MICROWAVE RADIATION FROM MIXED PHASE CLOUD AND PARAMETER RETRIEVALS

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INTRODUCTION

The measurement of microwave radiation has been widely used in atmospheric remote sensing, such as temperature profiling, and vapor and liquid column measurements [1] - [5]. The radiation from atmosphere is due to the absorption (emission) and scattering of electromagnetic (EM) wave by atmospheric particles (gaseous molecules, liquid water droplets and ice crystals). The absorption directly contributes to emission. The scattering due to larger particle affects the emitted radiation indirectly. The dependence of the measured radiation due to scattering and absorption is governed by radiation transfer (RT) equation. At microwave frequencies, liquid water particles and gaseous molecules mainly absorb EM wave and dominate the emission, while ice particles scatter EM wave. Therefore, the measured radiations depend on composition of cloud (liquid and ice) and mean particle size.

To solve RT equation for cloud radiation, a physical model of cloud is needed; in which cloud structure, drop size distribution and temperature are specified. In the past, cloud is usually modeled as a layer of random medium with single phase particles, or two-layer medium, in which each layer consists only one kind of particles (liquid or ice) [1][5]. In clouds, however, both liquid and ice phase particles (mixed phase) co-exist frequently. The mixed phase cloud may have different microwave radiation characteristics than a single layer cloud. Further studies of microwave radiation from the mixed phase cloud are needed to understand the radiation process and to develop a more accurate model for parameter retrieval.

In this paper, we study microwave radiation from mixed phase cloud and a method for retrieving cloud parameters using neural network. The cloud consists of three layers: top layer with ice droplets, bottom layer with liquid droplets, and the middle layer composed of both ice and liquid particles. The brightness temperature is calculated by numerically solving radiative transfer (RT) equation. Numerical result suggests that brightness temperature between mixed phase cloud and two-layer cloud differ significantly. The difference can be up to 10 degree for the same liquid and ice water paths as well as temperature structure. In this paper, model calculations are shown for mixed and single layer clouds. The mixed phase multi-frequency RT model results are then used to train neural network for retrieving cloud parameters such as water content and mean droplet size.

MODEL AND CHARACTERIZATION OF CLOUD

As shown in Fig. 1, we use a three-layer model to characterize a mixed phase cloud. The top layer consists of ice particles. The bottom layer is composed of liquid cloud droplets. The middle layer, mixed phase, contains both ice and liquid particles. Each layer have variable water content and drop size distribution. To calculate the microwave radiation, cloud depth, temperature, and particle size distribution as well as water vapor concentration need to be specified.

(1)

To simplify the calculation of brightness temperature and the retrievals of cloud parameters, we parameterize temperature, water vapor, and drop size distribution. Air temperature decreases smoothly with height. The temperature profile is approximated by a linear relation as

$$T(z) = T_A - \Gamma z$$

where, T_A is the effective temperature at the surface and the lapse rate. It should be noted that T_A and Γ are effective variables and are not necessarily equal to the actual near surface temperature and mean lapse rate, respectively.

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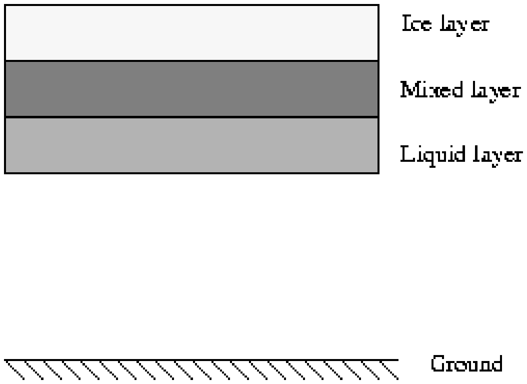

Figure 1. A three-layer model for partially mixed phase cloud. The three layers are liquid phase, mixed phase, and ice phase.

Water vapor density profile is approximated by an exponential function,

$$\rho_v(z) = \frac{V}{H_v}\exp\left(\frac{z}{H_v}\right) \tag{2}$$

where V is integrated water vapor content and H_v is water vapor scale height.

Particle size distribution is an important quantity in determining cloud microphysics and atmospheric radiation. Especially, ice particle sizes are comparable to wavelength and they are in Mie scattering regime. Both liquid and ice particle size distributions are assumed to be modified Gamma distribution as,

$$n(r) = ar^{\alpha}\exp(-br^{r}) \tag{3}$$

where r is the radius of particles, α and Υ are shape parameters, a is related to the water content (WC) and total number density and b is related to the mode of particle size distribution [5].

NUMERICAL RESULTS AND PARAMETER RETRIEVALS

The brightness temperature is calculated based on the exact solution of RT equation. To show the mixed phase effect on radiation we compare the results obtained using different cloud structures: two-layer model and mixed phase model (including partially mixed model is shown in Fig. 1). The fixed parameters are integrated vapor V = 0.8 cm, surface pressure P_0 = 84 KPa, cloud base height 3 km, and cloud top height 6 km. The surface effective temperature is $T_A = 283\ ^{o}$k. We choose the lapse rate $\Gamma = 0\ ^{o}$K/km for the results shown in Fig. 2 for a fair comparison, and $\Gamma = 6.5\ ^{o}$K/km for parameter retrievals. For the modified Gamma distribution of cloud droplets, the shape parameters are $\alpha = 2$ and $\Upsilon = 1$. The mode radii are r_{cl} = 0.02 mm for liquid droplets, and r_{ci} = 0.2mm for ice droplets. Liquid water path (LWP) is fixed at 0.5 mm. Brightness temperatures are calculated for three cases: (i) mixed phase model, (ii) partially mixed model and (iii) separate two-layer model. The results are plotted as a function of ice water path (IWP) and shown in Fig. 2.

