Using Multisensor Data to Improve Snow Prediction

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1 Introduction

Remote sensing of snow has paved the way for global quantification of snow depth/snow water equivalent (SWE) (using Microwaves) and Snow cover/Grain size (using Visible/NIR).

- Synthetic Aperture Radar (SAR) - global coverage (hyper-resolution), reduced uncertainty.
- Exploit differential behavior of snowpack on microwave wavelength and polarization
- Backscatter approaches
- Interferometric SAR (InSAR) techniques

Distributed snow hydrology modeling at spatial scales of SAR resolution.

- Priori information on snowpack micro/macro physical state for the retrieval algorithms
- Assimilation of snow depth/SWE retrievals for improved predictions.

2 Multi Sensor Data

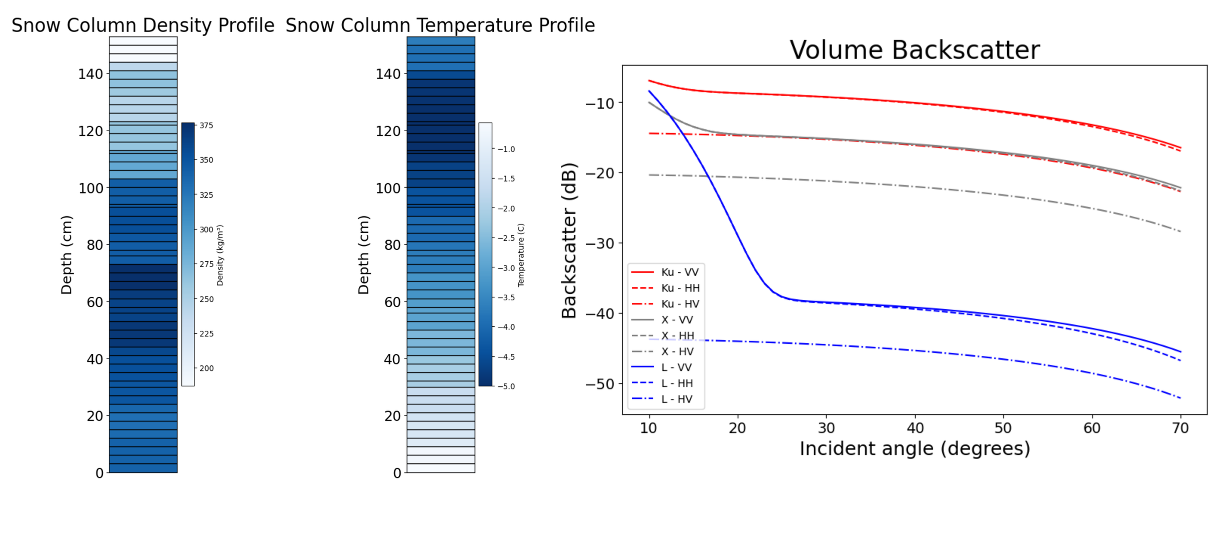
Existing and upcoming satellite missions with SAR (e.g., Sentinnel-1, ERS-1, ALOS-2, NISAR) can provide backscatter and phase information from snow covered grounds. Groundd-based snowpack measurements provide data for calibration and evaluation of remote sensing retrievals.

NASA SnowEx mission

- Multi-year extensive observation data over different landscapes
- Collocated ground and airborne measurements (SNOWSAR, SWESAR and UAVSAR)

High-frequency radiation at visible and near infrared channels is reflected from the surface and can be used to determine surface properties such as snow grain size and grain shape. Multiscale passive remote sensing datasets (Landsat, MODIS and VIIRS) can be used to calculate grain size at high spatiotemporal scales

2.1 Microwave backscatter



- Backscatter from the snowpack vary with frequency of SAR : Ku > X > L
- Backscatter decreases with increasing incidence angle
- Snowpack is almost transparent to the L-band.

2.3 Bayesian Retrieval Algorithm

MCMC approach is used to optimize the snow parameters by setting up prior using MSHM. For multiple concurrent measurements, $P(y|\eta)$ can be described by a multivariate normal distribution,

$$P(y|\eta) = (2\pi)^{\left(-\frac{N}{2}\right)} \mid \Sigma_y \mid^{-\frac{1}{2}} exp\left[-\frac{1}{2}(y - M(\eta))^T \Sigma_y^{-1}(y - M(\eta))\right]$$

where N is the number of measurements at a given location and time. Here *M(η)* is the physical model (e.g., the snow radiative transfer algorithm in this case) with physical parameters η (including *x*) and statistical error parameters ζ.

