Developing a Database for GPM Microwave Imager Snowfall Retrieval using 1D-VAR Optimization

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Abstract

This study utilizes a coincident dataset of the CloudSat Cloud Profiling Radar (CPR) and the Global Precipitation Measurement (GPM) Microwave Imager (GMI) to retrieve snow water content (SWC) profiles from GMI high frequency channels over ocean. The initial guess of SWC is converted from collocated CPR radar reflectivities using Ze-S relation and scattering database of non-spherical snowflakes. A 1D-VAR optimization is then applied to minimize the predefined cost function in a radiative transfer model. A single case is first examined. GMI seems to offset the missing part of CPR derived SWC profile due to strong attenuation at 94 GHz. This method is performed on all qualified SWC profiles over two years to develop a database for Bayesian retrieval. The retrieval test on two selected cases implies that this database can be used to retrieve snowfall information given brightness temperatures (BT) for GMI high frequency channels. The method in this study is also easily employed on other microwave imagers.

Data Description and Model Setting

The coincident dataset combines CloudSat CPR radar reflectivities, GPM GMI BT measurements and ECMWF auxiliary dataset for CPR. Only five channels from GMI are utilized (89V GHz, 166V GHz, 166H GHz, 183.31±1V GHz, and 183.31±7V GHz). Liquid water path in GMI level-2b product is also used to derive cloud liquid water (CLW).

Model simulations of BT for GMI high frequency channels are calculated by a radiative transfer model using a discrete ordinate method (Liu, 1998). This radiate transfer model calculates the single scattering properties of non-spherical snowflakes using a parameterization based on the discrete dipole approximation (DDA) (Liu, 2008). Two particle size distributions are employed in the radiative transfer model (Braham, 1990; Rutledge and Hobbs, 1983).

Cost Function of 1D-VAR Optimization

$$J(\mathbf{x}) = (\mathbf{x}-\mathbf{x}_0)^T\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_0) + (\mathbf{y}-H(\mathbf{x}))^T\mathbf{R}^{-1}(\mathbf{y}-H(\mathbf{x}))$$

$$\mathbf{x} = \begin{pmatrix} \log_{10} CLW_{51} \\ \log_{10} CLW_{52} \\ \vdots \\ \log_{10} CLW_{100} \\ \log_{10} SWC_{51} \\ \log_{10} SWC_{52} \\ \vdots \\ \log_{10} SWC_{100} \end{pmatrix} \qquad \mathbf{y} = \begin{pmatrix} T_b^9 \\ T_b^{10} \\ \vdots \\ T_b^{13} \end{pmatrix}$$

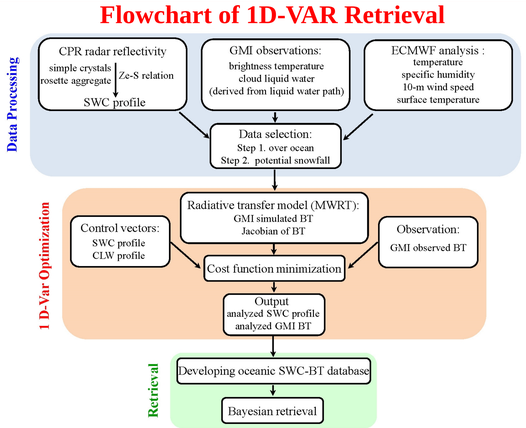
B: background error covariance
R: observation error covariance
H: observation operator

At n[th] iteration, Rogers (1976) gives the solution:

$$\mathbf{x}_{n+1} = \mathbf{x}_0 + \mathbf{B}\mathbf{H}_n^T(\mathbf{H}_n\mathbf{B}\mathbf{H}_n^T + \mathbf{R})^{-1}[\mathbf{y} - H(\mathbf{x}_n) - \mathbf{H}_n(\mathbf{x}_0 - \mathbf{x}_n)]$$

$\mathbf{H}_n$: Jacobian matrix of observation operator

Flowchart of 1D-VAR Retrieval



Single Case Study on March 11, 2015

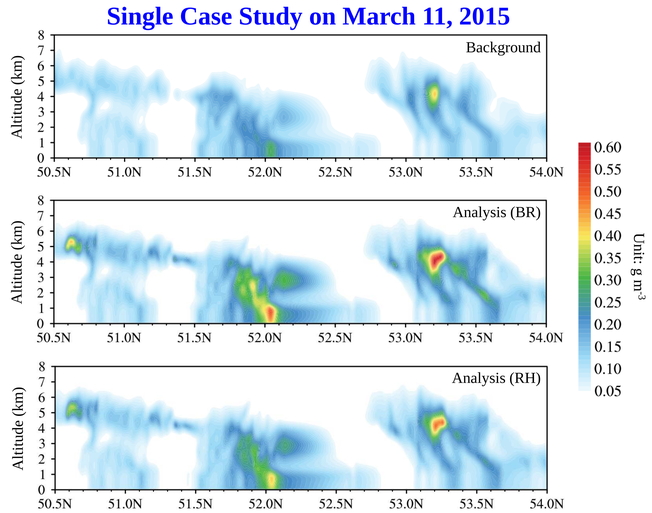


Fig. 1. Vertical distributions of snow water content from CPR background (top panel), analysis using Braham PSD (middle panel), and analysis using R&H PSD (bottom panel) for a single case on March 11, 2015.

