ELECTRICAL ENGINEERING AND COMPUTER SCIENCE
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Wednesday, August 9th, 8:45 - 9:00AM
Session: Modeling and Snow Measurements

Radiation Laboratory

Physical Model based SWE Retrieval Algorithm Using X- and Ku- band Radar Backscatter

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SNOWEX

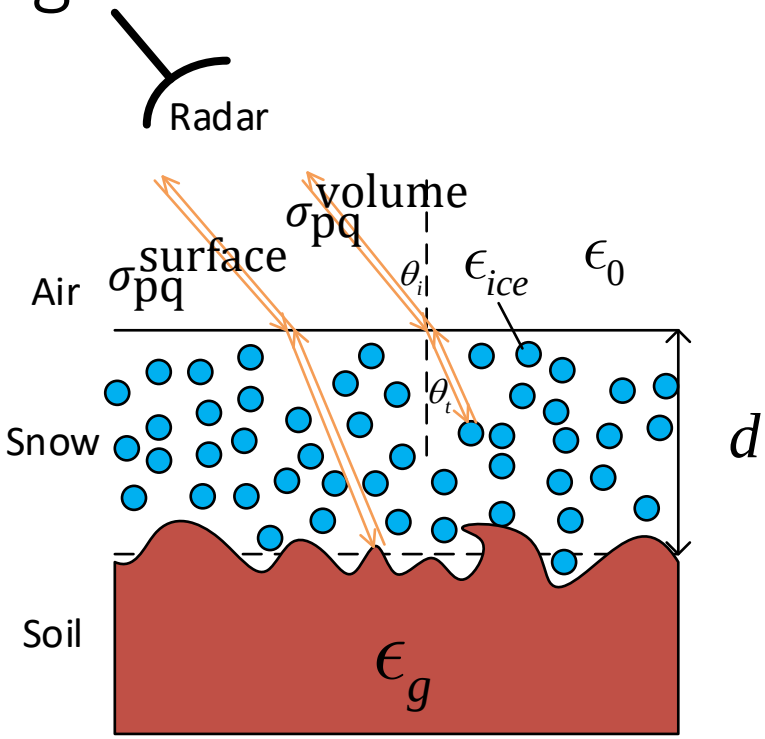
Outlines

A. Background scattering subtraction

B. Forward model:
   i. Bicontinuous / DMRT model and regression training
   ii. Parameterized model: only 2 parameters ω_X and τ_X

C. Physical model based SWE retrieval algorithm
   i. Radar retrieval algorithm
   ii. Classify backscatter w.r.t. ω_X
   iii. SWE retrieval performance Using SnowSAR backscatter σ_{VV} (9.6 GHz and 17.2GHz)

Radar backscattering: volume and surface scattering



Poster 20

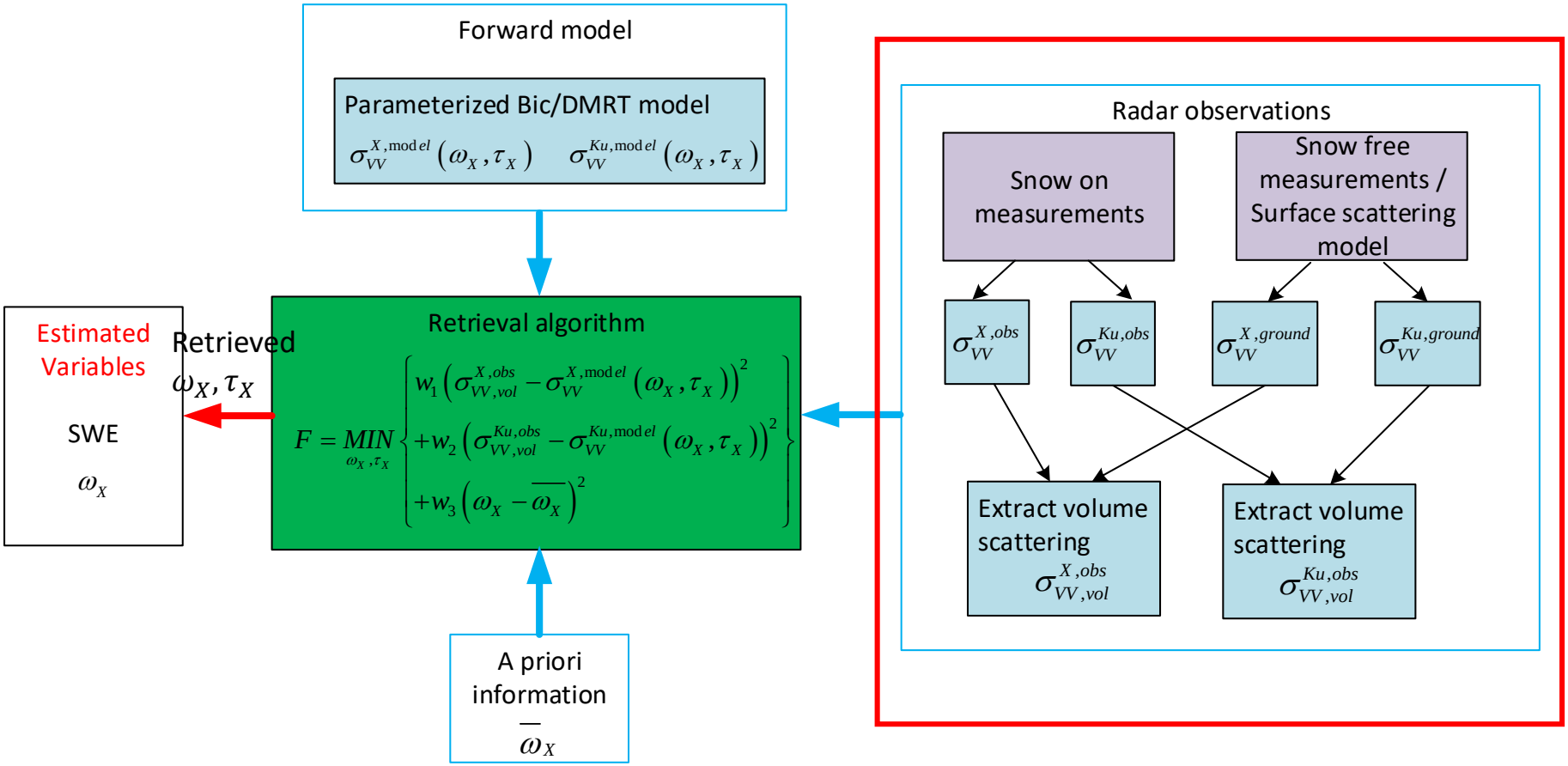
Shurun Tan et al., "Assessment of Background Scattering at X- and Ku-band in Snow Remote Sensing".

$$\sigma_{pq}^{total} = \sigma_{pq}^{volume} + \sigma_{pq}^{surface} \exp\left(-\frac{2\tau}{\cos\theta_t}\right)$$

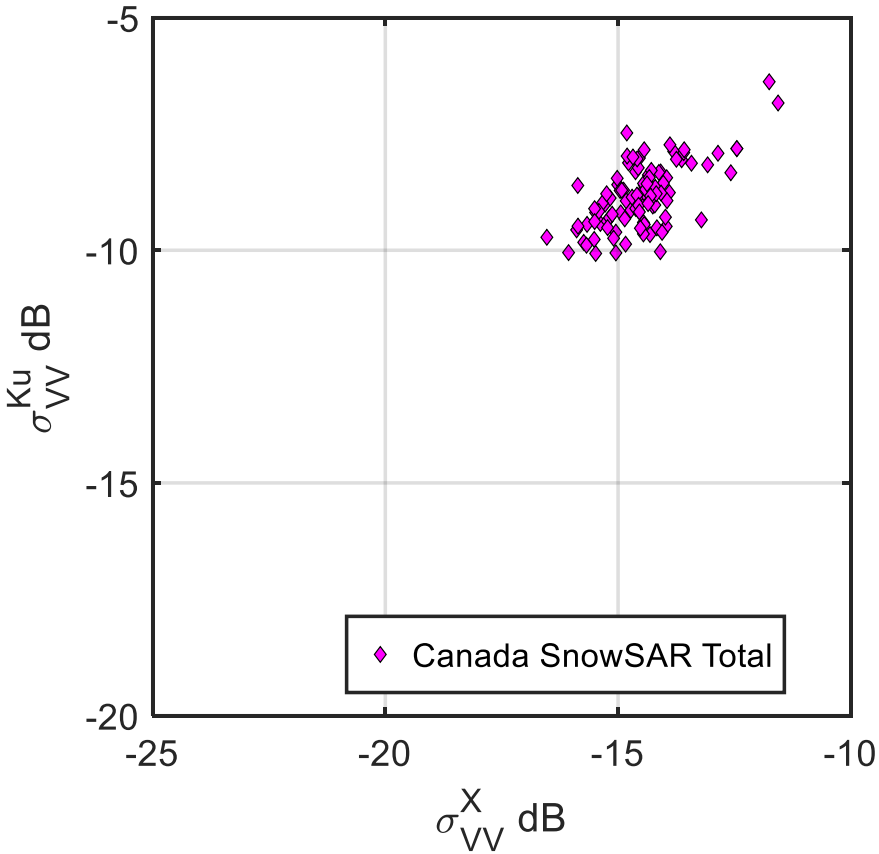
σ_{pq}^{volume}: volume scattering from snowpack → **Give SWE**