2.3 Snow Grain Size retrievals

Snow grain diameter is calculated using,

$$d = \frac{1}{\alpha b^2 f^2} ln^2\left(\frac{R}{R_o}\right)$$

Where $\alpha = 4\pi\chi_\lambda/\lambda$ is ice absorption coefficient, χ_λ imaginary part of refractive index of ice for wavelength λ. b is shape parameter taken as 3.62 for fractal particles, R_o is the reflection function of semi-infinite layer of snow, R is reflectance at NIR channel and f is given solar angle dependent parameter.

2.3 Interferometric SAR retrievals

Snow depth change Δz_s can be estimated from InSAR phase change $\Delta\varphi_s$ as

$$\Delta z_s = -\frac{\lambda}{4\pi} \cdot \frac{\Delta\varphi_s}{\cos\theta_i - \sqrt{\varepsilon - \sin\theta_i^2}}$$

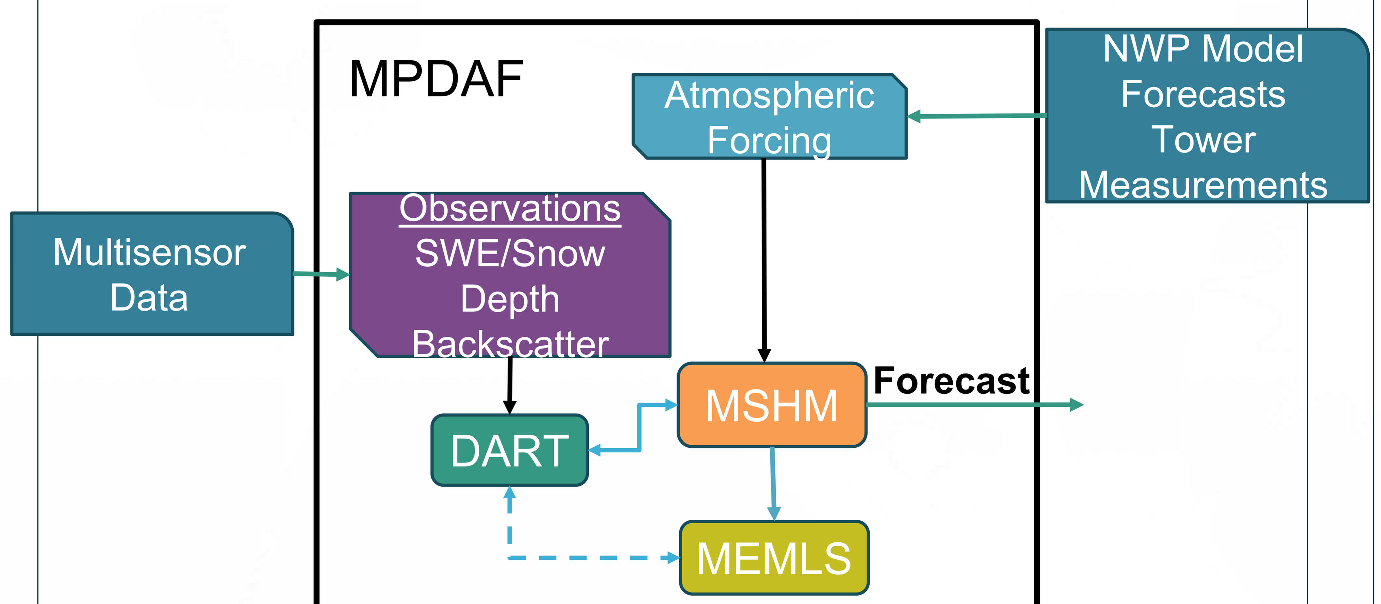
where λ is the SAR wavelength, θ_i is the incidence angle and ε is the bulk snowpack permittivity (Guneriussen et al., 2001).

