Vol.7 No.1 Advances in Atmospheric Sciences February 1990

The Investigation of Microwave Precipitation Measurement at 37GHz ①

Liu Jinli (刘锦丽), *Xiao Jianming* (肖剑鸣), and *Zhang Ling* (张凌)
Institute of Atmospheric Physics, Academia Sinica, Beijing 100011

Received October 5, 1988

ABSTRACT

In this paper we use a 10–layer radiation transfer model to systematically investigate the relation between brightness temperature and the rainfall rates at 37 GHz, including various viewing of microwave (MW) remote sensing and different surface condition, with main focus on the influence of the structure of ice–phase layer. The results show that the quantitative rainfall measurement can not be reliably obtained over the land from spaceborne radiometer at this wavelength and the structures of ice layer are very important in determining the "observed" brightness temperature for the spaceborne MW remote sensing.

I. INTRODUCTION

Precipitation plays an important role in the global circulation of the atmosphere. For investigating global climate variability and improving the nowcasting of severe storms, collecting the global data of accurate precipitation are required. The conventional measurement of rainfall are extremely inadequate and no direct rainfall measurement has yet existed over oceanic areas. In many areas over the lands the rain gauges have been sparsely deployed. Although in some areas meteorological radar may extend the gauge measurements it requires rigorous calibration and is affected by many other factors. Recently visible and infrared observations have been applied to the precipitation estimation based on infrared sounding of cloud–top temperature and cloud–image features. In principle, this kind of estimation can only be semi–quantitative rather than quantitative.

The passive microwave technique is of great potential use in precipitation measurement. Since microwave radiation can be directly related to the hydrometer themselves, and usually not seriously affected by most of the cloud layer above rain spaceborne MW remote sensing will be a main element in the global precipitation measurement.

In this paper, with a 10–layer plane–parallel radiative transfer model we systematically investigate MW precipitation measurement at 37 GHz, including upward viewing (ground–based), downward viewing (spaceborne) and 45 ° viewing remote sensing over land or ocean. Also we investigate the influence of ice layer structure (the thickness of ice layer, the ice water content, and particle size distribution etc.) on the precipitation measurement. Finally we discuss some uncertainties and possible complementary method in applying spaceborne MW radiometry at 37 GHz.

II. MODEL CALCULATION

Based on the model developed by Wilheit et al. (1977) we have developed a 10–layer

---

①This project is supported by National Science Foundation of China.

plane–parallel radiative transfer model. Considering the physical process of precipitation, for example, water drop collision, transforming water vapor into water drops etc., in the rainout area we introduced mixed layer below the freezing layer, permitting some vertical variability in single scattering albedo ω. Fig.1 is a schematic view of the model. The surface might be either a land (surface albedo is chosen as 0.1 and 0.2) or an ocean (as 0.5). The temperature lapse rate is taken as 6.5℃ / km, thus the surface temperature (T_s) is determined by the height of freezing level. Above the freezing level a variable thickness of ice layer and different ice water content are assumed; below the freezing level is a non–precipitating cloud layer; we divide the rainout layer into 7 layers, each of them having different percentage of ω_c and ω_r which are the single scattering albedo in the cloud area and in rain area respectively.

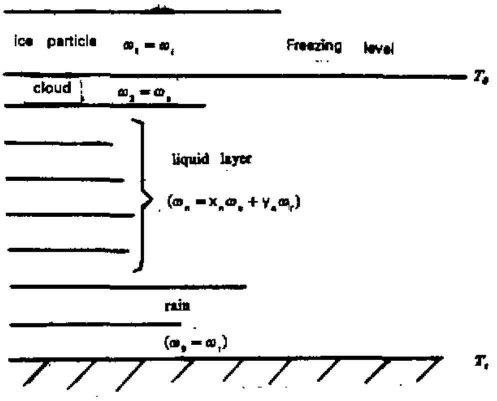

Fig. 1. Model used to relate MW brightness temperatures and rain rates.

In cloud and rain layers, Marshall–Palmer(M–P) water drop size distribution is assumed; in ice layer we choose M–P particle size distribution and actual particle distribution obtained from particle measurement systems 2D–C and 2D–P probe (mounted on the NCAR King Air aircraft) during MAYPOLE project(Colorado, USA in May, 1983).

The influence of water vapor and oxygen in calculating brightness temperature is corrected by using monthly average values of the extinction coefficient for July at Beijing. These values were calculated and listed by Group of Microwave Remote Sensing, IAP(1982).