$\sigma_{pq}^{surface}$: surface scattering from ground

Background scattering subtraction in the SWE retrieval algorithm

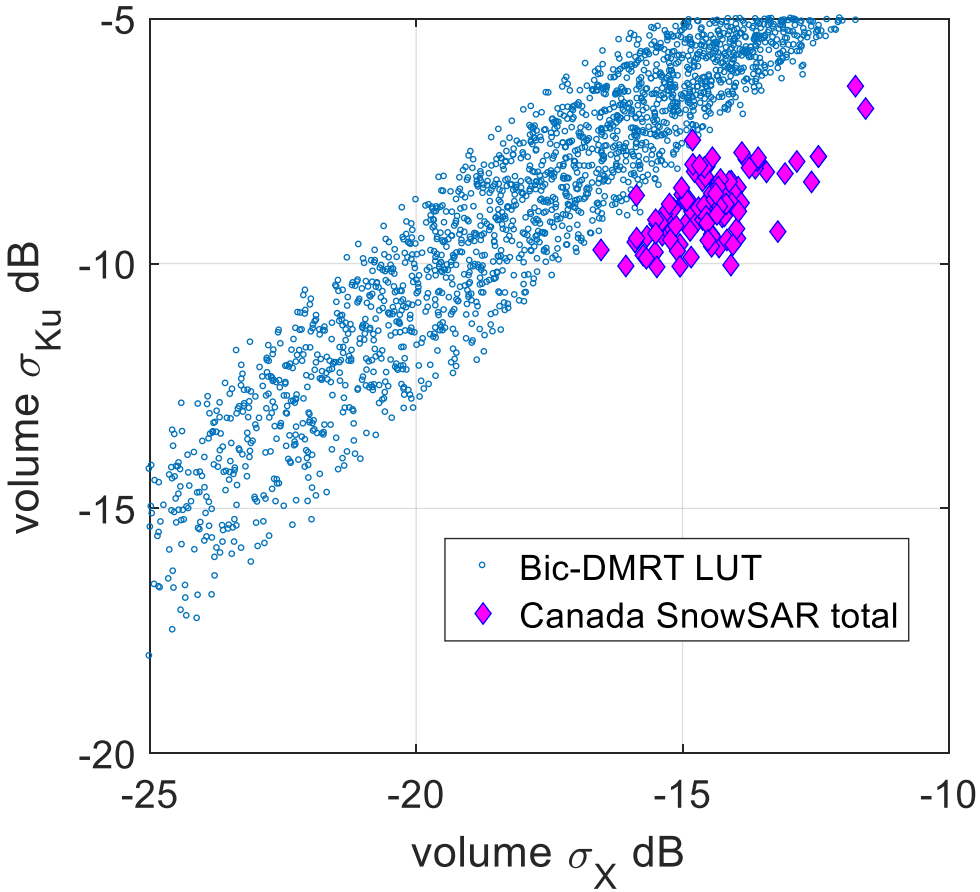


SnowSAR (Canada TVC 2013) X- and Ku-band backscatter: raw data



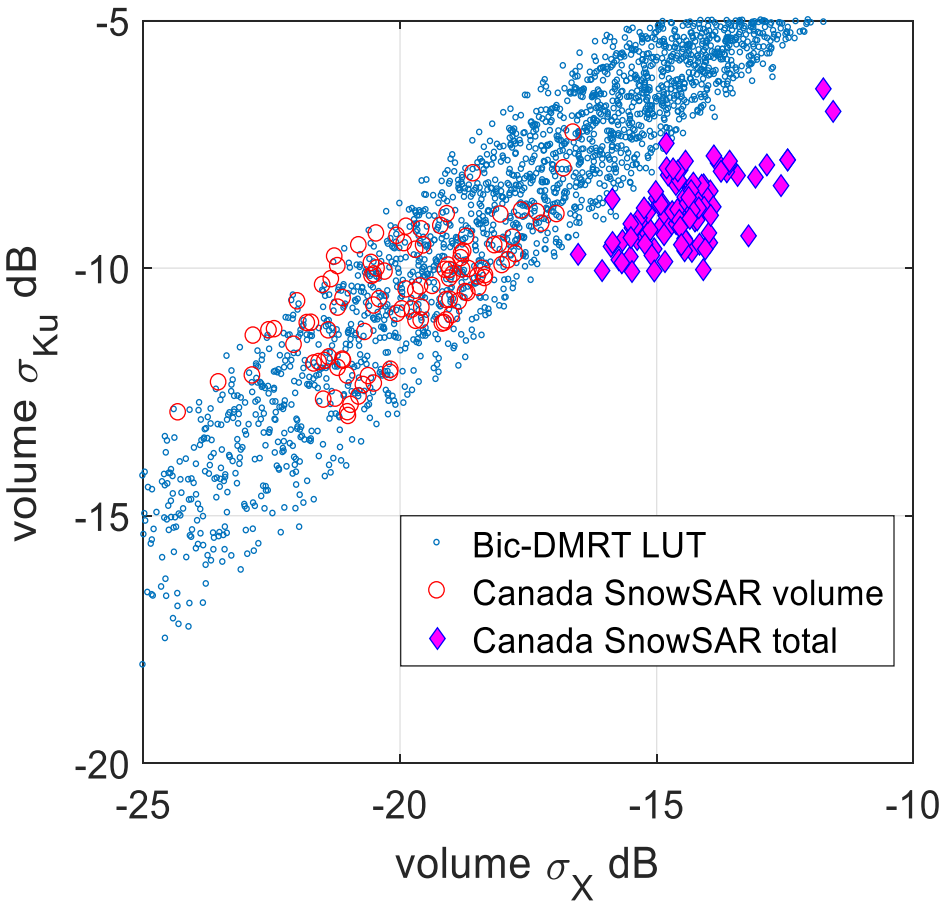
- σ_{VV}^{X}: ranged from -18dB to -11dB
- σ_{VV}^{Ku}: ranged from -11dB to -6dB