3.1 Snow Prediction

A multi-physics data assimilation framework (MPDAF) was developed -

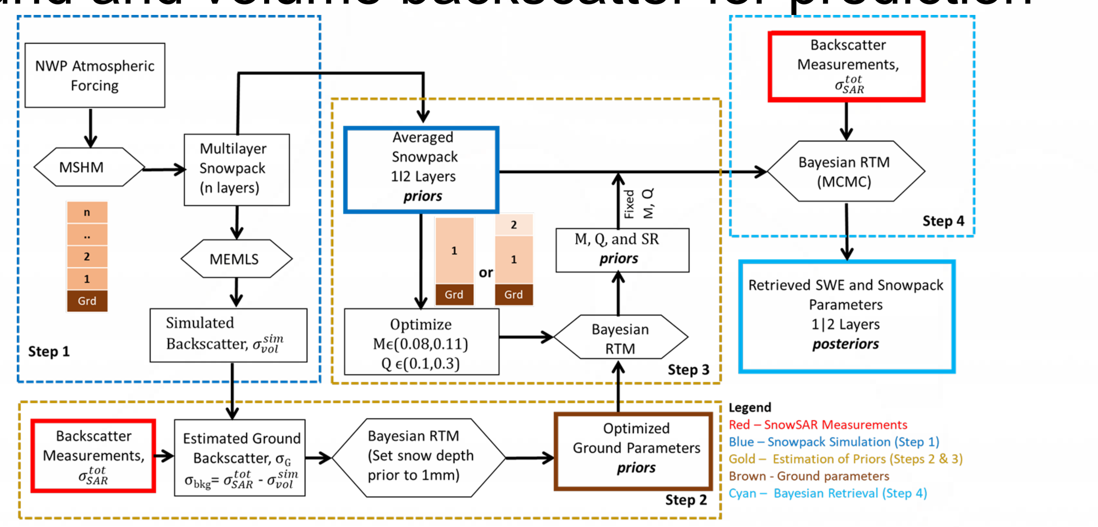
- Multilayer Snow Hydrology Model (MSHM)
- MEMLS
- Data Assimilation Research Testbed (DART)

In a dual-physics mode, the system is designed to assimilate snowpack or radar states. Model ensembles are generated by perturbing the atmospheric forcing data.



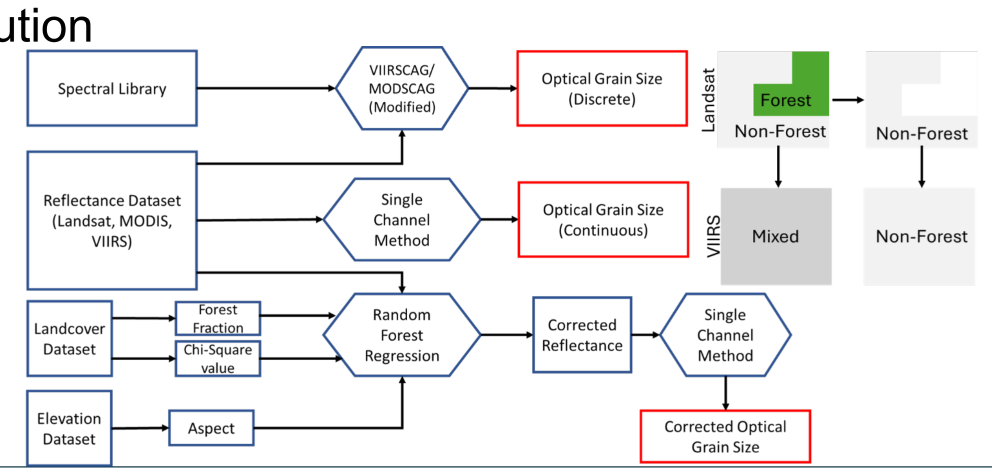
3.2 Multilayer SWE Prediction

Total backscatter measurements from SNOWSAR (X & Ku band) are decomposed into ground and volume backscatter for prediction