Statistics of Observed BT Minus Simulated BT for Single Case

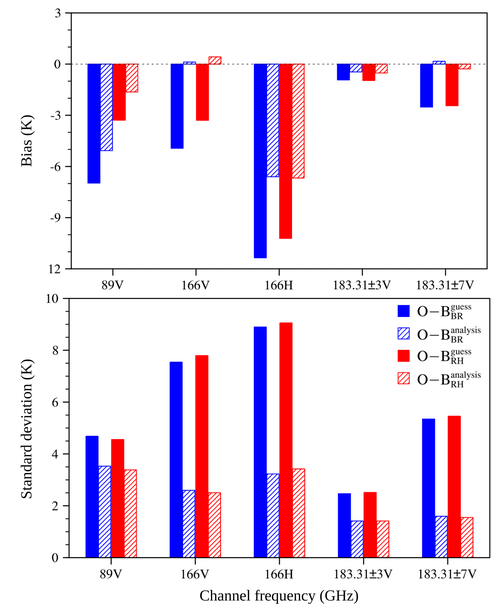


Fig. 2. Biases (top panel) and standard deviations (bottom panel) of observed BT (O) minus simulated BT (B) for GMI high frequency channels.

Contoured Frequency by Altitude Diagrams of All SWC Profiles

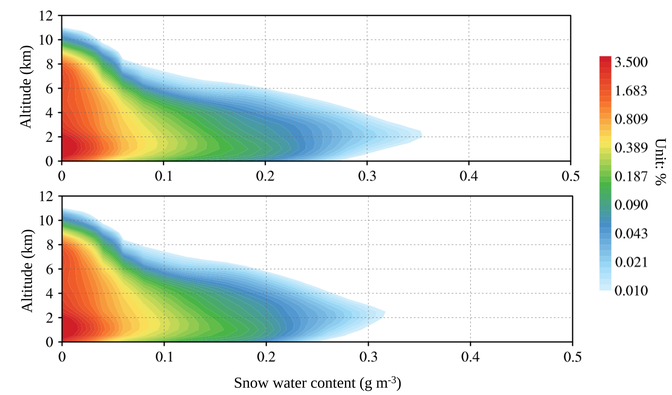


Fig. 3. Contoured frequency by altitude diagrams of all analyzed SWC profiles using Braham PSD (top panel) and R&H PSD (bottom panel).

Relation between Observed BT and Simulated BT

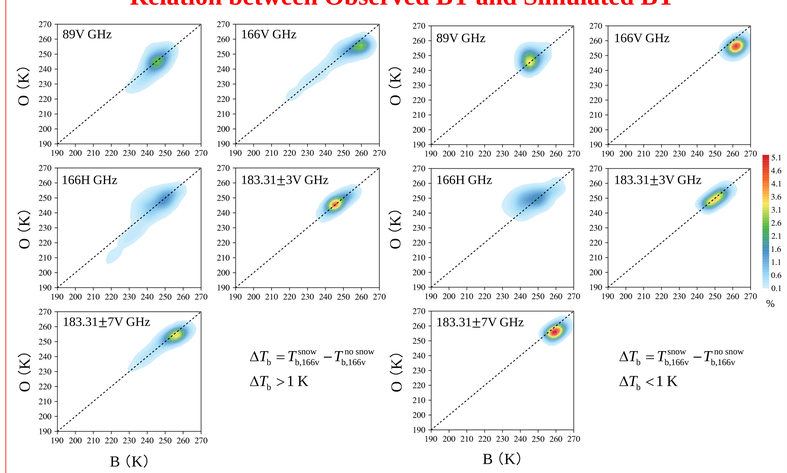


Fig. 4. Relation between observed BT (O) and simulated BT (B) for GMI high frequency channels. Shading represents normalized occurrence frequencies.