III. RESULTS

In this paper we only discuss the calculations in regard to the relation between brightness temperatures and rain rates at 0.86 cm (37 GHz), which is commonly recognized as one of the suitable wavelengths for spaceborne MW remote sensing of precipitation; another reason for selecting this wavelength is that we have a radar radiometer system with this wavelength which will be favorable to the verification of model calculation with field observation.

The variation of precipitation rate ranges from 0.1 to 50 mm / h.

(1) *Typical condition*

According to the average vertical temperature and water vapor profiles for July in Beijing, the freezing level is chosen as 4.5 km, thus the surface temperature is 302.25 K. The thickness of ice layer is taken as 0.5 km, containing 0.5 g / m^3 ice water content. The non–precipitating layer is 0.5 km in thickness, and the liquid water content is also taken as 0.5 g / m^3. The single scattering albedo ω in 10 layers is assumed as follows, $\omega_1 = \omega_i$, $\omega_2 = \omega_c$, $\omega_3 = 0.8\omega_c + 0.2\omega_r$, $\omega_4 = 0.6\omega_c + 0.4\omega_r$, $\omega_5 = 0.4\omega_c + 0.6\omega_r$, $\omega_6 = 0.2\omega_c + 0.8\omega_r$, $\omega_7 = 0.1\omega_c + 0.9\omega_r$, $\omega_8 = \omega_r$, $\omega_9 = \omega_r$, in which ω_i, ω_c and ω_r are the single scattering albedo in ice area, in nonprecipitating area and in raining area respectively. The calculation results for different surface condition and various viewing angle are shown in Fig.2 and Fig.3, respectively.

In Fig.2, surface albedo (A_s) is taken as 0.1 and 0.2 over the land, and 0.5 over the ocean for downward viewing spaceborne remote sensing. It can be seen that for the downward viewing over the land, as rain rates vary from 0.1 to 15 mm / h, the variation of the brightness temperature is less than 10 K, and very sensitive to different surface condition (comparing the curves for $A_s = 0.1$ and $A_s = 0.2$). These mean that it is difficult to estimate the rain rate by using spaceborne radiometer at 37 GHz over the land; the same conclusion also was deduced by Rodgers et al.(1979) employing Nimbus–6 ESMR measurements. On the contrary, over the ocean, the brightness temperatures are more sensitive to the rain rates; the brightness temperatures monotonously increase with rain rates. When they vary from 0.1 to 15 mm / h, the difference of the corresponding brightness temperature is about 47 K. So it is possible to use the spaceborne radiometer at 37 GHz over the ocean to estimate small and moderate rain rates.

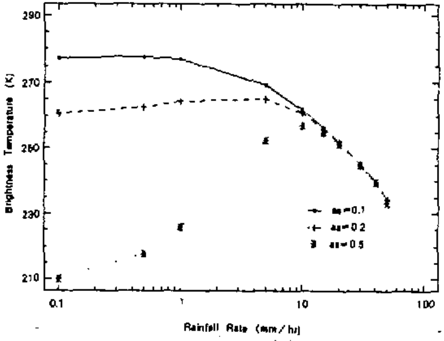

Fig.2. Brightness temperature versus rain rate for spaceborne MW remote sensing (37GHz) on different surface condition (surface albedo as 0.1, 0.2 and 0.5).

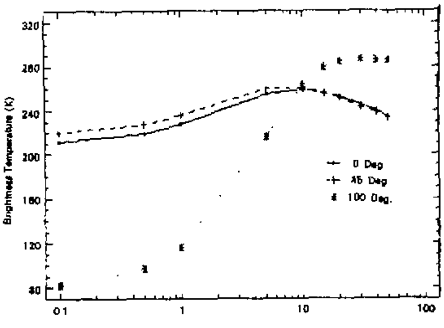

Fig.3. Brightness temperature versus rain rate for various viewing angle (0 ° , 45 ° , 180 °) of MW remote

sensing over the ocean.

In Fig.3, 0 deg, 45 deg and 180 deg correspond to downward–viewing, 45 ° viewing angle and upward–viewing with spaceborne radiometer at 37 GHz over the ocean respectively. It can be found that the curves of 0 deg and 45 deg viewing are very similar, suggesting that 45 deg viewing angle is also possible to be used in the rainfall measurement. For upward viewing ground–based radiometer, the relation of the brightness temperatures and rain rates is much better than that for downward viewing. On this condition, brightness temperatures monotonously increase with rain rates and have large dynamic range, particularly in small and moderate rain rates (<15 mm / h). It indicates that the ground–based microwave radiometer at this frequency is satisfied for estimating rainfall rates. This conclusion was also deduced by Zhou et al. (1982).

(2) *Different ice water content in ice layer*

We choose two different ways for changing ice water content of ice layer.

