ON THE EFFECT OF THR DROP SIZE DISTRIBUTION (DSD) AND MELTING LAYER TO THE BRIGHTNESS TEMPERATURE OF A SPACEBORNE PASSIVE MICROWAVE RADIOMETER

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1. INTRODUCTION

Since the TRMM launch in 1997, global rain estimation by microwave radiometer has been improved referring the PR data. The microwave radiometer observation becomes the major observation tool for the Global Precipitation Measurement (GPM). However, there are still gaps of global rainfall distribution between PR and TMI (e.g. Berg et al., 2002). One of the major issues for rain retrieval algorithms for spaceborne microwave radiometers is to introduce an appropriate drop size distribution (DSD) model and melting layer (bright band, BB) model. Most of the algorithms assume Marshall-Palmer type DSD because it is one of the typical DSD model and it is easy to convert rain rate to DSD. However, recent studies using the TRMM data indicates that difference of DSD model used in the PR and the TMI algorithm causes the difference in rainfall estimation between the PR and the TMI. In this study, sensitivity to a DSD model is examined using plane parallel radiative transfer model by Liu (1998).

Considering that use of the common cloud physical model between the PR and the TMI algorithms, it is also necessary to introduce a melting layer model to the TMI algorithm. Because its complexity, the existing melting layer models have limitation to express the actual melting layer. However, in order to assess the effect of the melting layer to the brightness temperature, a melting layer model which is used for TRMM/PR’s algorithm is introduced to the Liu’s radiative transfer model.

2. MODEL DESCRIPTION AND ANALYSIS METHOD

2.1 DSD model

A gamma distribution type DSD model is used in this study in order to realize natural variability of DSD. The DSD is expressed as,

$$N(D) = N_0 D^\mu \exp(-\Lambda D) = N_0 D^\mu \exp\left(-\frac{(3.67 + \mu)D}{D_0}\right)$$

where, D is the drop diameter in mm, the D0 is median diameter in mm and \(\mu\) is the shape parameter. In this study, N0 in the DSD is obtained from the rain rate, D0 and \(\mu\), using an empirical fall velocity function (\(\nu(D)\)) as follows,

$$R = 3600 \cdot 10^{-4} \pi \int_0^\infty D^3 \nu(D) N(D) dD$$

$$= 3600 \cdot 10^{-6} \pi \int_0^\infty D^3 \cdot 3.778D^{0.67} N(D) dD$$

$$= 6 \cdot 10^{-4} \cdot 3.778 \cdot N_0 \pi \frac{\Gamma(3.67 + \mu + 1)}{\Lambda^{3.67 + \mu + 1}} \ [mm / h]$$

For a given rainfall rate, \(\mu\) and median diameter (D0) in the gamma distribution varied from -3 to 5 for \(\mu\) and 0.6 to 2.0 mm for D0. The RTM developed by Liu (1998) is modified to allow variable DSD model and the brightness temperature is calculated under a assumption that the rain structure is assumed to have constant DSD and rain rate, and the rain layer has 3 km in depth. Neither snow layer nor melting layer is assumed in this test. Figure 1 shows an example of the relationship between rain rate and brightness temperature for TMI frequencies. This calculation uses sea surface temperature of 300 K, Fresnel scattering at the sea surface and Marshall-Palmer DSD.
2.2 Melting layer (Bright band, BB)

For the melting layer model, a bright band model used for the TRMM PR’s algorithm (2A23, Awaka et al., 1997) is introduced which is called Nishitsuji model. The outline of the model is as follows: it assumes constant flux (rain rate) throughout the BB. The volume water content (Pw) of a melting particle is a function of the distance from the freezing level which is given by a lookup table (Fig. 2) based on the experimental (observational) data. The density of the melting particle (g/cm^3) is given by square root of Pw. This relationship is also used above the freezing level. The dielectric constant of a mixed material (melting particle) is given by the Wiener’s equation,

\[ \frac{\varepsilon_s - 1}{\varepsilon_s + U} = P_w \frac{\varepsilon_w - 1}{\varepsilon_w + U} + P_i \frac{\varepsilon_i - 1}{\varepsilon_i + U} + P_a \frac{\varepsilon_a - 1}{\varepsilon_a + U} \]

where, \( U \) is a shape parameter, \( \varepsilon_s \) is the dielectric constant of melting particle, \( \varepsilon_w \) is the dielectric constant of water, \( \varepsilon_i \) is the dielectric constant of ice, \( \varepsilon_a \) is the dielectric constant of air, \( P_i \) is a ice content, and \( P_a \) is an air content. The third term on the right hand side is negligible. In this mode, \( U \) is function of distance from the freezing level and is also given by a lookup table. Figure 3 plots the Pw and U profile below the freezing level. In this model, the DSD model is given by,

\[ N(D) = N_0 10^{-Ba} \]

where, \( a \) is a radius of particle in cm, and the slope parameter \( B \) is a function of Pw. This DSD form is similar to the exponential DSD, like as Marshall-Palmer distribution,

\[ N(D) = N_0 e^{-4.1R^{0.21}20a} \]

were, \( R \) is the rain rate (mm/h). Then, \( B \) is expressed as,

\[ B = 20\log(e)4.1R^{-0.21} \]

for Marshall-Palmer distribution. The \( B \) at given Pw is obtained to the curve in Fig. 4 started at the \( B \) value at Pw=1 which obtained from the Marshall-Palmer DSD. The RTM code is modified to allow the DSD model and dielectric constant of melting particles, also the number of layer around the BB is increased to describe the bright band. In addition, back scattering calculation is added in order to compare the radar observation.