Bic/DMRT LUT compare with Canada SnowSAR



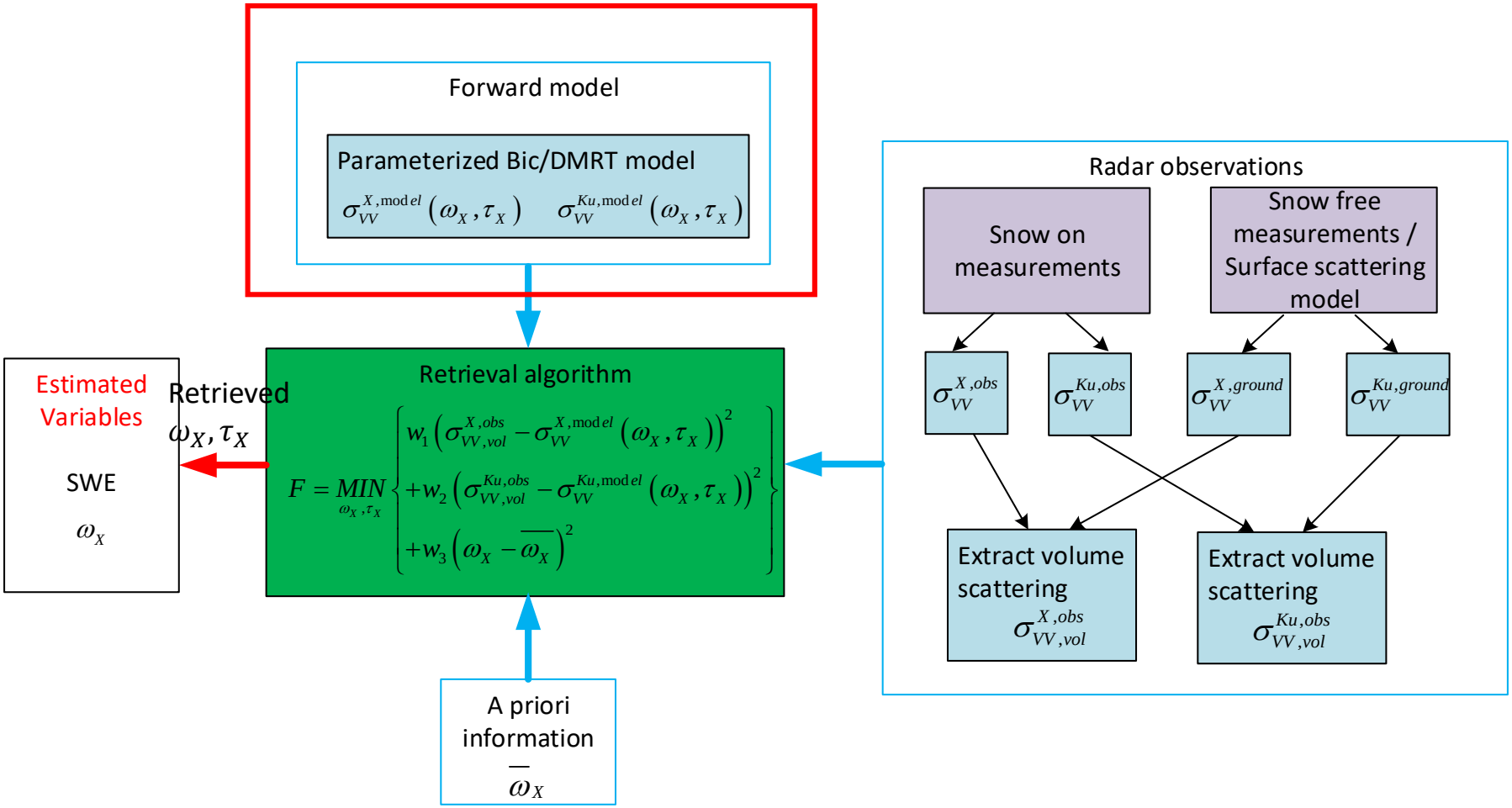
- Model: volume scattering
- SnowSAR data: volume scattering + background scattering

Background scattering subtracted from raw data



- Volume scattering of SnowSAR within model predictions
- Shift data more in X band than Ku band
- Larger dynamic range in volume scattering

SWE retrieval algorithm flow chart



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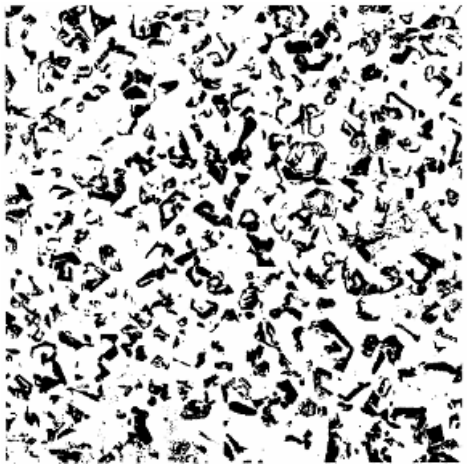
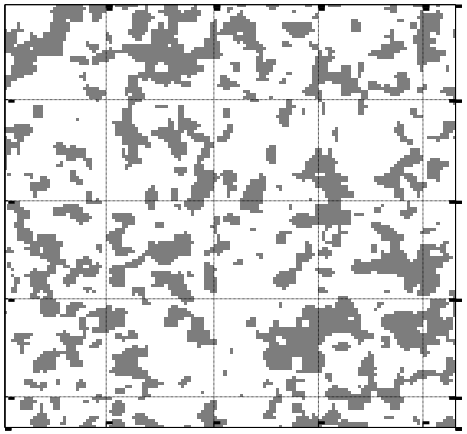
Computer Generated Snow: **Bicontinuous Medium**



A. Wiesmann, C. Mätzler, and T. Weise, "Radiometric and structural measurements of snow samples," *Radio Sci.*, vol. 33, pp. 273-289, 1998.

Real snow cross section image

5mm
10mm
15mm
20mm

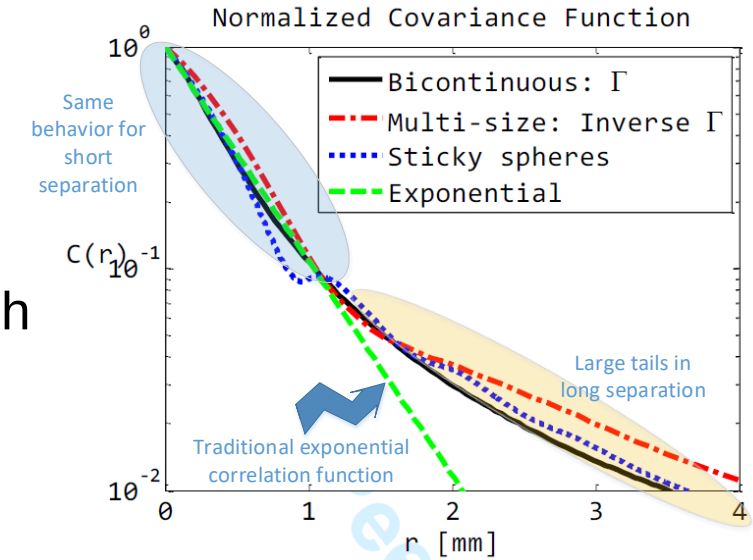


Computer-generated

Poster 7

Weihui Gu et al., "DMRT Models for Active and Passive Microwave Remote Sensing"

Comparison through correlation function



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Snow homogeneous: Bicontinuous Dense Media Radiative Transfer (Bic/DMRT)

coherent

Solve Maxwell's Eq. over a block of computer snow ($3\lambda - 5\lambda$) with DDA: get effective P, κ_e, ε_{eff}

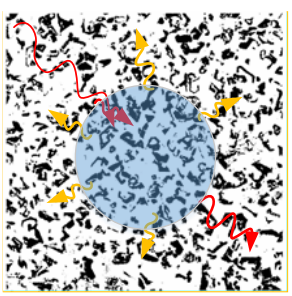
incoherent

Substitute the effective parameters into & Solve RTE:

Backscatter: σ

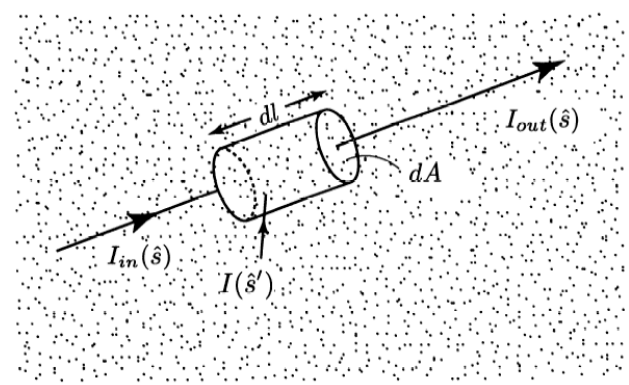
Discrete Dipole Approximation (DDA)

$$\bar{E}(\bar{r}_i) = \bar{E}_{inc}(\bar{r}_i) + \frac{k^2}{\varepsilon}\sum_{j=1}^{N} \bar{\bar{G}}(\bar{r}_i,\bar{r}_j)\cdot \Delta V_j(\varepsilon_r(\bar{r}_j)-1)\bar{E}(\bar{r}_j)$$



Radiative Transfer Equation

$$\frac{dI(\hat{s})}{ds} = -\kappa_e I(\hat{s}) + \int d\hat{s}'\, P(\hat{s},\hat{s}')I(\hat{s}')$$



$P(\hat{s},\hat{s}')$: phase matrix

κ_e: extinction coefficient

$I(\hat{s})$: Intensity in direction $\hat{s}$

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Poster 7

Weihui Gu et al.

