the field observation range

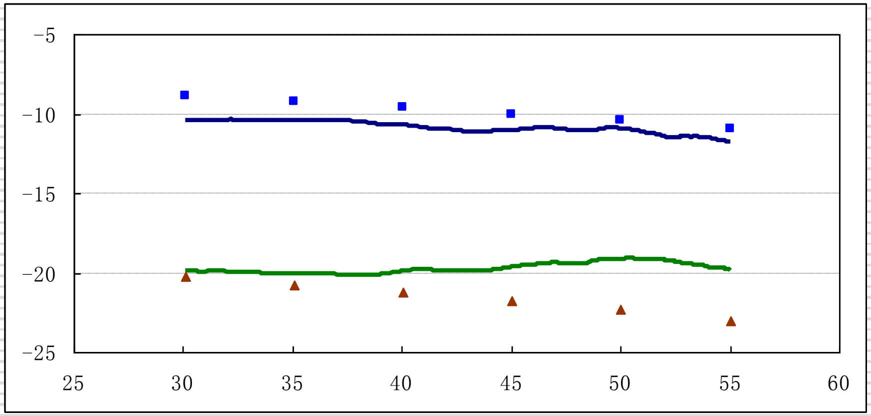
Input parameters for Model Simulations

	Jan. 17	Feb. 5
RMS height I*	0.24 cm	0.38 cm
Correlation length I*	25 cm	20.5 cm
RMS height II*	0.95 cm	0.95 cm
Correlation length II*	18 cm	18 cm
Ground Dielectric Value	5.2	5.2
Particle Radius	0.50 mm	0.54 mm
Snow Depth	38 cm	36.6 cm
Snow Density	260.5 kg/m3	278.0 kg/m^3

* I: air-snow surface; II: snow-ground surface

Model Validation – Results



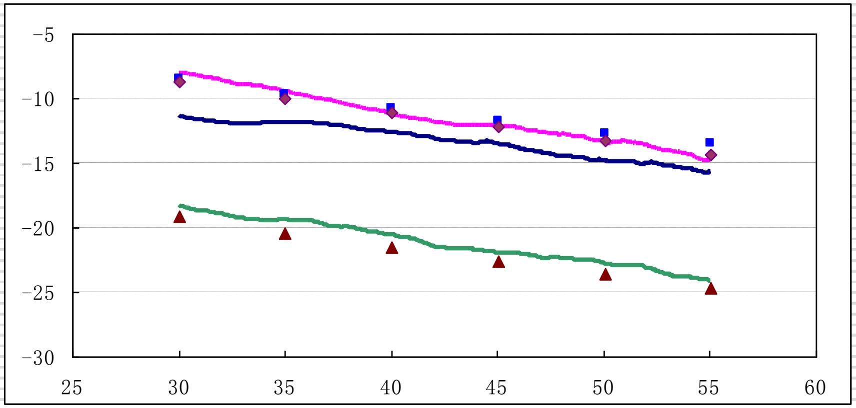


RMSEs 1.38dB, 0.98dB and 1.32dB for VV, HH and VH respectively (X-Band)

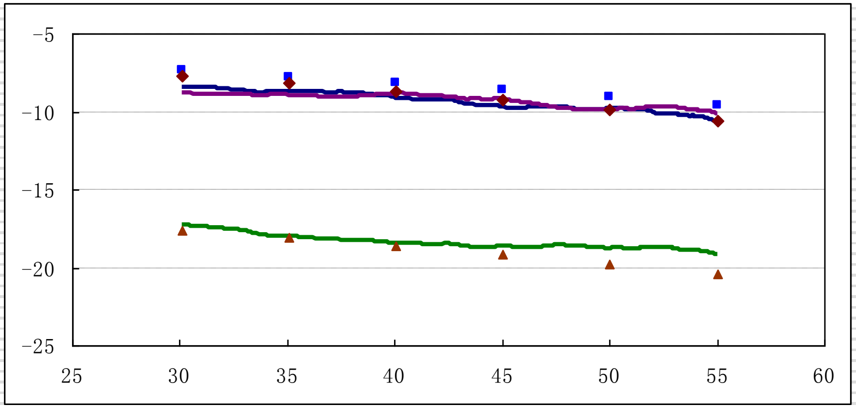
RMSEs 1.06 dB and 2.13 dB for VV and VH respectively (Ku-Band)

