Exploring The Approach Of DMRT-ML For SWE Retrieval Using AMSR2 Observation

NASTARAN SABERI[1] AND RICHARD E. KELLY[1]

ABSTRACT:

The importance of modeling the physical state of snow is widely recognized as a challenging aspect in the microwave remote sensing of snow. Snow physical properties have strong influence on emitted wave from substratum, this makes snow properties retrieval using surface brightness temperature observed by passive microwave sensors feasible. Time series records of daily snow coverage and its most critical properties such as snow depth and snow water equivalent (SWE) could be helpful in many applications depending on data spatial resolution, ranges from modeling snow variations in a small catchment to global climatologic studies. The Advanced Microwave Scanning Radiometer 2 (AMSR2) launched on JAXA's Global Change Observation Mission Water in 2012 with 10-15 years mission, continues observation record of Earth from space. The SWE product for AMSR2 is being developed as a satellite-based retrieval system that relies on static ancillary data sets to parameterize land surface properties that initialize retrievals. In this research Dense Media Radiative Transfer Theory for Multi Layered (DMRT-ML) snow pack, a physically based numerical model, is applied (Picard *et al*., 2012). The model is based on the Dense Media Radiative Transfer (DMRT) theory for snow scattering and extinction coefficients computation and uses Discrete Ordinate Method to numerically solve the radiative transfer equation. Using DMRT-ML assumptions, the application of the DMRT-ML model to the February 2013 snowstorm in southern Ontario to the Eastern seaboard of USA is explored. To supply DMRT input variables, Canadian Meteorological Center (CMC) daily analysis snow depth product and AMSR2 brightness temperature have been used. AMSR2 data has been utilized for surface physical temperature estimation. Using forward DMRT simulation for one layer snowpack, model sensitivity to snowpack grain size via AMSR2 observations is studied. This provides insight into the inversion look-up table matrix that is being developed using DMRT-ML for AMSR2 SWE retrievals.

Keywords: Remote Sensing, Passive Microwave Radiometry, SWE, Dense Media Radiative Transfer Theory.

INTRODUCTION

Every natural surface with a temperature greater than 0 K radiates a thermal signal in the microwave region of the spectrum. Assuming that a grey body surface at T_g temperature is radiating in the presences of sky at T_s (with constant equivalent temperature), microwave
radiometry model for equivalent brightness temperature of this surface can be expressed by

[1] Interdisciplinary Center on Climate Change (IC3) and Department of Geography and Environmental Management, University of Waterloo, ON, Canada

(Elachi & Zyl, 2006):

$$T_i(\theta) = T_s + \varepsilon_i(\theta) * (T_g - T_s) \qquad (1)$$

Where, T is brightness temperature with s for the sky and g for the ground component respectively, ε is the emissivity, i is the polarization and θ is observation angle. A model assumption of no cloud emission and no atmospheric absorption is considered.

The spectral emissivity (ε_λ) is a representation of the radiant emission from an object; it expresses the object's capability to emit radiation due to thermal energy conversion relative to a blackbody with the same temperature (Elachi & Zyl, 2006). Due to its independence to the physical temperature of the object, emissivity is often used for modeling emission processes in passive microwave studies rather than brightness temperature (Picard *et al*., 2012).

Electromagnetic radiation passing through a dry snowpack medium interacts with the snow in forms of scattering, absorption, reflection, refraction and transmission processes. Two different groups of methods that have been developed to model the snow pack and derive estimates of snow parameters such as snow depth, SWE and grain size, are empirical-based approaches and physically-based modeling approaches.

In this study, a more physically based approach; the DMRT-ML algorithm developed by Picard *et al*. (2012) has been applied to simulate brightness temperatures during a snowstorm event in 2013 in Ontario, Canada. CMC analysis snow depth data, a surface physical temperature estimation by applying an empirical formula on AMSR2 brightness temperature values, an assumed density and a range of grain sizes have been used as inputs to the model. Simulation results are compared with AMSR2 brightness temperatures.