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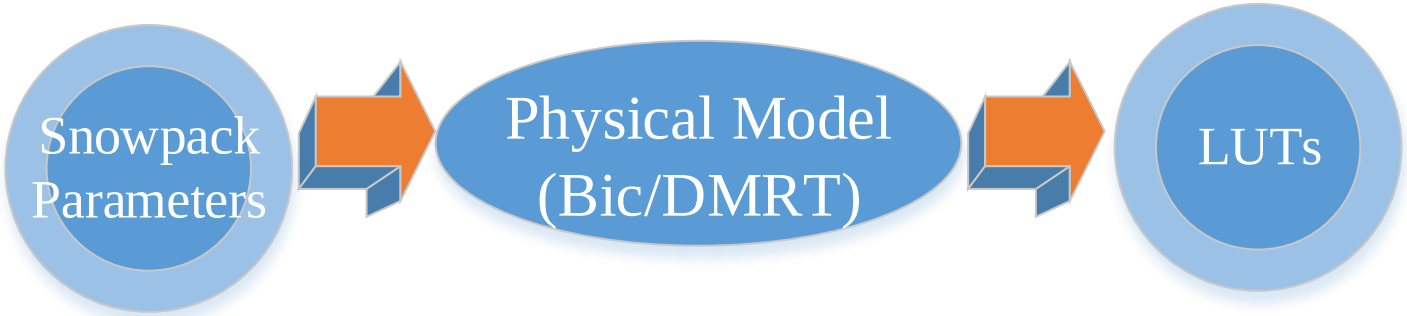
Look-up table (LUT) of Bic/DMRT



Parameters	Minimum	Maximum	Interval
Volume fraction f_v	10%	45%	5%
b parameter	0.6	1.6	0.2
$\langle\zeta\rangle$ parameter (m^{-1})	5000	15000	2000
Snow depth d (m)	0.1	1.2	0.1

SWE	$(\langle\zeta\rangle, b, \rho_{snow}, d)$	$(\sigma_{VV}^{X}, \sigma_{VV}^{Ku})$ dB	ω_X	τ_X	…
55.02	(9000, 1.2,10%,0.6)	(-15.3, -10.6)	0.6805	0.0166	…
64.19	(9000, 1.2,10%,0.7)	(-14.9, -10.1)	0.6805	0.0194	…
73.36	(9000, 1.2,10%,0.8)	(-14.6, -9.7)	0.6805	0.0221	…
…	…	…	…	…	…

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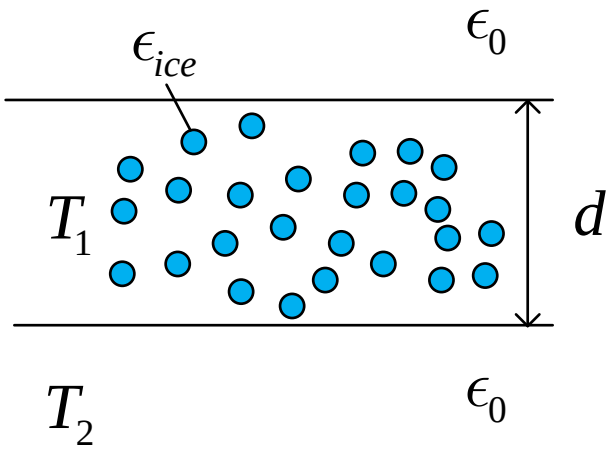
Parameterization: scattering albedo ω and optical thickness τ, retrieve τ_a



κ_s: scattering coefficients
κ_a: absorption coefficients
κ_e: extinction coefficients

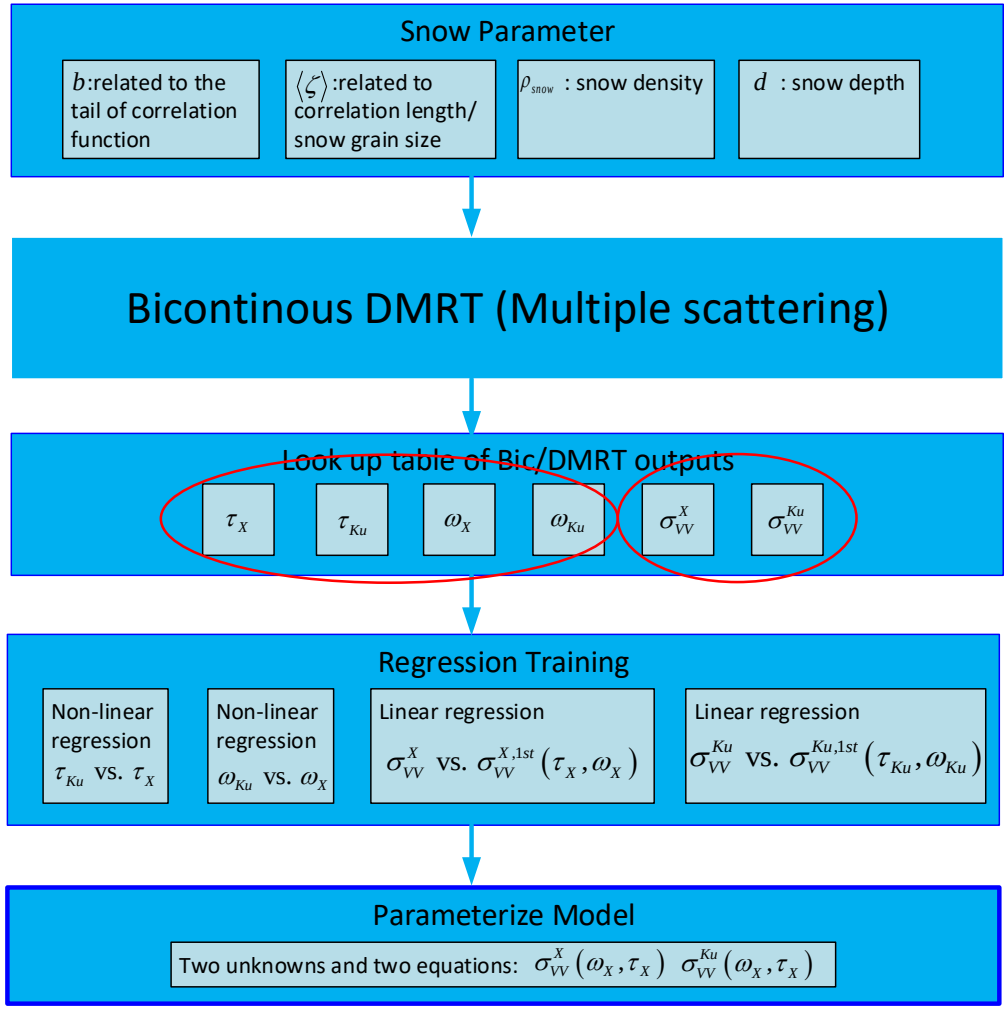
$$\kappa_e = \kappa_a + \kappa_s$$

- Scattering albedo: $$\omega = \frac{\kappa_s}{\kappa_s + \kappa_a} = \frac{\kappa_s}{\kappa_e}$$
- Optical thickness: $$\tau = \kappa_e d$$
- Absorption loss is proportional to SWE

$$\tau_a = (1-\omega)\tau = \kappa_a\, d \propto \mathrm{SWE}$$

- Two frequencies, four parameters: $\omega_X, \tau_X; \omega_{\mathrm{Ku}}, \tau_{\mathrm{Ku}}$