Comparison between simulation and X/Ku-Band measurements (Kuhtai Jan. 17)

Model Validation – Results



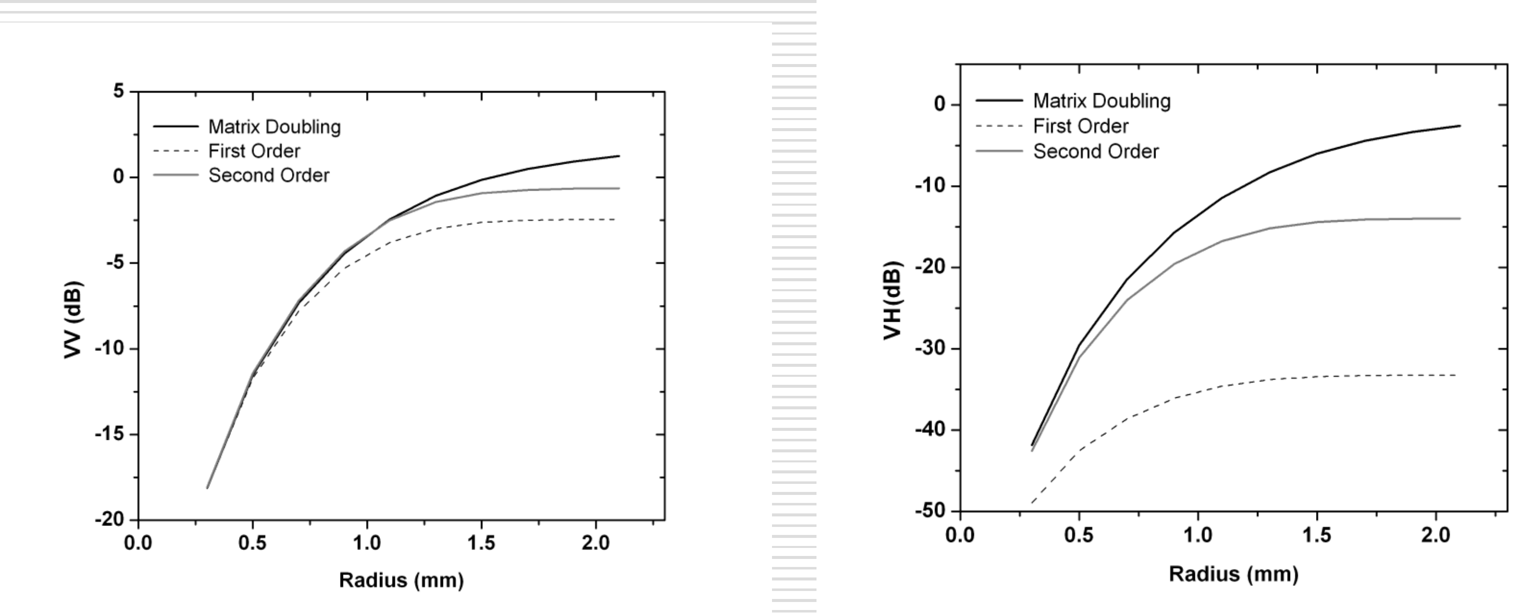
RMSEs 2.16dB, 0.39dB and 0.83dB for VV, HH and VH respectively (X-Band)



RMSEs 1.00dB, 0.57dB and 0.71dB for VV, HH and VH respectively (Ku-Band)

Comparison between simulation and X/Ku-Band measurements (Kuhtai Feb. 05)