DENSE MEDIA RADIATIVE TRANSFER THEORY FOR MULTI LAYERED (DMRT-ML)

DMRT is based on Quasi Crystalline Approximation (QCA) and Quasi Crystalline Approximation-Coherent Potential (QCA- CP), which model particle positions pair distribution function and coherent wave interactions are considered. In so doing, these approximations allow wave interactions to be modeled as a dense media (Tsang *et al*., 2000). In DMRT-ML, snow scattering and extinction coefficients and the form of the phase function are computed based on DMRT theory whereby the radiative transfer equation is solved using the Discrete Ordinate method (DISORT) (Picard *et al*., 2012). Two applicable implementations of DMRT-ML based on underlying assumptions of different versions of DMRT theory, are:

- ***QCA-CP mono-disperse***: In this version applying "short range" stickiness and also Grody's empirical method for large particles is elective;
- ***QCA-CP poly-disperse***: In this version as Rayleigh distribution is assumed, so no stickiness and no large particles are assumed (Picard *et al.* 2012).

DMRT-ML requirements for emission simulation from layered snow pack at the surface are following inputs:

- Physical temperature (K);
- Snow density (kg m^{-3});
- Snow grain size (mm);
- Stickiness (dimensionless);
- Liquid water content (kg m^{-2});
- The characteristics of the substratum e.g. soil moisture, texture and temperature in the case of a soil substratum;
- Down-welling atmospheric brightness temperature (K);

METHODOLOGY

Using forward model simulation of DMRT-ML, the sensitivity to snowpack grain size regarding AMRS2 frequencies is explored. This enables the derivation of a look-up table matrix using DMRT-ML for snow properties (depth and density) retrievals (Kelly *et al.*, 2003). The general process is summarized in the flow chart below (Figure 1). 33 sites is selected for which, AMSR2 Tb values, CMC-snow depth and physical temperature of the surface were collected to drive the DMRT-ML. Density for DMRT-ML simulation, were assumed to have constant value of 200 kg/m^3. The stickiness parameter between grains has been assumed to be zero (the second implementation of model has been used). In this study, since the snowpack was dominantly a single layer deposition, a single layer was assumed for simplicity of simulation. The DMRT- ML model was run multiple times to estimate H & V polarizations brightness temperatures at 6, 10, 18, 36 and 89 GHz frequencies. The model was used, therefore, to explore DMRT sensitivity to snow grain sizes ranging from 200µm – 700µm in radius.

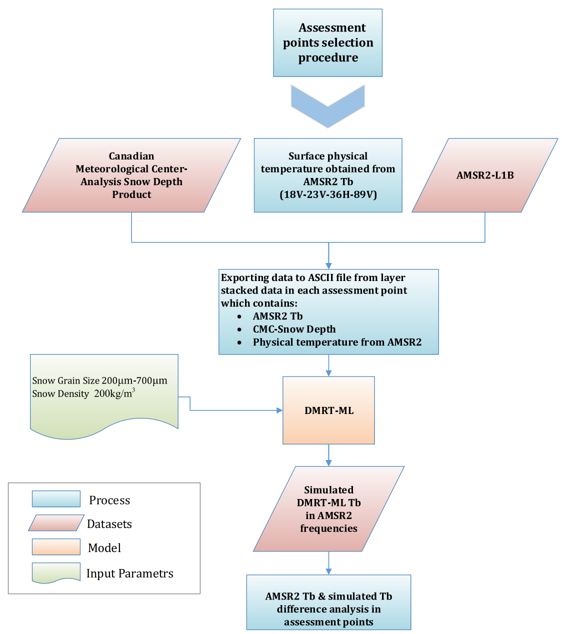

Figure 1. DMRT-ML evaluation procedure using AMSR2 and CMC-snow depth data

Study Area and Dataset

A snowstorm that occurred between 8th and 9th February 2013 impacting a region from southern Ontario to the Eastern seaboard of Canada and the USA is used as a case study for this research. The datasets used include:

- AMSR2- L1B (Tb_{lo}[1] & Tb_{hi}[2] with spatial resolution of 0.06 ° & 0.12 °, Geographic-WGS 84) to derive physical temperature for DMRT input;
- Canadian Meteorological Center-Snow Depth Analysis Data (0.25 °, Geographic-WGS 84) for DMRT input (Brasnett, 1999);
- GTOPO30 (0.0083°, Geographic-WGS 84) for slope calculation as a derivative used in site selection approach;
- MOD12Q1- global forest fraction data in IGBP classification for site selection.