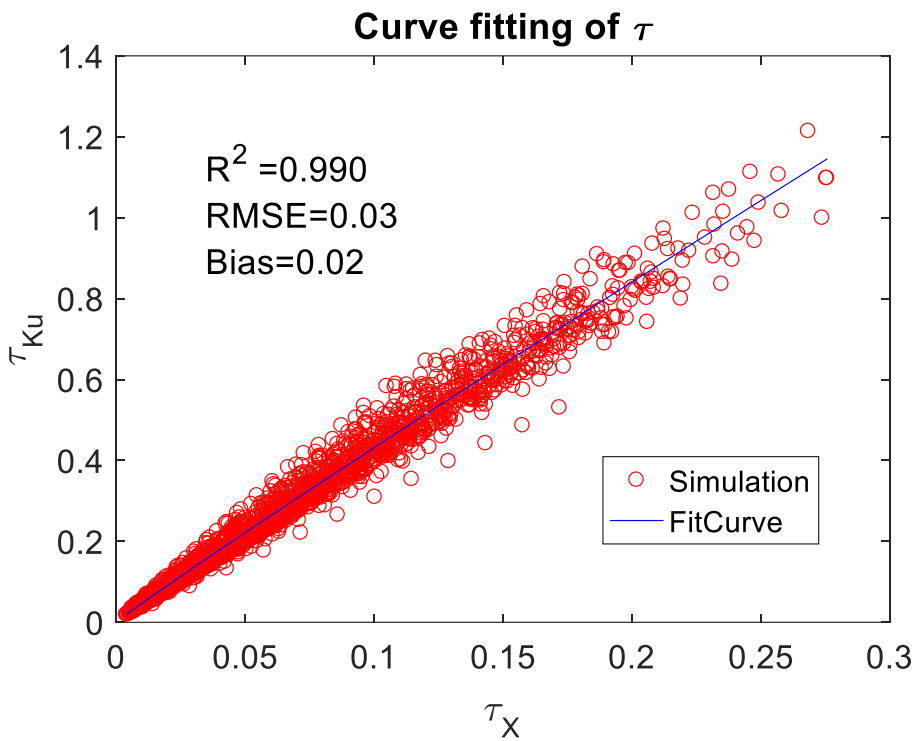
Regression training: reduce $\omega_{Ku}, \omega_X, \tau_{Ku}, \tau_X$ to ω_X, τ_X



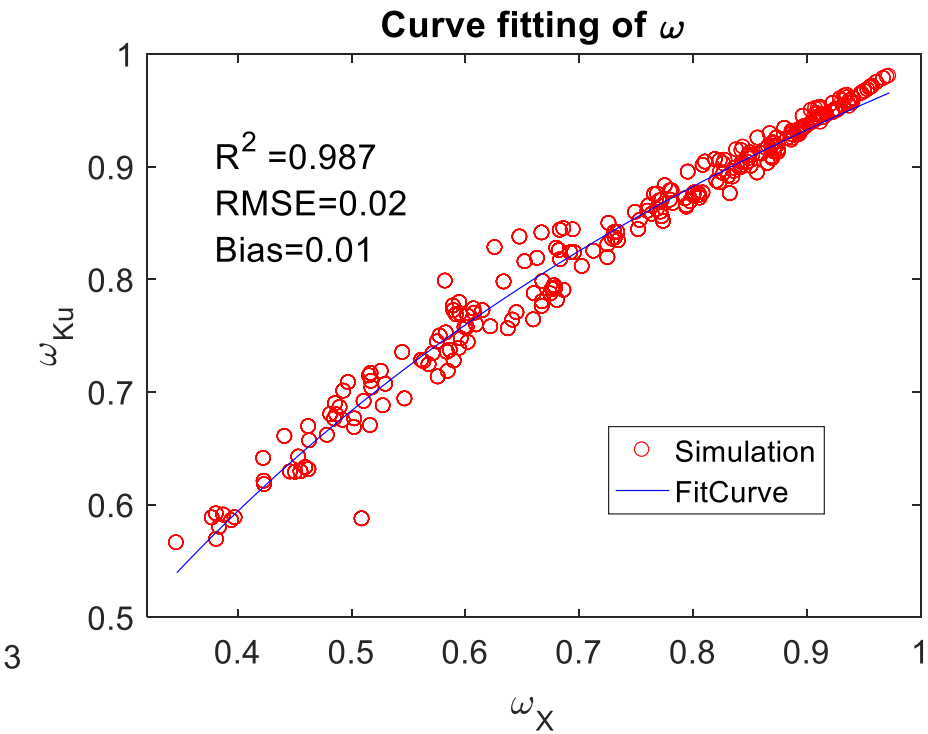
- ❑ Four parameters
- ❑ Two observations

- ❑ Two parameters
- ❑ Two observations

Regressions between τ_{Ku} and τ_X, ϖ_{Ku} and ϖ_X: based on LUT

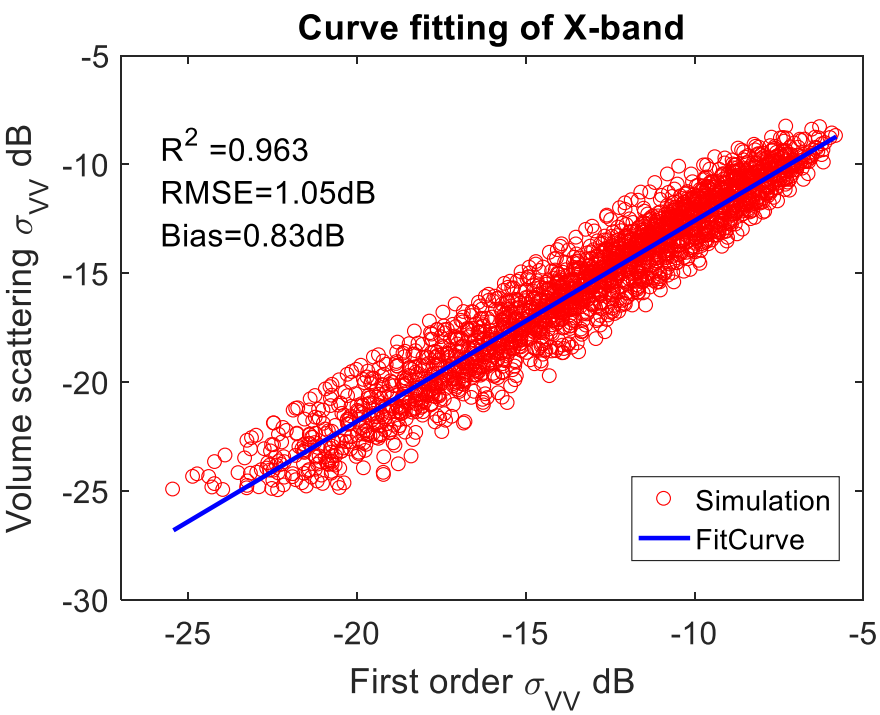


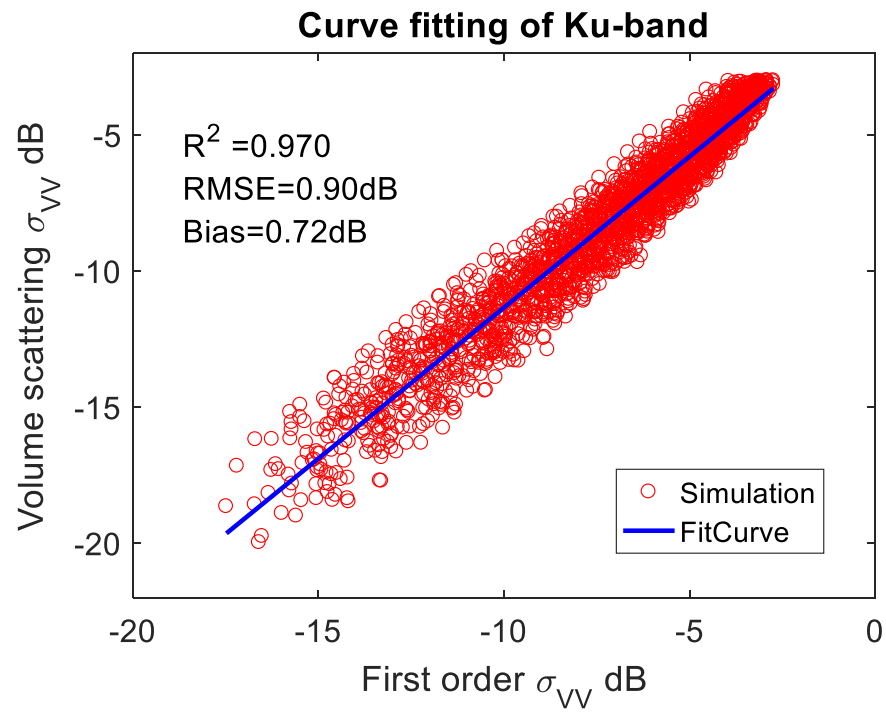
Correlation between (τ_X, τ_{Ku})



