SNOW RETRIEVAL ALGORITHM FOR PASSIVE MICROWAVE REMOTE SENSING BASED ON DENSE MEDIA RADIATIVE TRANSFER THEORY

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1. ABSTRACT

The Quasi-crystalline Approximation and the Dense Media Radiative Transfer Equation (QCA-DMRT) have been applied to active and passive microwave remote sensing of snow [1] [2]. The salient features of the model include weaker frequency dependence than Mie scattering for the same grain size and a stronger forward scattering than Rayleigh phase function. We use passive microwave satellite data from AMSR-E to develop retrieval algorithms for the snow water equivalent (SWE). The passive retrieval algorithm makes use of the brightness temperatures at 18.7GHz and 36.5GHz and a least-squared optimization algorithm, where the snow grain size and snow depth are the two variables in the cost function. The retrieval algorithm has been applied to Alaska and Western United States. The results of retrieval algorithm are validated with SNOTEL ground measurement data from the USDA Natural Resources Conservation Service. The performance of SWE retrieval is beyond the heritage algorithm.

The classic heritage snow retrieval algorithm was based on Chang's paper [3], developed in 1987 for the SSMI mission. Chang's algorithm is a linear regression algorithm. One value is used from the satellite data, which is the brightness temperature difference of horizontal polarizations between 18.7 GHz and 36.5 GHz. This value is used to retrieve the one snow parameter - snow depth. This linear retrieval algorithm has two problems. Firstly, the brightness temperatures depend strongly on the grain size in addition to the snow depth. Secondly, given a grain size, the relation between brightness temperature differences will saturate as SWE increases [4].

The DMRT-based optimization algorithm retrieves both snow depth and snow grain size using two channels, 19 GHz and 37 GHz which are available from launched and proposed satellites, such as SMM/I, SMM/R, AMSR-E and MIS. The DMRT formulates the radiative transfer equation taking into account the collective scattering effects of the ice grains. It shows that the brightness temperatures of both channels are influenced by volume scattering in snow. The absolute value of the brightness temperature contains more information on the snow structure [5]. The advantage of the DMRT-based algorithm is that it uses the values of brightness temperatures and not just the difference. The dependence of brightness temperature on the physical temperatures of the snow and underlying ground are as follows,

$$T_{B,snow} = e_{s,eff}(r,d,g)T_{snow} + e_{g,eff}(r,d,g)T_{ground} \tag{1}$$

Where T_{snow} and T_{ground} are the physical temperature of the snow and ground respectively. The quantities $e_{s,eff}(r,d,g)$ and $e_{g,eff}(r,d,g)$ are, respectively, the effective emissivities of the snow and the ground. They are effective values as they include the full solution of DMRT equations, which depend on the ground permittivity with the roughness effect of snow-ground interface r, the snow depth d and the snow grain size g. To enable the algorithm to operate in real time, we pre-compute the effective emissivities $e_{s,eff}(r,d,g)$ and $e_{g,eff}(r,d,g)$ for 60 grain sizes g and 40 snow depths d, which are used to set up a look-up table. Note that the grain size g and the snow depth d are dynamic parameters. On the other hand, the roughness condition of the ground (r parameter) is a static parameter. The r parameter is categorized into five levels beginning from the smooth interface. The global map of the ground roughness condition will be provided at the beginning of the snow season. Thus there are 5 look-up tables of effective emissivities $e_{s,eff}(r,d,g)$ and $e_{g,eff}(r,d,g)$ with 1 look-up table for each static parameter r. For a given set of grain size and snow depth, the DMRT brightness temperatures can be obtained by interpolation of the look up table and evaluate Eqn. (1). The forest effect considered as an absorption layer is also included in the model. The total brightness temperature is calculated as

$$T_B = (1 - ff) \cdot T_{B,snow} + ff \cdot T_{B,for} \tag{2}$$

$$T_{B,for} = T_{for}(1 - e^{-L}) + T_{for}(1 - e^{-L})re^{-L} + T_{snow}(1 - r)e^{-L} \tag{3}$$

Where $T_{B,snow}$ is calculated by DMRT model, T_{for} and T_{snow} are the physical temperature of the forest and snow, L is loss factor of the forest layer and r is the reflectivity of the forest snow layer, ff is the forest coverage (in percentage) of the pixel.

In the retrieval algorithm, the snow grain size g and snow depth d are the two variables in the cost function $O(d,g)$. These two parameters are searched until the two forward model brightness temperatures agree with the two brightness temperatures from the satellite data in a least square optimization. With an initial guess, Newton's method was used to iteratively to solve the least squared problem. The initial guess is physically based. The algorithm operates in real time by using a look-up table of DMRT and a good initial guess for the least square optimized retrieval.

The retrieval algorithm has been applied to the Western United States and Alaska. The satellite data were obtained from AMSR-E database (National Snow and Ice Data Center, NSIDC). The footprint of AMSRE is 25km by 25km, therefore pixel has mixed landscapes. The water body, ocean and urban areas are pre-eliminated. Based on the snow classification, we have tested the DMRT algorithm for three major dry snow types: Tundra snow, Taiga Snow and Alpine snow. The DMRT retrieved results are in good agreement with SNOTEL for the entire snow season.

2. BIBLIOGRAPHY

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