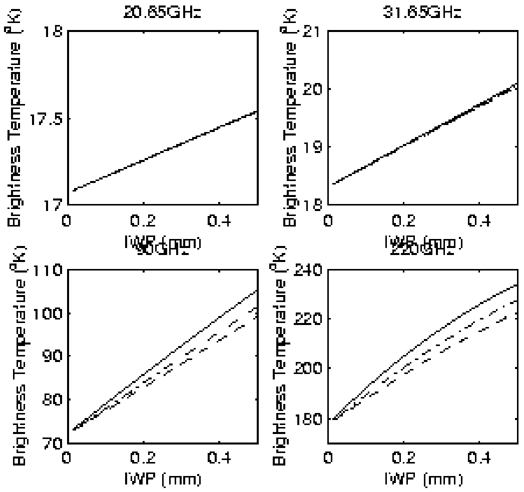

Figure 2. Comparison of brightness temperature between two-layer model nad three-layer mixed phase model. The results are shown for 20.65, 31.65, 90 and 220 GHz. Three lines are: (1) solid line for mixed phase model, (2) dot-dash line for partially mixed model, and (3) dashed line for two-layermodel. A 10^{o}K difference can be seen for 220 GHz.

The three different cloud structures exhibit almost the same brightness temperature at frequencies of 20.65 and 31.65 GHz, but they are different at 90 and 220 GHz up to 10 ^{o}K. This is because the microwave radiation is dominated by the absorption of gaseous and liquid particles at 20.65 and 31.65 GHz. However, at higher microwave frequencies of 90 and 220 GHz, the contribution from ice particles becomes important. The scattering mechanism is different for single and mixed phase clouds. In the case of mixed phase cloud, the emission from liquid droplets is scattered by ice particles that are in the immediate vicinity and hence the emitted radiation is higher.

The brightness temperature nonlinearly depends on water content and mean droplet size. Because of the non-linear relation, it is difficult to retrieve the atmospheric parameters using a simple curve-fitting technique. However, neural network techniques have shown advantages in dealing with the non-linear problems and been used in passive remote sensing measurements. Here, we apply neural network techniques for parameter retrieval from multi-frequency brightness temperature based on the radiative transfer model calculations.

We constructed a neural network-based retrieval model using the integrated water vapor V, liquid water path LWP, ice water path IWP, and ice droplet size r_{ci}, and radiation at four frequencies: T_1, T_2, T_3, and T_4. Considering the training speed and memory requirement, we used a radial basis neural network with the brightness temperature $X=(T^1, T_2, T_3, T_4$ as input, and the atmospheric parameters Y= (V, LWP, IWP, r_{ci} as output. Accuracy of neural network is tested using a data set that is different from the training data set. The brightness temperatures at frequencies 20.65, 31.65, 90, and 220 GHz are used.

The retrieved results are plotted as functions of input parameters as shown in Fig. 3. The solid lines are for self-test, i.e. test and training data sets are the same. The straight line shows the convergence for the self-test case. The dashed lines are the tests for a different data set. The retrieved parameters are close to the input parameters. After 2401 batch training, the normalized output errors are 0.0092 for self-test and 0.13 for different data set, respectively.

CONCLUSIONS

In this paper, we described a three-layer mixed model to characterize microwave radiation from mixed phase cloud. The brightness temperature is calculated by numerically solving RT equation. The results are compared with that using the two-layer single-phase model and the difference in brightness temperature is up to 10 degree. The mixed phase RT model results are used to retrieve atmospheric parameters such as water vapor, liquid water path, ice water path and, mean ice droplet size. The results are encouraging, the technique will be applied for actual measurements, and radar data will be used for independent verification of the same.

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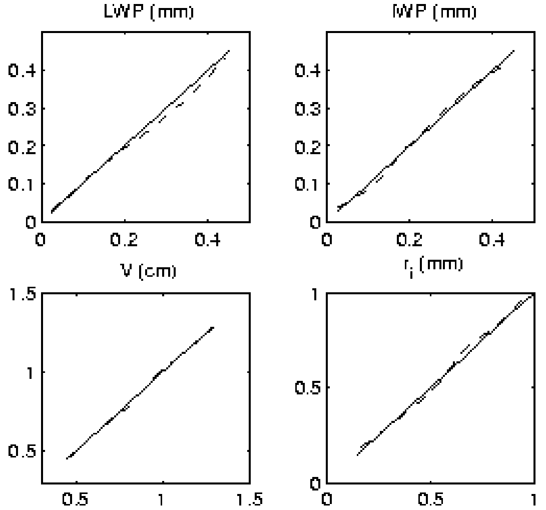

Figure 3: Neural network retrieval of atmospheric parameters: integrated water vapor (V), liquid water content (LWP), ice water path (IWP), ice droplet size (r_{ci}). The solid line is for the self-test case. The dashed line is for a different data set from the training data.

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