Correlation between (ω_X, ω_{Ku})

Regression between single and multiple scattering

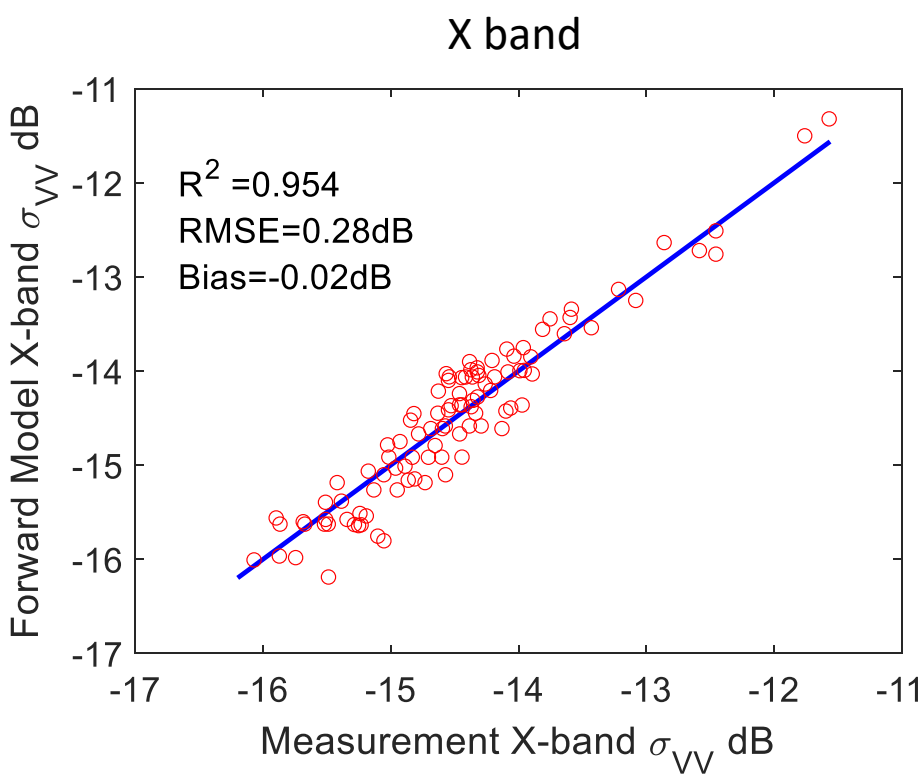


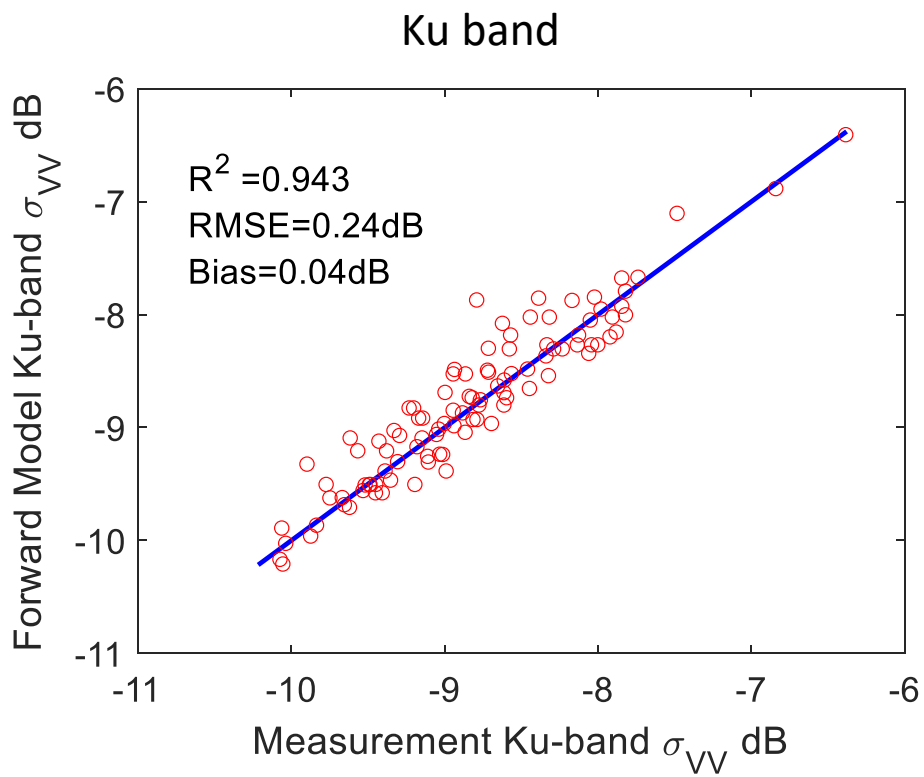


Backscatter for X band $\sigma_{\mathrm{X}}\left(\sigma_{\mathrm{X}}^{(1)}(\varpi_{\mathrm{x}}, \tau_{\mathrm{X}})\right)$

Backscatter for Ku band $\sigma_{\mathrm{Ku}}\left(\sigma_{\mathrm{Ku}}^{(1)}(\varpi_{\mathrm{Ku}}, \tau_{\mathrm{Ku}})\right)$

