A basic study on a new satellite algorithm for snow

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Abstract

This study developed a satellite algorithm for snow depth and snow grain size based on the microwave radiative transfer theory used the dense Media model and the 4-stream fast model and validated by using the in-situ snow depth data at the 75 ground-based stations in the northern hemisphere and the Advanced Microwave Scanning Radiometer for the Earth Observation System (AMSR-E) on Aqua launched by NASA in 2002. The results of validation were shown good correspondence of observation value and estimation value.

Keyword: snow, radiative transfer theory, remote sensing, microwave

1. Introduction

The climate conditions that exist in the various regions of the earth are formed by the water cycle on the scale of the earth on the land, atmosphere and ocean.
The water cycle between the land and the atmosphere causes climate variations on the scale of the earth as a result of significant hydrological variations over both the long term and short term over the land. Moreover, over land, the various land surface conditions are formed by vegetation and snow. Hence, it is difficult to grasp the hydrological variations of land in a quantitative way.
Particularly, the snow has the peculiarity as follows.

- Snow has high reflectance (albedo).
- Soil moisture increase by the melted snow water suppresses the rise of heat in the soil surface at spring and summer.

Accordingly, snow is greatly affecting the water cycle on the scale of the earth. Hence, it is a monumental challenge that grasps the snow quantity in a quantitative way.

In order to quantify snow conditions in some way, the observation way that the observation instruments arrange uniformly over the snow area of earth is idealized way. However, this is unrealistic from the point of view of the observation scale.

As alternate solution against such observation way, the application of satellite remote sensing for snow observations was inspired by the significant growth in the use of the microwave observation technique using various number of vibration and observation frequencies. In addition, the development of an all-weather snow observa - tion method that utilizes a microwave radiation instrument continues to attract attention.

This study devises a satellite algorithm that automatically estimates the snow grain size and snow depth based on microwave radiative transfer basis theory. Finally, we evaluate the validity of the algorithm by comparison between the estimated snow depth and the observed snow depth.

2. Previous microwave radiative transfer model and Satellite algorithm

In the past, many satellite algorithms based on micro - wave radiative transfer theory have been developed for calculating snow depth.

In this section, explains about microwave radiative transfer model (Koike & Suhama(1993)) and satellite algorithm (Koike et al (1999)) became the prototype of a new algorithm at this study.

2.1. Microwave radiative transfer model for snow by Koike & Suhama(1993)

Koike & Suhama(1993) applied the England radiative transfer model(1975) to snow. And they proposed the Microwave radiative transfer model from snow layers as shown in Fig.1.

In addition, The England radiative transfer model (1975) is a model based on the theory that the radiation from a scattering medium consists of two components; direct radiation and diffuse radiation. And this scattering medium is a medium of homogeneous thickness of average including spherical scatterers of average number on a half-infinite medium. In this algorithm, the scattering medium is assumed to be snow layers which consisted of uniformly spherical ice particles.

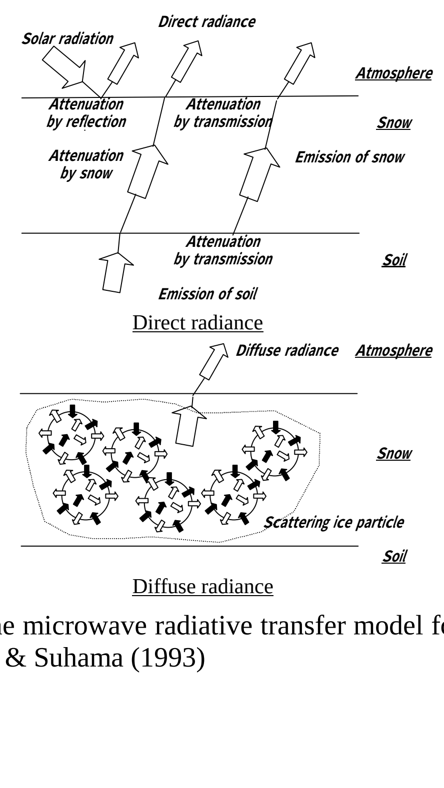

Fig.1: The microwave radiative transfer model for snow by Koike & Suhama (1993)

2.2. Satellite algorithm by Koike et al (1999)

Koike et al (1999) assumed the snow grain size and the snow density in this England radiative transfer model. And they developed satellite algorithm as follows.