The case study and the methodology for site selection are presented in Figure 2.

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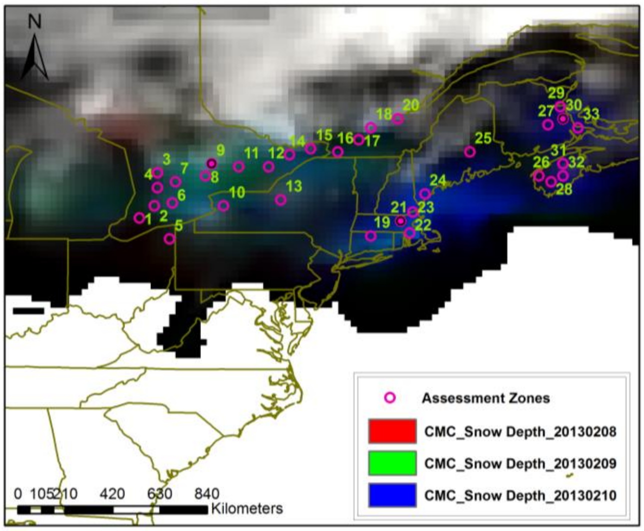
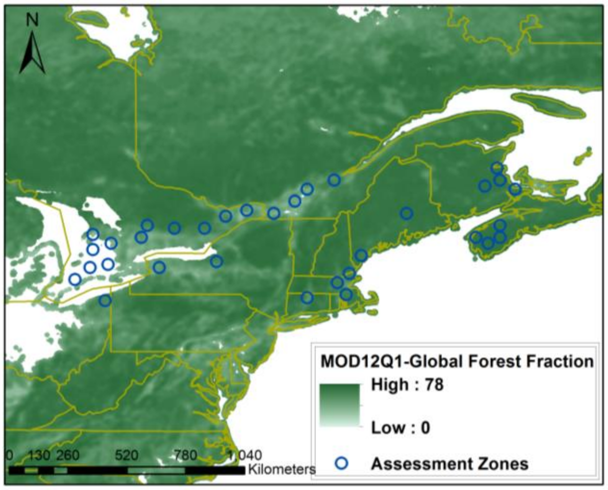
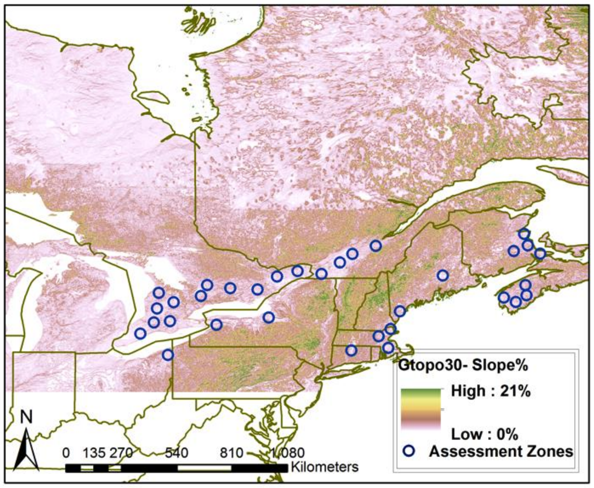
[1] Tb in low frequencies of 6GHz, 10GHz, 18GHz, 23GHz and 36GHz in V & H polarizations (18GHz-V, 23GHz-V and 36GHz-H are used in physical temperature computation)

[2] Tb in high frequency of 89GHz in V & H polarizations (89GHz-V is used in physical temperature computation)



(a)





(b) (c)

Figure 2. (a) Selected study points in south of Ontario and seaboard of US and CMC-Snow Depth RGB composite of days 8, 9 and 10th Feb. Grey scale pixels shows no snow depth change, while green and blue shows higher snow depth in Feb 9th and Feb 10th respectively. (Seas and oceans are not masked out in CMC snow depth analysis product)

(b) Global Forest Density product of MOD12Q1 (25*25 km), which has been utilized to opt sites with lower forest cover density in order to decrease retrieval uncertainty.