Validation of parameterized Bic/DMRT model: Canada SnowSAR





- Good agreement: achieve RSME < 0.28dB

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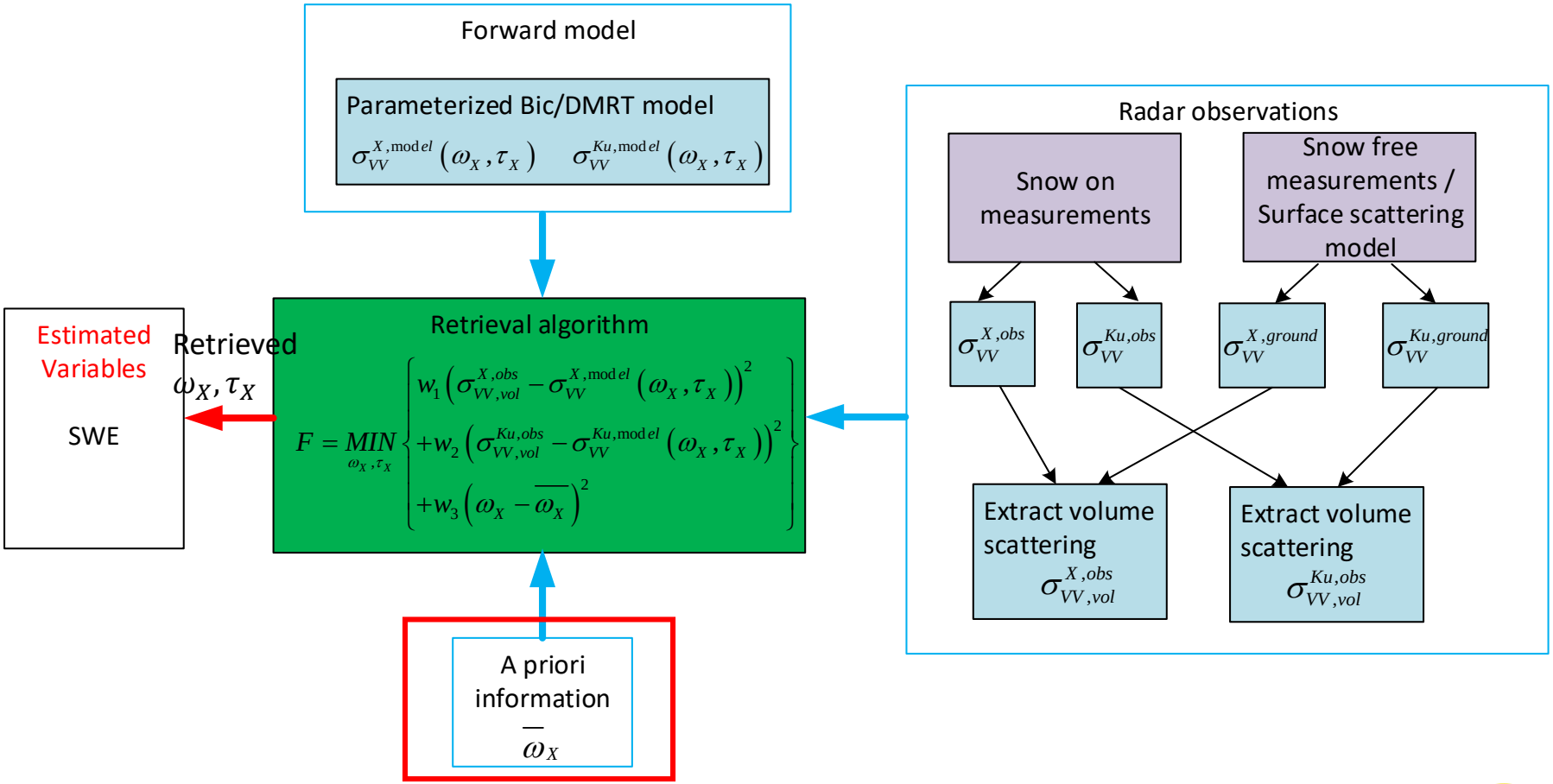
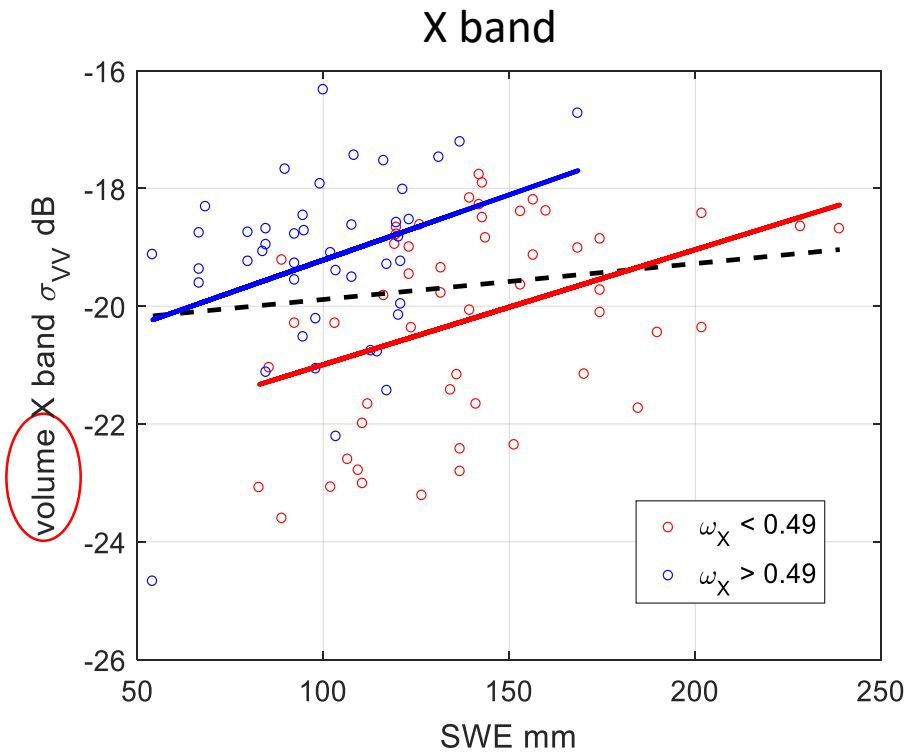
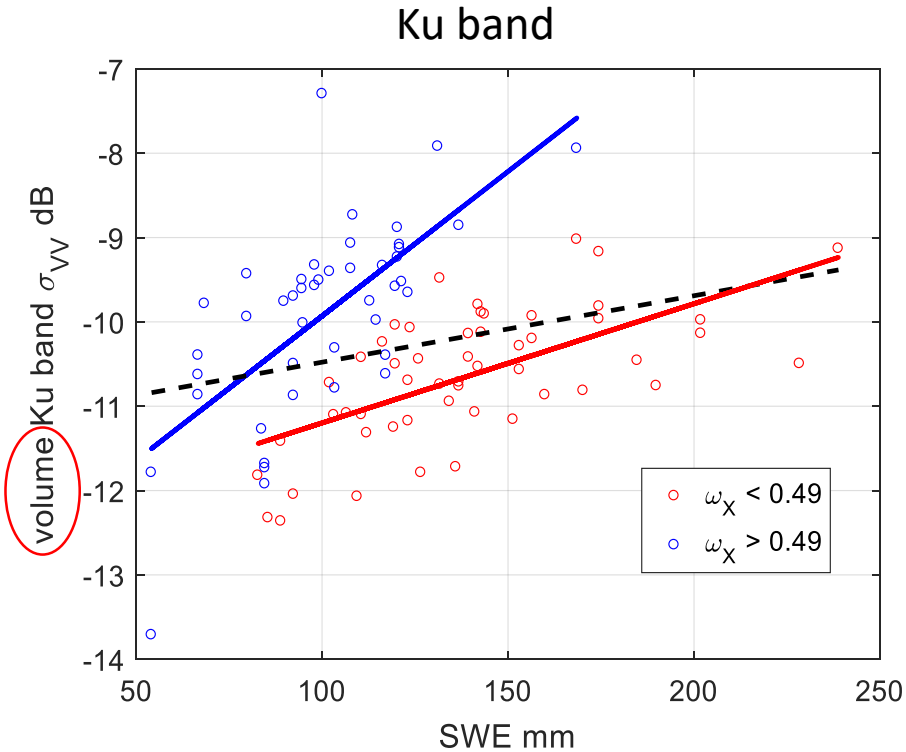
SWE retrieval algorithm flow chart



Classification: two classes of backscatter, Canada SnowSAR



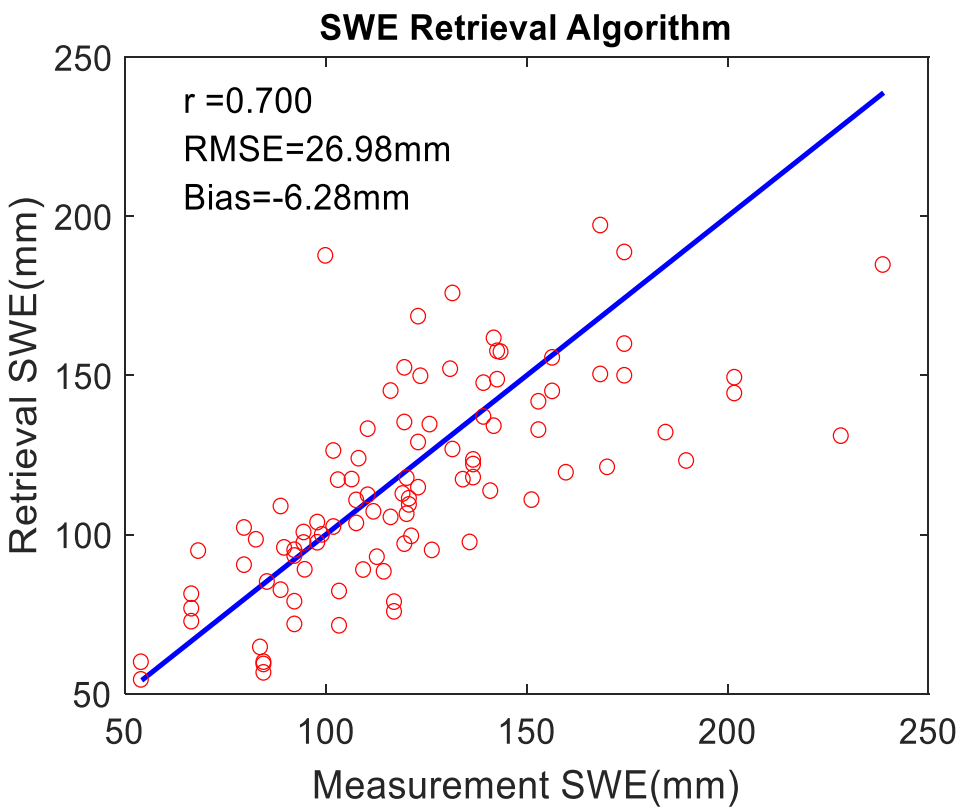


- ***Background scattering subtraction*** & ***backscatter classification w.r.t. ω_X*** enhances sensitivity of backscatter to SWE
- SWE doubles, Backscatter increases about 2-3dB