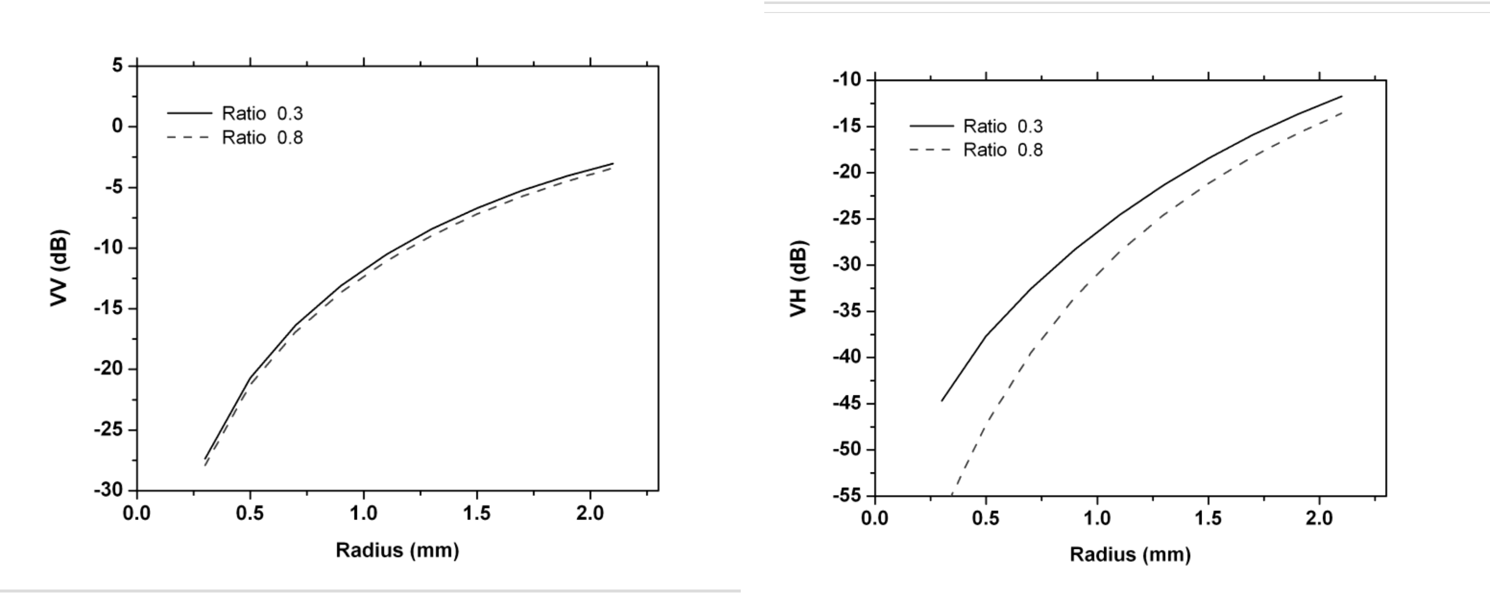
Analysis – Multiple scattering effects



Volume backscattering coefficient for co-polarization (left) and cross-polarization (right) as a function of albedo

(frequency **17**GHz; Incident Angle 40 degree,SWE 100 mm)