(i). Changing ice layer thickness

When changing the thickness of ice layer from 0 to 4 km and keeping the ice water content as 0.5 g / m^3 for spaceborne remote sensing over the ocean, we obtained a set of curves for downward viewing shown in Fig.4. It can be seen that the global trends of these curves are similar in small and moderate rain rates (0.1–15 mm / h). The only difference is the value of brightness temperature, each curve having 3–4 K differences corresponding to the same rain rates. These differences would result in a considerable error if we use spaceborne radiometer to estimate rain without the knowledge of ice layer thickness.

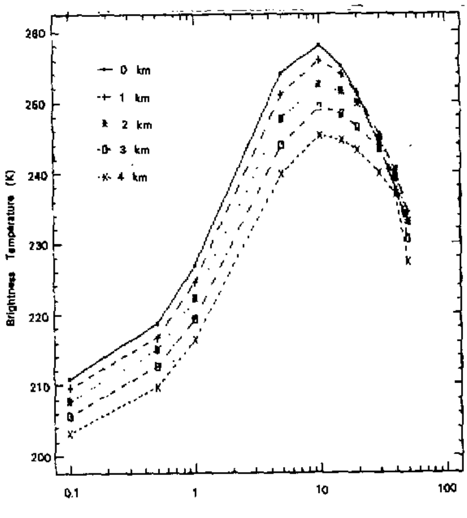

Fig.4. Brightness temperature versus rain rate for spaceborne MW precipitation measurements over the ocean in various ice layer thickness(0, 1, 2, 3, 4 km), IWC = 0.5 g / m^3.

(ii). Changing the value of ice water content

When holding the ice layer thickness constant at 0.5 km, and choosing the ice water content as 0.05, 0.3 and 0.5 g / m^3, the comparing results are shown in Fig. 5. It can be seen that when the values of ice water content increase from 0.05 to 0.5 g / m^3, the brightness temperature will increase 3–4 K corresponding to the same rain rates. It also indicates that the differences between IWC = 0.3 g / m^3 and 0.5 g / m^3 are not so large as the above condition.

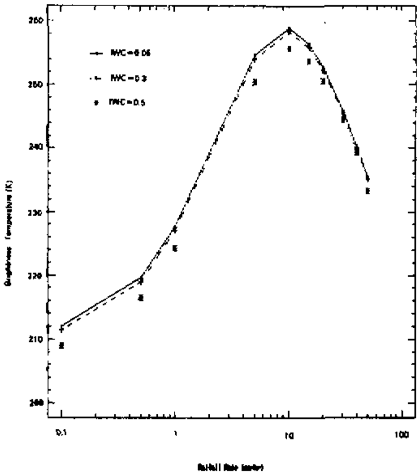

Fig.5. Same as Fig.4 but in different values of ice water content (0.05, 0.3 and 0.5 g / m^3).

In summary, whenever we change the thickness of ice layer or the values of ice water content in ice layer, both of them result in the changes of total ice water content on the radiation path. Therefore we need to know the total ice water content on the path for getting reliable results when using spaceborne radiometer.

For ground–based radiometer, the influence of ice water content are much smaller than the spaceborne observation. The calculation results show that in moderate and large rain rates (> 5mm / h) the values of ice water content had almost no effect on brightness temperatures; for small rain rate there is some influence, for example, when rain rate is 5mm / h, the brightness temperature is decreased by 1.5 K when ice water contents increased from 0.05 to 0.5 g / m^3 (keeping ice layer thickness as 0.5 km).

(3) *Different size distribution in ice layer*

In analyzing the actual ice particle size distribution from 2D–probe aircraft data obtained in Colorado,USA in 1983, it was found that a big difference exists between M–P particle size distribution and actual distribution, especially when the ice water content was larger than 0.1 g / m^3.

Here we choose two actual particle size distributions corresponding to IWC = 0.03 g / m^3 and 0.3 g / m^3 to do the model calculation. The results for actual distribution (IWC = 0.03 g / m^3) and M–P distribution are given in Fig.6. It can be seen that for spaceborne remote sensing, the difference between two distributions is less than 2K corresponding to the same rain rate. The calculations also show that we can use the M–P particle size distribution instead of the actual distribution with little error, when ice water content is less than 0.03 g / m^3.