Radar datasets used

Dataset	Loacation	Date	Frequency	Polarization
Finland SnowSAR1	Sodankylä, Finland	Mar. 17th, 2011	X and Ku band	VV&HV
Finland SnowSAR2	Sodankylä, Finland	December 19th, 2011 to March 24th, 2012	X and Ku band	VV&HV
Canada SnowSAR	Trail Valley Creek (TVC), the Northwest Territories, Canada	winter 2012~2013	X and Ku band	VV&HV

Performance of SWE retrieval algorithm: Canada SnowSAR

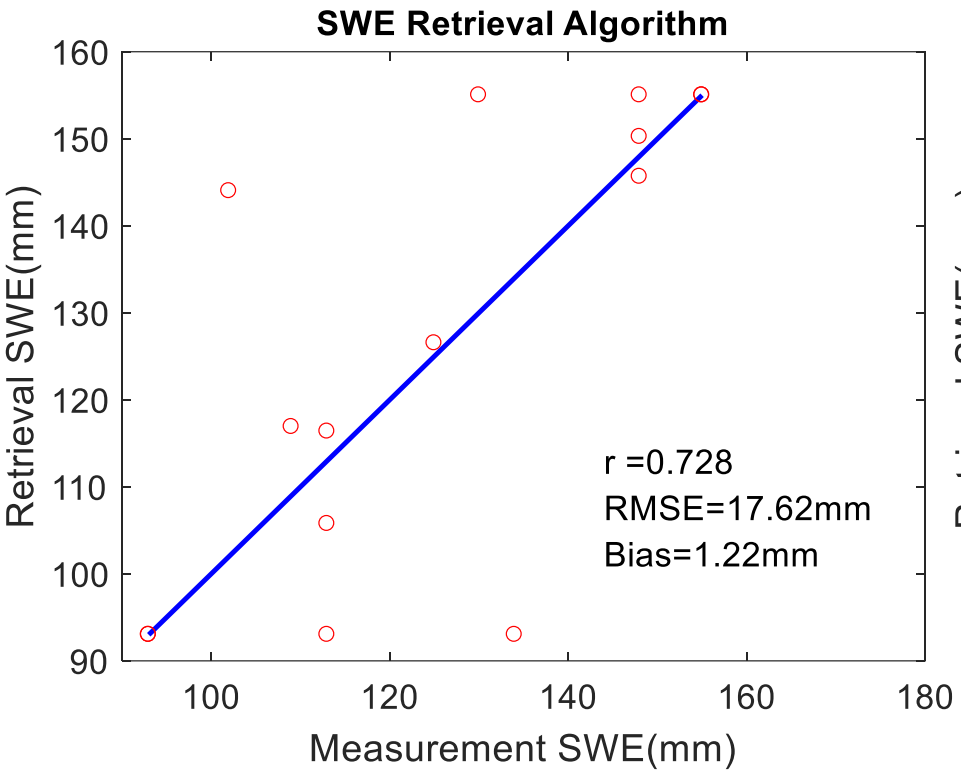


- ❑ Achieves RMSE = 26.98mm, and *r* = 0.7
- ❑ For SWE < 200 mm, RMSE = 24.31mm

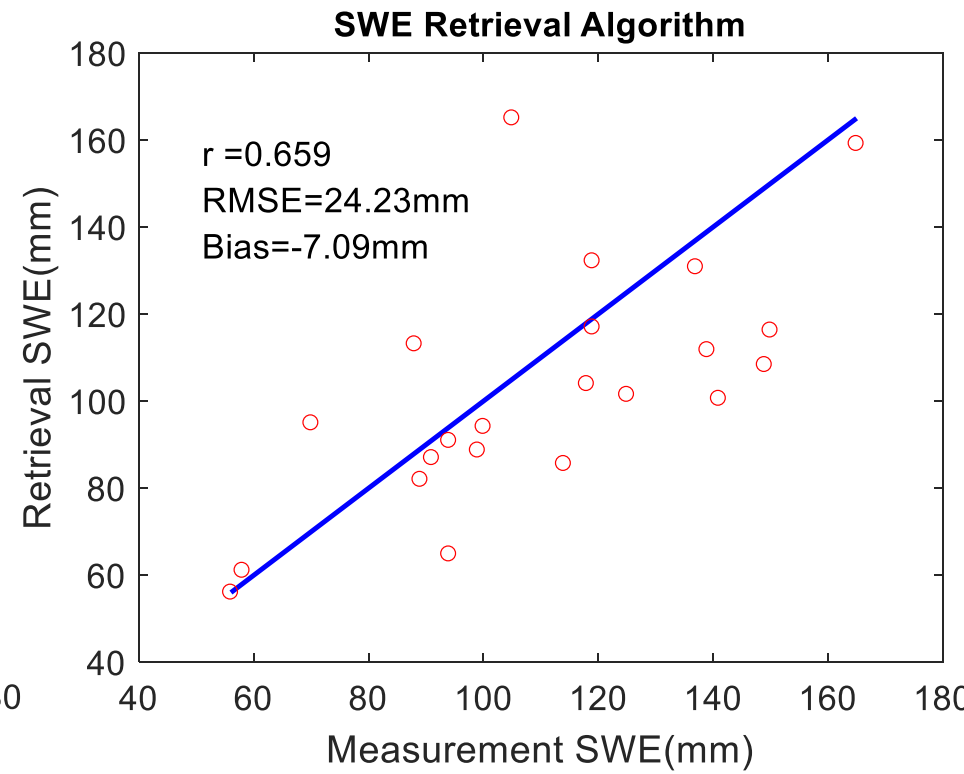
SCLP requirement: RMSE < 20mm for SWE < 200mm and RMSE < 10% of total SWE for SWE > 200mm

Performance of SWE retrieval algorithm: Finland SnowSAR1 and SnowSAR2

SnowSAR1



SnowSAR2



- Achieves RMSE = ~18 mm
- Achieves RMSE = ~24 mm

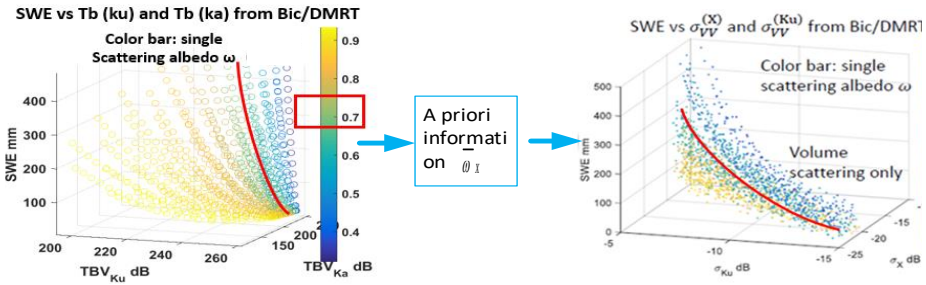
Methods to improve the algorithm

Better background scattering subtraction

- Radar observation σ_{obs} from snow free conditions
- Polarimetry: volume / surface scattering decomposition
- Combine active and passive measurements to retrieve both soil and snowpack parameters

Better a priori estimate of ω_X (or effective grain size)

- Solution 1: snow thermodynamics model with ancillary meteorological data
- Solution 2: combine active and passive microwave measurements



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Summary

A. Background scattering subtraction:
   i. Affects more in X band than Ku band
   ii. Volume backscatter sensitive to SWE

B. Forward model: parameterized Bic/DMRT
   i. Regression training: 2 observations vs. 2 unknowns (ω_X and τ_X)
   ii. Validated against SnowSAR data

C. Retrieval algorithm: $\mathrm{SWE} \propto \tau_{a,X} = (1 - \omega_X)\tau_X$
   i. A priori ω_X
   ii. Classify backscatter w.r.t. ω_X restores its high sensitivity to SWE
   iii. Performance: RMSE <30mm for SWE up to 300mm

Thanks for your attention!
Any question?