(c) Slope map (in percentage) derived from GTOPO30 DTM as a filter for assessment selection in areas with lower slope values due higher uncertainty in steep lands.

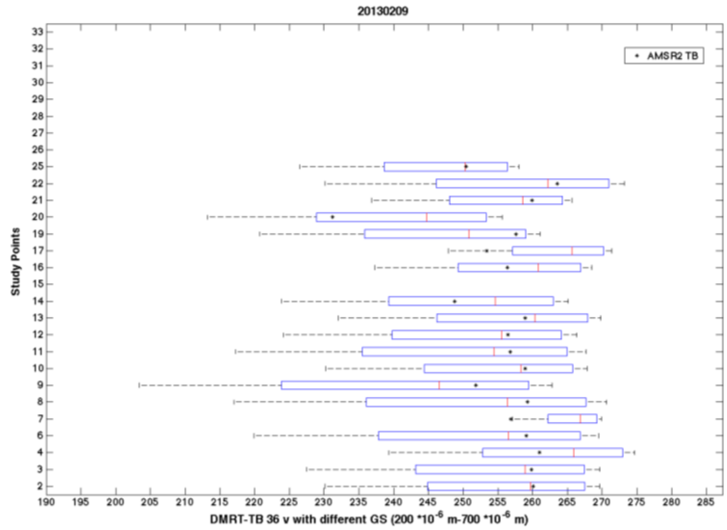
RESULTS

DMRT-ML sensitivity is presented via comparing simulated brightness temperature (considering 200μm – 700μm grain size range) and brightness temperature observed in the study points during the 7-12th of February. ID numbers are sorted from West to East (longitude of -82 to -64.5) to look through snowstorm effect on snow properties, which has passed over West to Eastern seaboard. Missing points are attributed to being located in AMSR2 granules gap for the satellite observation during night passes. It should be noted that, although study zone selection was applied considering water body boundaries, three points which has had a considerable Tb drop compared to AMSR2 Tb were omitted afterwards. This procedure was done by applying proximity analysis to the water bodies.

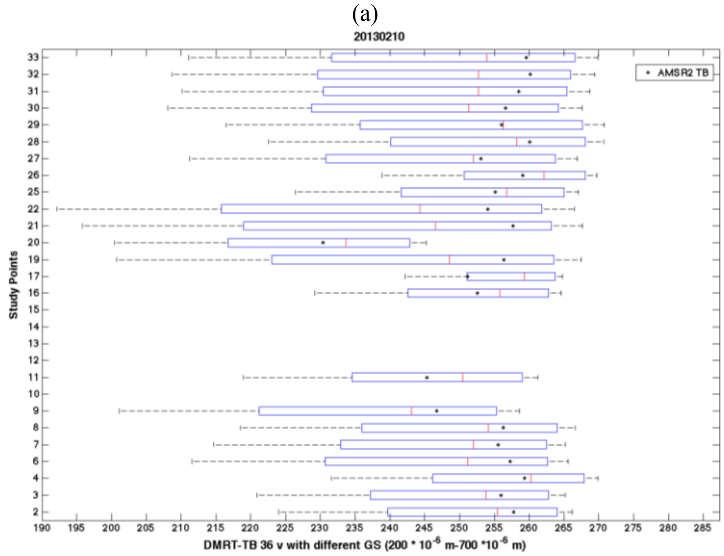
In Figure 3(a-c) box plots are used for better visualization and analysis of quartiles placement in simulated Tb with 200-700µm ranges of grain size as well as its median and also observed AMSR2 Tb (presented by asterisks). In this figure these data are study points, which related data were available during 2013 February 9th-10th and 11th. Also, in figure 4 just common points are plotted for more clarity. Also, previously, correlation between simulated and AMSR2 values in 36 GHz-V were explored by significance of the correlation assessment using T-distribution test with 0.95 confidence level. The test proves the positive significant correlation between observed and simulated Tb.