- By the snow depth and the snow temperature changes, calculates the brightness temperature for two frequencies (19GHz&37GHz) from snow layer.
- Based on the result of this calculation, a transform table is made for transforming the brightness temperature of two frequencies into snow depth and snow temperature.
- By using a transform table, calculates the snow depth and snow temperature from the brightness temperature corresponding to the two frequencies.

As just described, the satellite algorithm of Koike et al (1999) calculated snow depth and snow temperature using a difference of 19GHz brightness temperature and 37GHz.

2.3. Point at issue

England radiative transfer model for snow (Koike & Suhama(1993)) has issues as follows.

2.3.1. Restriction on Snow grain size and Snow density

England radiative transfer model has restriction on snow grain size and snow density.

Snow grain size can not use except 0.6mm or thereabout. And Snow density can not use except 0.3 g/cm^3.

When snow depth is calculated using the difference of brightness temperature by a microwave radiative transfer theory, deep snow depth is calculated by small snow grain size and low snow density and shallow snow depth is calculated by big snow grain size and high snow density.

Hence, England radiative transfer model having a restriction on snow grain size and snow density can not calculate snow quantity matching actual snow.

2.3.2. Restriction on Frequency

High frequency plays an important role in detection of the volume scattering influence with increase snow grain size.

However, England radiative transfer model can not use except frequencies of 19GHz and 37GHz. This condition is major fault in this model.

2.3.3. Overestimation of the attenuation effects inside snow

England radiative transfer model overestimates the attenuation effects inside snow. And the calculated brightness temperature severely decreases with increase of snow thickness and frequency. Moreover, the difference of 19GHz brightness temperature and 37GHz brightness temperature increases in size. As the result of this characteristic, this model and algorithm calculates shallow snow depth against deep snow depth.

3. Introduction of a new microwave radiative transfer model

As has been previously described, the conventional radiative transfer model such as England radiative transfer model has many issues.

Accordingly, this study introduced a new microwave radiative transfer model. That is Dense Media radiative transfer model(Tsang(1992)) and 4-Stream Fast radiative transfer model(Liu(1998)).

In the conventional radiative transfer model, conceives snow particles (scatterers) are independent. Hence, the extinction coefficient becomes linear dependent on the number of particles (the fractional volume).

On the contrary, Dense Media radiative transfer model conceives correlation of each scatterers. Hence, the extinction coefficient calculated by Dense media radiative transfer model becomes lower than conventional model. And the behavior of extinction coefficient becomes such as the diagram below indicates.

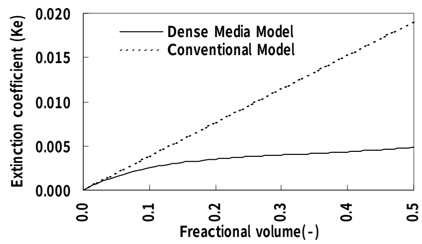

Fig.2: The difference of the extinction coefficient by conventional model and the extinction coefficient by Dense media model.

As has been previously described, Dense Media radiative transfer model calculates optimum extinction coefficient. Then, this model calculates optimum atenuation effects inside snow. And the difference of 19GHz brightness temperature and 37GHz brightness temperature decreases in size. Hence, this radiative transfer model can calculate deep snow when snow depth is calculated using the difference of brightness temperature. This model characteristic is important advantage.

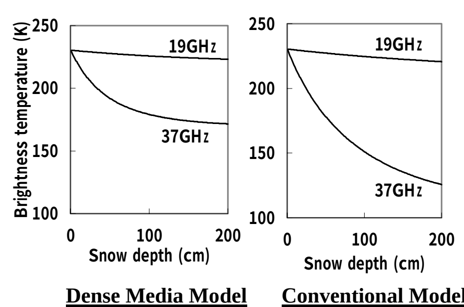

Fig.3: The difference of the brightness temperature by conventional model and the brightness temperature by Dense media model.

In this satellite algorithm, the extinction coefficient and albedo calculated by the Dense Media radiative transfer model introduced to 4-Stream Fast radiative transfer model and calculated the brightness temperature.

4. The structure of a new satellite algorithm

In this new satellite algorithm, inputted snow depth (1-200cm) and snow temperature (223-273K) into the radiative transfer model and calculated the brightness temperature of 19GHz&37GHz and made a snow depth transformation table such as the diagram below indicates.