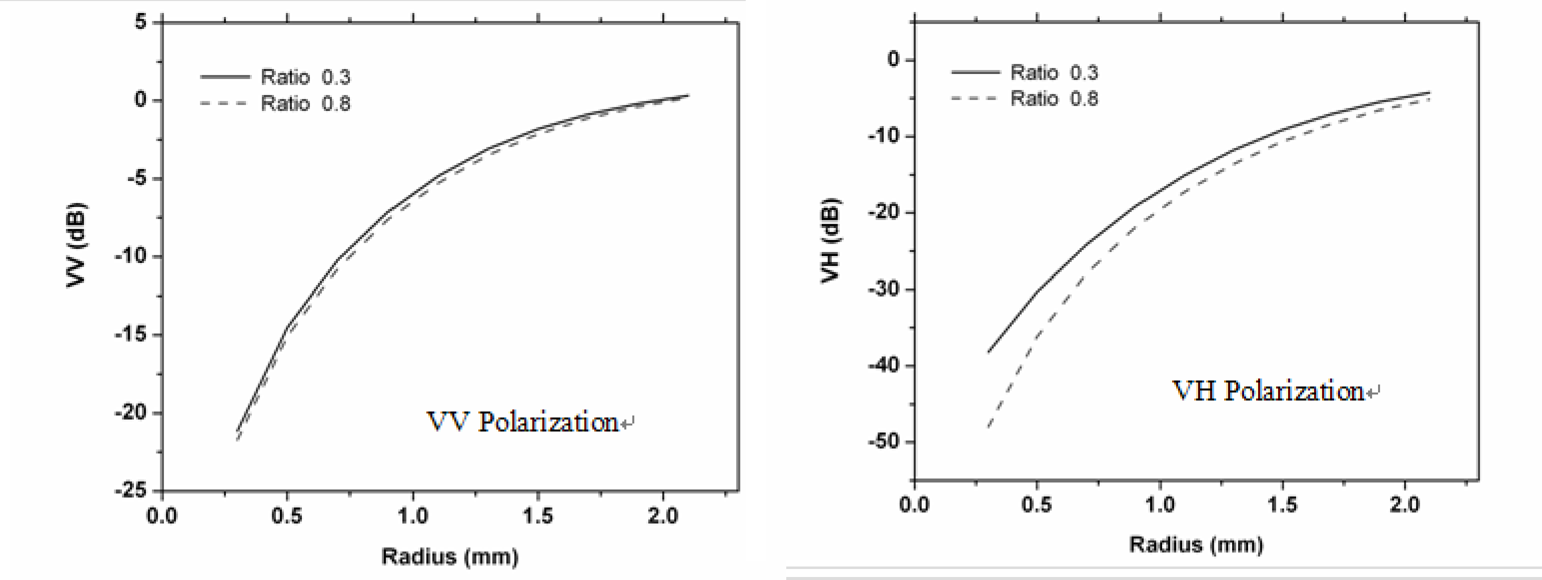
Analysis – Shape Effects



Volume backscattering coefficients of Co- (Left)and cross- (right) polarizations as a function of albedo with different particle shapes

(frequency **9.6** GHz; Incident Angle 40 degree,SWE 100 mm)

Analysis – Shape Effects



Volume backscattering coefficients of Co- (Left)and cross- (right) polarizations as a function of albedo with different particle shapes

(frequency **9.6** GHz; Incident Angle 40 degree, SWE 450 mm)

Stratification Analysis- Theory

Volume scattering from two-layer snowpack can be theoretically described by an equivalent one-layer snow if (1) dielectric difference between different layers is neglected and (2) only single scattering is considered

$$\sigma_{pp\_1} = 0.75 \cdot T_{pp}^2 \cdot \omega_1 \cdot \mu \left[1 - \exp(-2\kappa_{e1} \cdot d_1 / \mu) \right]$$

$$\sigma_{pp\_2} = 0.75 \cdot T_{pp}^2 \cdot \omega_2 \cdot \mu \left[1 - \exp(-2\kappa_{e2} \cdot d_2 / \mu) \right] \cdot \exp(-2\kappa_{e1} \cdot d_1 / \mu)$$