When we choose 0.3 g / m^3 to do model calculation, there is a large difference between the actual and M–P distributions. For the actual distribution, the brightness temperature is much lower than that for the M–P distribution. Even considering some correction for the extinction coefficient, the difference between them is still very large. There are two points to consider about the difference: (a) the processing method (Heymsfield & Parrish, 1979) of 2–D probe data might result in an error in calculating the reconstructed diameter for large ice particle; (b) the calculating extinction coefficient for ice particle situation is based on Mie scattering scheme with the "reconstructed" diameter of ice particles, and we do not know whether this is valid for the ice particles or not. It seems to be overestimated. To solve this problem, we need simultaneous, co–located observations from spaceborne MW, aircraft particle measurements and ground–based radar probing, combined with model calculations.

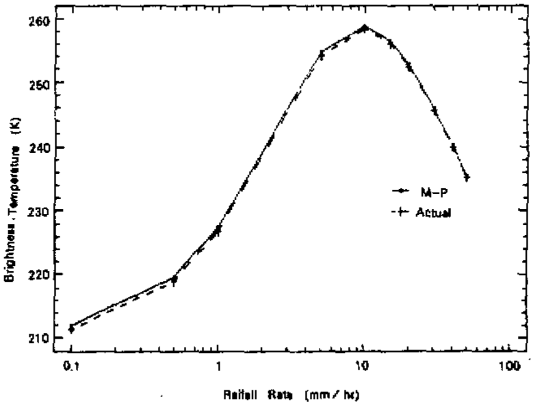

Fig.6. **Brightness** temperature versus rain rate for actual particle size distribution **and M–P distribution** (IWC = 0.03 g / m^3).

IV. CONCLUSION AND DISCUSSION

1. The wavelength of 37 GHz for spaceborne MW remote sensing is only suitable to use over ocean. Because "observing" brightness temperature is very sensitive to surface condition and of limited dynamic ranges with various rain rates, it seems to be shown that we could not obtain reliably quantitative rainfall measurements over the land at this wavelength. On the contrary, this waveband is very suitable for ground–based (upward viewing) MW remote sensing of precipitation. In this situation the brightness temperature monotonously increases with rain rate and has large dynamic range with various rain rates especially to small and moderate rain rates.

2. The structure of ice layer, in particular the ice water content, plays an important role in determination of the " observed" brightness temperature. This is more critical to spaceborne remote sensing. Therefore, for obtaining reliable result of rain rate from downward viewing MW remote sensing, at least the knowledge of ice layer is necessary. It is possible to identify ice phase layer by using dual–polarization radar in certain condition (Liu & Herzegh, 1986) and we could roughly estimate the value of ice water content by radar reflectivity measurements. By combining observation of spaceborne MW radiometer and radar, it may be possible to obtain reliable quantitative measurement of rain rate.

3. From model calculation it can be seen that, when changing the structure of ice layer (e.g. particle size distribution, ice water content, super–cooled droplet and humidity etc.) or changing the proportion of cloud droplets and raindrops in mixed layer, it would result in the

changes of both extinction coefficient and single scattering albedo and consequently the brightness temperature. In addition, the structure of the transition layer (such as bright band in radar meteorology) from ice phase to liquid phase is also important in brightness temperature measurements. In the present model, we did not take this layer into consideration. Finally, in radiative transfer algorithm, the limited horizontal extension of the real clouds should be considered.

To improve the model calculation, we need to consider the above information in more detail.

We thank Drs. Parrish and Heymsfield for their generous assistance in processing 2D−probe aircraft data. The aircraft data are provided by NCAR.

REFERENCES

Gruop of Microwave Remote Sensing, IAP (1981), Microwave propagation and radiation characteristics of clear and cloudy atmosphere over China, National Defence Industry Press, Beijing, 200pp.

Heymsfield, A.J. and J.L. Parrish (1979), Techniques employed in the processing of particle size spectra and state parameter data obtained with the T−28 aircraft platform, NCAR Tech Note (NCAR / TN−134+1A), NCAR, Boulder, Colo., 78 pp.

Liu Jinli and P. Herzegh (1986), Differential reflectivity signatures in icephase precipitation: Radar−Aircraft comparisons, preprints 23−rd Conf. on Radar Meteor., 59−61.

Rodgers, E.B., H. Siddalingaiah, A.T.C. Chang and T.T. Wilheit (1979), A statistical technique for determining rainfall over land employing Nimbus−6 ESMR measurements, *J. Appl. Meteor.*, **18:** 987−991.

Whilheit, T.T., A.T.C. Chang, M.S.V. Rao, E.B. Rodgers and J.S. Theon (1977), A satellite technique for quantitatively mapping rain rates over the oceans, *J. Appl. Meteor.*, **16:** 551−560.

Zhou Xiuji, Lu Daren, Huang Renheng and Lin Hai (1982), *Atmospheric Microwave Radiation Remote Sensing*, Science Press, Beijing, 300pp.