In order to make a comparison other bright band model, a bright band model develop by Yokoyama and Tanaka (1984) is also introduced. This is a non break-up and non coalescence model, and the water content of the each size of a drop is determined by the heat budget between the environmental air and melting particle assuming the temperature of the melting particle is zero degree Celsius. In this study, the DSD is modified to gamma distribution in order to see the effect of the dependency on the DSD model as well as the model comparison. The mixing rule to calculate the dielectric constant used in this model is Maxwell-Garnett equation. Table 1 summarizes the characteristics of both models.

Figure 5 shows Z profiles for variable frequencies up to 100 GHz based on Nishitsuji model for the case of that the rain rate is 10 mm/h. Looking at the shape of BB and the slope above freezing level, this model is fairly realistic. Note that the Yokoyama-Tanaka model can not be applied above the freezing level.

![Fig. 2. The vertical profile of volume water content (Pw). Zero indicates the freezing level, and positive range shows below the freezing level.](image)

![Fig. 3. Vertical profile of Pw and U below the freezing level. The Pw is expressed in linear scale.](image)
3. RESULT

3.1 DSD model

The sensitivity test for the DSD model is done for the rain rate of 10 mm/h in 10 GHz shown in Fig. 6. The result shows that calculated brightness temperature varies more than 20 K. This result, however, includes extreme DSD parameter which scarcely appears in nature. A constraint is added to have more realistic situation: a Z-R relationship or constant rain water content. Assuming that Rayleigh approximation, Z is expressed by gamma function as,

\[ Z = aR^b = N_0 \frac{\Gamma(6+\mu+1)}{\Delta^{6+\mu+1}} \]

and the D0 is expressed by a, b, and R as,

\[ D_0 = \left(6 \cdot 10^{-4} \cdot 3.778 \cdot aR^{b-1} \frac{\Gamma(3.67+\mu+1)}{\Gamma(6+\mu+1)}\right)^{\frac{1}{2.13}} (3.67+\mu) \]

In this study, constant “a” value (a=200) is assumed. In Fig. 6, constant Z-R line for variable “b” value is plotted.

Table 1. Comparison of two bright band models

<table>
<thead>
<tr>
<th>Model</th>
<th>2A23 (Nishitsuji)</th>
<th>Yokoyama-Tanaka</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constraints</td>
<td>Const. R</td>
<td>Const. R, Non- breakup, Non-coalescence</td>
</tr>
<tr>
<td>Water content</td>
<td>Given by an empirical table.</td>
<td>Heat equilibrium condition in each size</td>
</tr>
<tr>
<td>Fall velocity</td>
<td>Interpolation using rain fall velocity and snow fall velocity</td>
<td>Ratio of the air drag of melting particle to that of rain drop.</td>
</tr>
<tr>
<td>DSD</td>
<td>Slope parameter (B) is a function of Pw</td>
<td>Based on the constant flux of each particle</td>
</tr>
<tr>
<td>Dielectric constant</td>
<td>U is function of Pw.</td>
<td>Mie calculation of two-layer particle (Maxwell-Garnett mixing formula in this study.)</td>
</tr>
</tbody>
</table>

Fig. 6. Calculated brightness temperature for variable D0 and µ. In this case, rain rate is 10 mm/h. The stat mark indicates the Marshall-Palmer DSD

If the constant rain water content (solid line) is considered, the change in the brightness temperature is about 10 K mainly by the negative \( \mu \) values, because of the difference in the Mie effect. Constant Z-R relationship (dashed line) shows almost independent from \( \mu \) values, and the maximum changes in the brightness temperature is about 5 K. Considering that the Z-R relationship changes with the rain type, changes in the brightness temperature for different Z-R relationship is examined. In this study, the “b” value in the Z-R relation of \( Z=200R^b \) is varied from 1.4 to 1.8 (note that Marshall-Palmer type is 1.6). About 15 K changes by this test.

3.2 Melting layer

The brightness temperature from melting layer model is compared with the brightness temperature from rain only
model. The precipitation structure is assumed to have constant rainfall rate whole the precipitation layer. Figure 7 shows an example of calculated brightness temperature for 10, 19, 37, and 85 GHz. In the lower frequencies, the brightness temperature with melting layer show the same or smaller value than the brightness temperature of rain only model for weaker rain rate. At the higher frequencies, same tendency is seen. But the brightness temperature of melting layer model becomes higher for weaker rain rate. This result indicates the Nishitsuji model may not affect serious changes in the brightness temperature because stratiform rain appears relatively weaker rain condition. However, this is still preliminary result and the model implemented to the RTM has still space for improvement such as vertical resolution of melting layer and the depth of snow layer.

![Brightness temperature vs rain rate](image)

Fig. 7. The relationship between rain rate and brightness temperature for TMI frequencies. The solid line shows no melting layer case, and the dashed line shows melting layer case. The environmental condition is July 1, 1998 at 0 degree north and 155 degree east that is obtained from GANAL.

The Yokoyama-Tanaka model is used for the sensitivity test of melting layer shown in Fig. 8. Several Kelvin increment appeared for the rain rate of 1 mm/h for 10 GHz, and the difference increases to about 20 K for the rain rate of 10 mm/h. This result is quite different from the result of the Nishitsuji model, mainly because of the different mixing rule of melting particle and the depth of snow layer.

![Brightness temperature vs rain rate](image)

Fig. 8. Same as Fig. 6 except for melting layer model case of 1 mm/h rainfall. The melting layer model is develop by Yokoyama and Tanaka (1984).

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### REFERENCES