⇓

$$\sigma_{pp\_total} = 0.75 \cdot T_{pp}^2 \cdot \omega \cdot \mu \left[1 - \exp(-2\kappa_e \cdot (d_1 + d_2) / \mu) \right]$$

$$\omega = \frac{\sigma_{pp\_1} + \sigma_{pp\_2}}{0.75 \cdot T_{pp}^2 \cdot \mu \left[1 - \exp(-2\kappa_e \cdot (d_1 + d_2) / \mu) \right]}$$

$$\kappa_e = (d_1 \cdot \kappa_{e1} + d_2 \cdot \kappa_{e2}) / (d_1 + d_2)$$

Stratification Analysis -Simulation

Simulation Inputs for a two-layer snow

	From	To	Step
Volf_1	**0.1**	**Volf_2**	**0.1**
Volf_2	**0.1**	**0.4**	**0.1**
Depth_1	**0.1 m**	**1.0 m**	**0.2 m**
Radius_1	**0.3 mm**	**Radius_2**	**0.3 mm**
Radius_2	**0.3 mm**	**2.4 mm**	**0.3 mm**

Inputs for a one-layer snow

	From	To	Step
Volf	**0.1**	**0.4**	**0.01**
Radius_1	**0.2 mm**	**3.0 mm**	**0.1 mm**

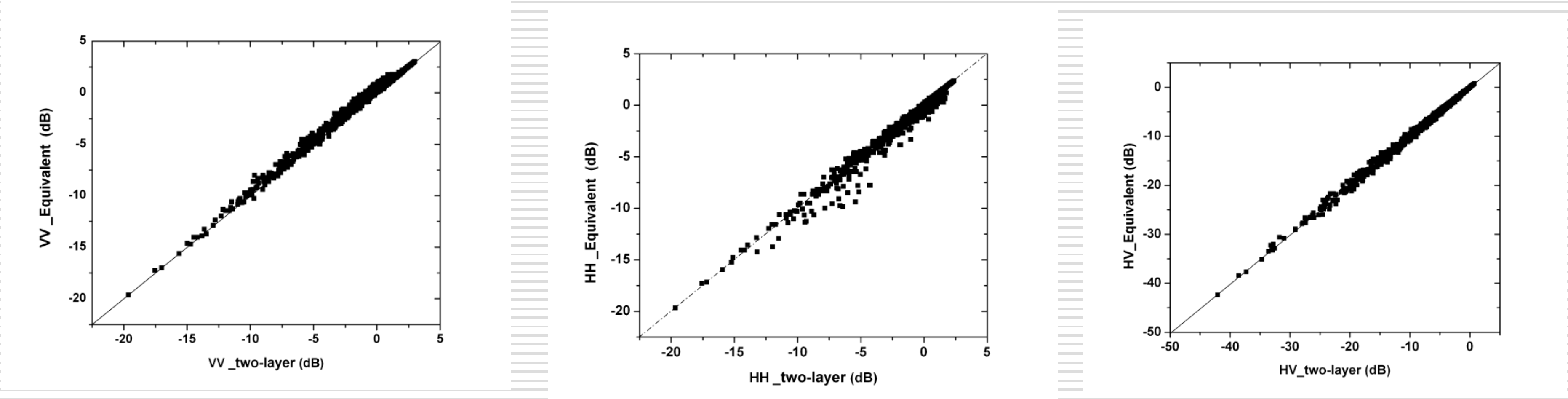
*Total Depth 1.1 meter; ellipsoid axis ratio 0.7; incident angle 50 degree; frequency 15.5 GHz

⇩

To find equivalent one-layer snow

(minimum difference in radar backscattering and same SWE)

Stratification Analysis - Results



RMSE=0.38 dB

RMSE=0.45 dB

RMSE=0.31 dB

Comparisons between simulated radar backscattering from two-layer snowpack (X-Axis) and equivalent one-layer snowpack (Y-Axis)

(Left: VV Middle:HH Right:HV)

Conclusion

- The proposed model shows good agreement with CLPX measurements
- Comparisons between 1st-order, 2nd-order and high-order snow model showed the valid conditions for each model
- Shape effects can be important for cross-polarized return when scattering is weak or moderate

Conclusion

- Equivalent one-layer snow can be used to study the volume scattering from multiple-layer snow, especially for VV and HV polarizations
- The use of equivalent one-layer snow can underestimate HH polarized return when dielectric difference between different snow layers is significant