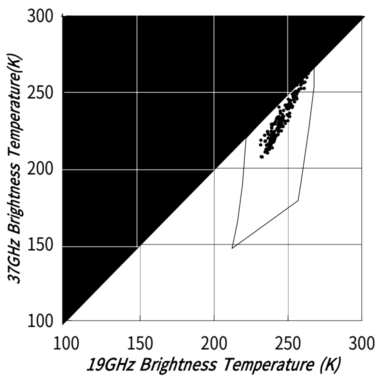

Fig.4: The snow depth transformation table

And inputted snow depth (1-200cm) and snow temperature (223-273K) into the radiative transfer model and calculated the brightness temperature of 89GHz and made a brightness temperature transformation table such as the diagram below indicates.

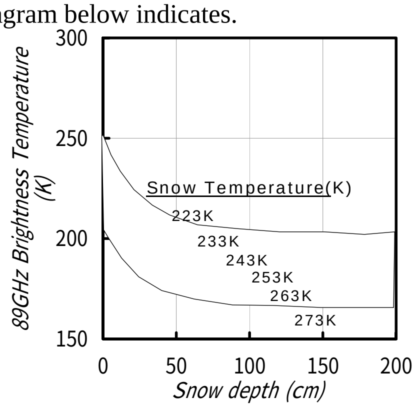

Fig.5: The 89GHz brightness temperature transformation table

Moreover, considered the structure of a satellite algorithm as follows.

1) The first, input satellite brightness temperatures (19GHz&37GHz) to the snow depth transformation table of the six kinds of snow grain sizes. And calculates snow depth and snow temperature of each snow grain size.
2) The second, input 89GHz satellite brightness temperature to the brightness temperature transformation table of the six kinds of snow grain sizes. And calculates 89GHz brightness temperature of each snow grain size.
3) Calculates the modulus of difference of the calculated 89GHz brightness temperature and the 89GHz satellite brightness temperature(⊿TB89).
4) Compares ⊿TB89(89GHz brightness temperature difference) corresponding to each grain size, and selects the 89GHz minimum brightness temperature difference(⊿TB89min).
5) Decides on the optimum snow grain size corresp - onding to the selected ⊿TB89min.
6) Decides on the optimum snow depth and the optimum snow temperature by using optimum snow grain size.

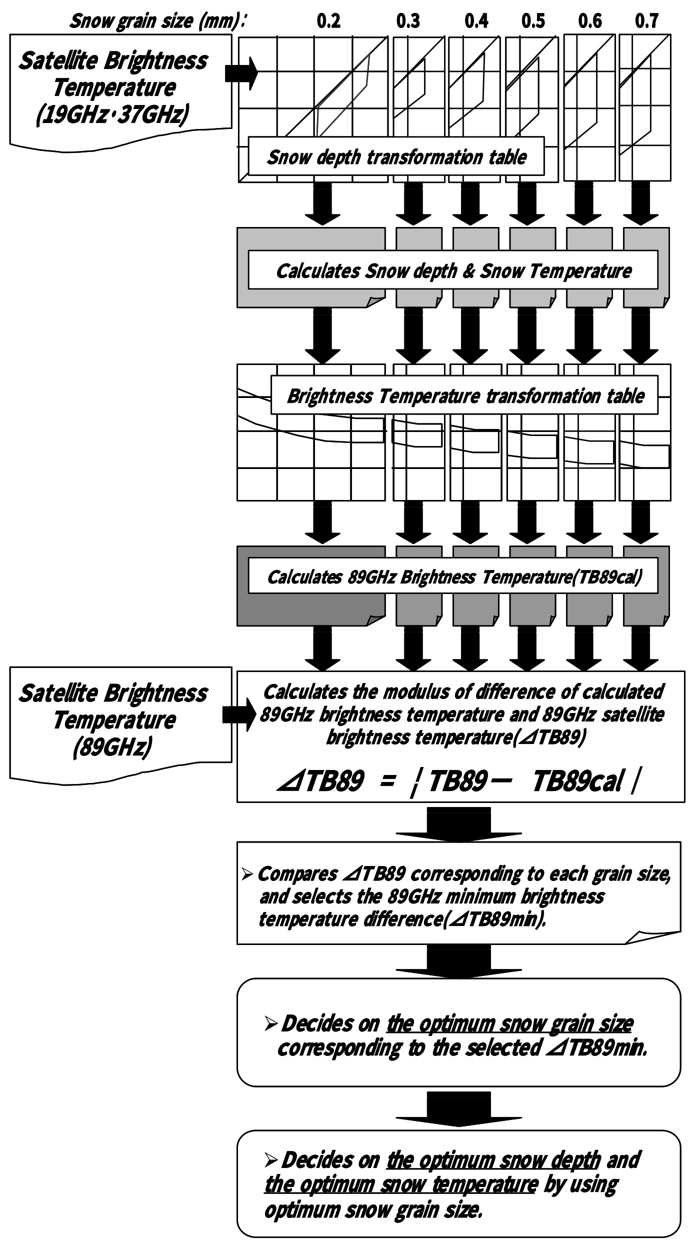

Fig.6: The snow quantity calculation satellite algorithm in this study

The above process is a new snow quantity calculation satellite algorithm in this study.