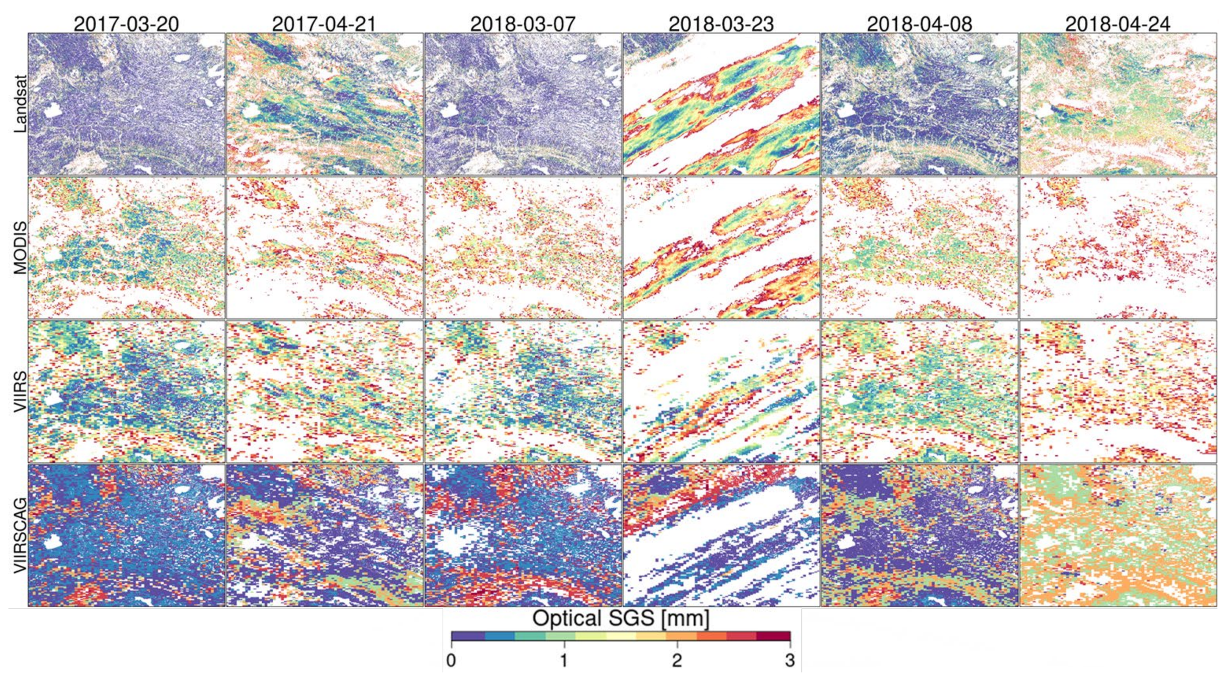


3.3 Grain Size Prediction

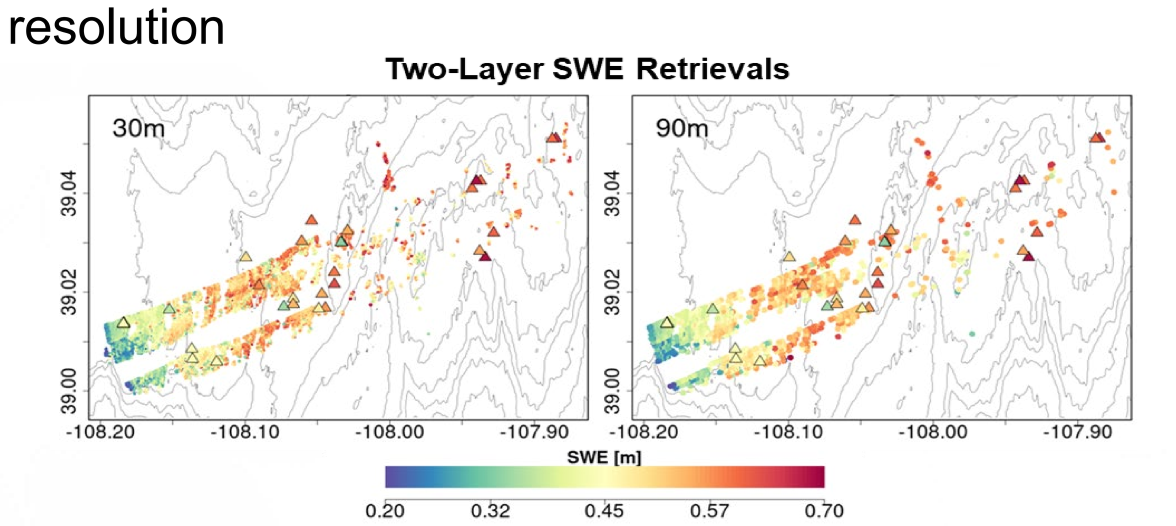
Methodology used to determine snow grain size at different resolution (30m, 500m and 1Km) and snow reflectance in forest dominated environments at coarser resolution