Statistics of Observed BT Minus Simulated BT for All SWC Profiles

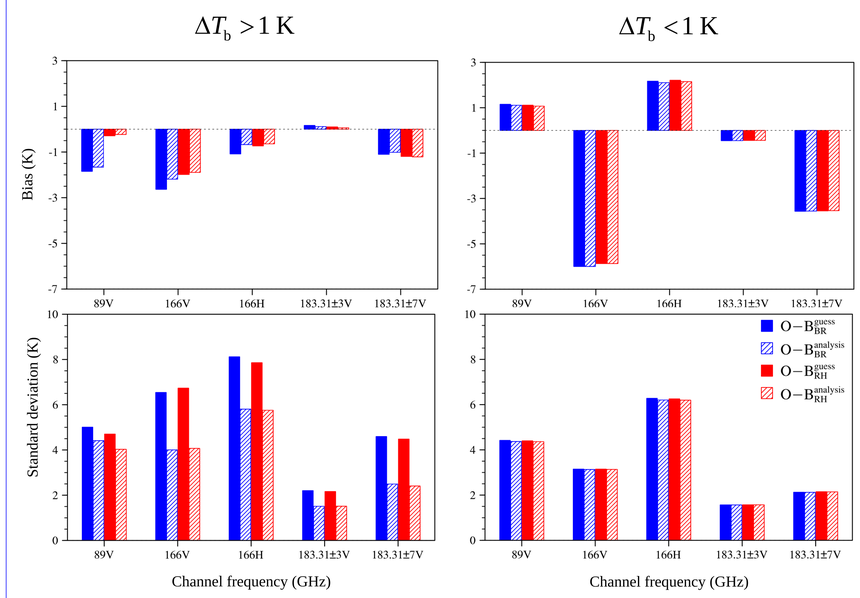


Fig. 5. Biases (top panel) and standard deviations (bottom panel) of observed BT (O) minus simulated BT (B) for GMI high frequency channels.

Bayesian Retrieval Test

$$\mathbf{x}_{rt} = \sum_i \mathbf{x}_i \exp[-0.5\chi_i^2] / \sum_i \exp[-0.5\chi_i^2]$$

$$\chi_i^2 = \sum_{j=1}^{M} [T_j - R_j(\mathbf{x}_i)]^2 / \sigma_j^2$$

$\mathbf{x}_{rt}$: retrieved state variable
$\mathbf{x}_i$: i^{th} state variable in database
T_j: j^{th} channel in observed BT vector
Rj: j^{th} channel in simulated BT vector
σ_j: standard deviation for channel j

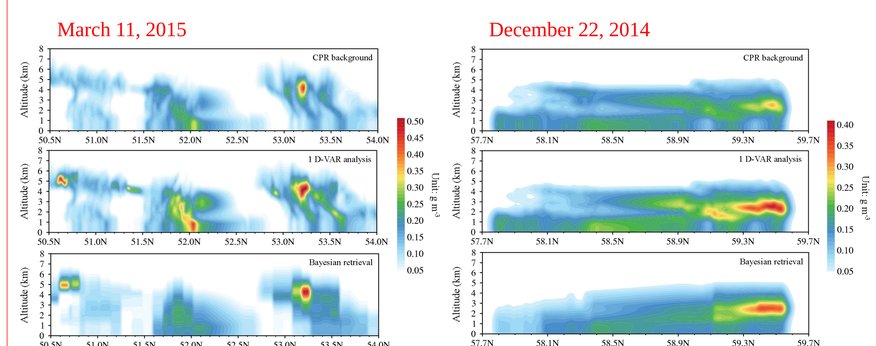


Fig. 6. Vertical distributions of snow water content from CPR background (top panel), analysis using Braham PSD (middle panel), and analysis using R&H PSD (bottom panel) for two selected cases.

Summary and Conclusions

A coincident dataset of CPR radar reflectivities and the GPM GMI BT measurements is employed to develop a database for microwave imager snowfall retrieval over ocean. Only five channels above 89 GHz from GMI are selected. The 1D-VAR optimization is performed in a radiative transfer model utilizing the DDA method. Two PSDs are used in this radiative transfer model. The results from a single case indicate that GMI contains important information of vertical SWC profile, which can compensate for the missing part of CPR derived SWC profile. The biases and standard deviations of observed BT minus simulated BT for GMI high frequency channels are decreased dramatically after optimization. This variational method is then applied on all qualified SWC profiles over two years. A parameter ΔT_b is defined to represent the intensity of snowfall. When ΔT_b is larger than 1 K, the biases of GMI high frequency channels are generally small. The standard deviations of those microwave channels are decreased significantly after optimization. When ΔT_b is smaller than 1 K, the biases of GMI high frequency channels are generally large, especially for 166V GHz. The standard deviations of those GMI channels are almost unchanged after optimization. The results imply that GMI is not sensitive to very light snowfall and fails to correct the initial guesses of SWC profiles through 1D-VAR optimization. On the other hand, GMI is effective in adjusting SWC profiles for moderate and heavy snowfall. A Bayesian retrieval test is finally performed. The results from two selected cases manifest that this database can be used in retrieving snowfall information over ocean from GMI high frequency channels. The method in this study is also applicable for other microwave imagers that have similar high frequency channels.

References

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