5. The estimation of a new snow quantity calculation satellite algorithm

In this study, we estimated the validity of a new satellite algorithm by comparing the calculated values of this algorithm and the GTS snow depth data.

The findings below were made using the average of the modulus of the difference in the observed snow depth and the calculated snow depth as the estimation index.

1) When this value is 20cm or less, the compatibility is good.

2) When this value exceeds 20cm, the compatibility is poor.

In this result, the good compatibility was 65 sites among 75 sites.

The snow depth correlation chart of observed snow depth and estimated snow depth is shown in Fig7, 8. Fig.7 is result of estimation by conventional algorithm. And Fig.8 is result of estimation by algorithm of this study. And an example among 75 sites of time-series estimation snow depth is shown in Fig.9.

As shown in Fig.7 & 8 & 9, accuracy of estimation was enhanced at deep snow by using a new algorithm.

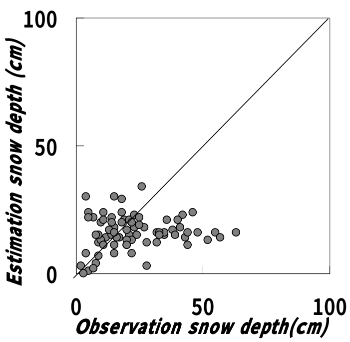

Fig.7: The snow depth correlation chart by the conven - tional algorithm

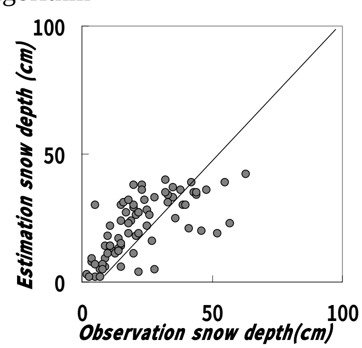

Fig.8: The snow depth correlation chart by the new algorithm

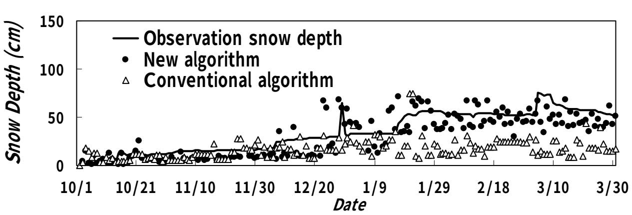

Fig.9: An example of time-series estimation of snow depth

Moreover, world distribution map shown conditions of compatibility is shown in Fig.10.

As shown in Fig.10, the compatibility of a Russia federal northern part (region of heavy snows) was improved.

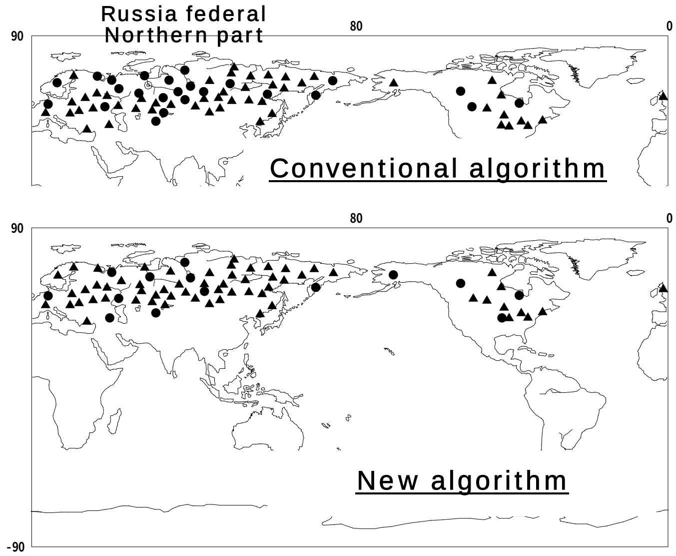

Fig.10: The world distribution map about compatibility
▲:Good compatibility ●:Poor compatibility

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