In Figure 3 close agreement between DMRT median values and AMSR2 values for half of the study points can be seen. Also, there is skewness to smaller grain sizes in most of the points, as the median is closer to the right quartiles. Due to the similar behavior of given results in study points, which are numbered from East to West (storm direction), results can be clustered to three regions. This is attributed to comparable snow depth and spatial adjacency in these points. There are also some points with consistent agreement and some with consistent underestimation and overestimation (each group makes less than 10% of the total study points). Sites 7 and 17 are two examples that simulated DMRT with bigger grain size are closer to observed values. Looking through snow depth changes during these consecutive days, in these points snow depth were 5- 10 cm. Subsequently, the interesting result of this investigation is good agreement between median distribution of simulated data and observed data in most of the sites.

In Figure 4 (a-c), Tb variations during study period are presented in three different study points. These points are highlighted in Figure 2(a). A notable agreement between simulation for 400 and 500µm and observed data in these sites can be perceived. Less agreement of results in point 30- day 8th is attributed to shallow snow coverage of 5cm, while during 10th-12th results are improved as snow depth is increased to ~30cm during snowstorm days.



(a)



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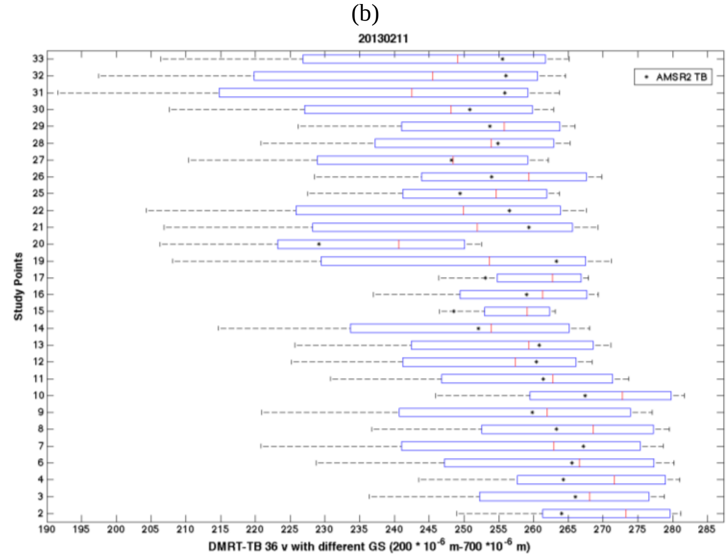

(c)

Figure 3. (a-c) Box-plots of DMRT (200-700 µm Grain size assumption) Tb 36 GHz-V during Feb 9th ,10th and11th