4.1 Grain Size and SWE retrievals

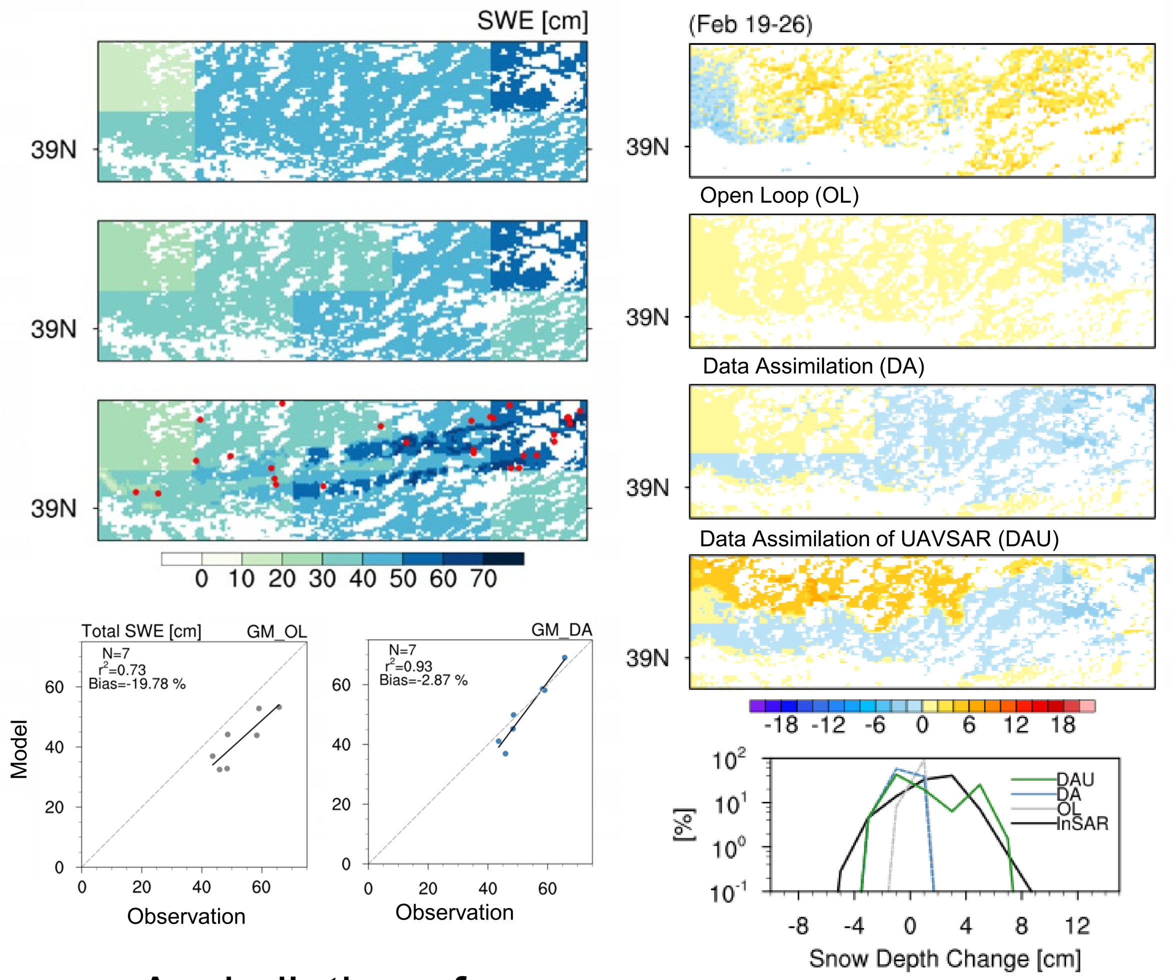


Spatial distribution of snow grain size shows differences in grain size estimates at different resolution



Composite spatial distribution of SWE (2-layer retrievals) successfully retrieved for grassland pixels for the four SnowSAR flights. SnowEx'17 snowpits are marked by triangles and colored according to SWE.

4.2 Assimilation of Retrievals



Assimilation of snow depths from backscatter retrievals improves modeled SWE. Bias: -20 to -3 %
r^2 : 0.73 to 0.93

Assimilation of snow depths from InSAR retrievals improves the simulated snow depth changes and its spatial variability.

5 Summary

Differential behavior of snowpack to microwave wavelength and polarization can be exploited to quantify total snow depth or SWE at high resolution with low uncertainty using SAR.
Ground-based measurements can be used to calibrate and validate the retrievals.
Assimilation of retrievals from backscatter approaches or InSAR techniques shows strong potential to improve modeled snowpack macro-physical properties and capture spatial and temporal variability at hyper-resolutions.

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References:

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