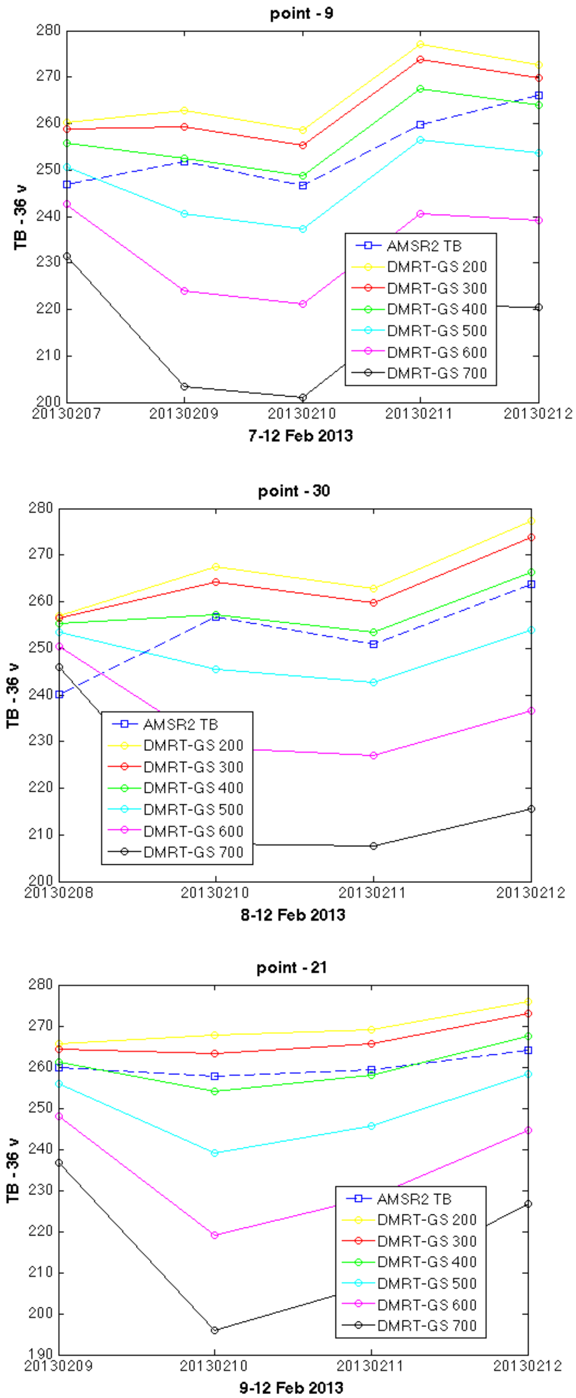

Figure 4. Some instances of assessment points simulated and observed Tb trend during Feb 7th to 12th

DISCUSSION AND CONCLUSION

In this study, DMRT-ML as a fundamental basis of the implied methodology for investigating SWE retrieval sensitivity was applied. Due to the significant influence of snow grain size on microwave thermal radiation as the most affecting input variable, the DMRT-ML sensitivity to the grain size has been analyzed. The methodology was applied on 6 consecutive days 7-12th February

2013 before, during and after snow storm happened in southern Ontario, Canada. Brightness temperature in AMSR2 L1B granules products were used to compare simulated and observed values.

Simulated Tb by DMRT had higher values in 200-300 μm grain sizes compared to AMSR2 Tb and also lower values in snow grain sizes bigger than 400 μm. This can be explained by higher scattering and also absorption of bigger snow grains.

Figure 5, shows Tb scatter plot and linear correlation of AMSR2 and DMRT values for 400μm grain sizes in Date 2013-02-10. Furthermore, the correlation analysis was done after outlier omission with respect to results achieved using box plots for simulated data distribution analysis. Consequently, as simulation results were well correlated with the observed data, this could be promising for making use of DMRT-ML in the inverse modeling methodology.

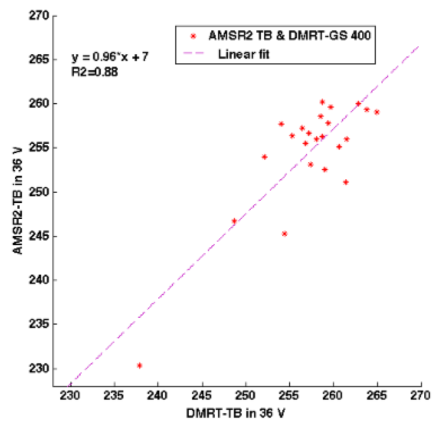

Figure 5. AMSR2 and DMRT-grain size 400 μm scatter plot and linear fit

Atmospheric contribution information, which is quantified by comparing ground references and measured values at sensor could also be supportive in results analysis (Wang & Manning, 2003) and might be considered in our future work. Also, providing suitable surface physical temperature from an independent source rather than using AMSR2 observation and stratified snow density and grain size reference could be applicable in future studies to explore multi layered DMRT performance more rigorously.

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