

# Study and Comparison of Simulation of Satellite Microwave Observations in Cloudy and Rainy Areas using RTTOV and CRTM

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## **Abstract**

Presently, a variety of satellite observations have been assimilated in Chinese GRAPES. However, it is mainly the satellite measurement on the clear atmosphere that has been focused on. Studies are ongoing to explore how to use the satellite observations in cloudy and rainy areas. The rapid radiative transfer model is the observation operator in radiance data assimilation system. The simulation of satellite observations in cloudy and rainy areas in the rapid radiative transfer model is a basic, also the key issue to use the satellite data affected by cloud and precipitation.

Study and comparison of simulation of satellite microwave observations in cloudy and rainy areas are carried out in this paper by using both RTTOV and CRTM, two rapid radiative transfer models being developed in UK Meteor Office and US JCSDA, respectively. With the hydrometeors from WRF forecast as input, the radiative effects of hydrometeors on the simulation of AMSUA/B microwave satellite observations are investigated. Preliminary results show that the response function and the simulation of satellite brightness temperature for RTTOV and CRTM present almost the same characteristics, but with difference in magnitude. The response functions of hydrometeors obtained from Jacobin correspond well with the distribution of hydrometeors. The magnitude of CRTM is larger than that of RTTOV. For AMSUA, the radiative effect of cloud and rain increases the simulated brightness temperature, especially on those window channels with low frequency. The ice and snow decreases the brightness temperature simulation of satellite observations. For AMSUB, hydrometeors mainly decrease the simulated brightness temperature. The result of CRTM is also larger than that of RTTOV. In addition, graupel has great effect on the simulation of AMSUB satellite observations.

## **1 Introduction**

A variety of satellite observations have been assimilated in most NWP centers. What is more, the use of satellite data greatly improves the accuracy of numerical forecast. However, only a few percent of satellite data are really used presently. It is shown by the ECMWF statistics that more than 97% satellite observations are discarded by the data assimilation system. One of the main factors is the satellite data is affected by cloud and precipitation. Large uncertainties and strong non-linearity remain in many of the physical parameterizations, particularly those associated with moist convection and the radiative effects of clouds, utilized in all of forecast, radiative transfer model and data assimilation scheme. It makes the assimilation of satellite data affected by cloud and precipitation a very difficult problem.

With the development of physical parameterization scheme, especially the inclusion of radiative effect of hydrometeor particles in RTTOV and CRTM, two rapid radiative transfer models being developed in UK Meteor Office and US JCSDA, respectively, more and more study is carried out to explore how to use the satellite data in cloudy and rainy areas. The simulation of satellite observations affected by cloud and precipitation in the rapid radiative transfer model is a basic, also the key issue.

The study and comparison of simulation of satellite microwave observations in cloudy and rainy areas are presented in this paper by using both RTTOV and CRTM. The radiative transfer models and methodology are introduced in section 2. The influence of hydrometeors on the simulation of satellite brightness temperature and the statistics of bias are given in section 3 and 4, respectively. The final section is a brief conclusion and discussion.

## 2 The radiative transfer models and methodology

### 2.1 The radiative transfer models

In the radiative transfer model RTTOV, the cloud package for infrared and microwave radiances are completely different. The scattering effects for the former are parameterized while it is treated explicitly in an individual interface, known as RTTOV-SCATT. The scattering effects of hydrometeors at microwave frequencies are computed using the delta-Eddington approximation. It uses a two-independent column approximation. The clear-air RTTOV is called from within RTTOV-SCATT and returns the brightness temperature of the clear sky column. Then RTTOV-SCATT computes the cloudy or rainy brightness temperature. The total brightness temperature is produced by combine linearly the two independent columns.

The Community Radiative Transfer Model (CRTM) is being developed currently in the Joint Center for Satellite Data Assimilation (JCSDA) USA. It is designed to make use of satellite data under all weather conditions by including scattering and emission from the earth's atmosphere. The scattering effects of cloud and precipitation particles are all based on Mie theory. It is the same as that of RTTOV for microwave frequencies. But CRTM uses the common interface for the clear and cloudy or rainy conditions.

### 2.2 Methodology

There is a need of hydrometeors information for the radiative transfer model to do the simulation of microwave radiances scattered by cloud and precipitation. It is provided by the forecast of WRF model. The hydrometeors include cloud water, rain water, ice, snow and graupel. The total integrated hydrometeors output from WRF model for the typhoon case studied in this paper is shown in Fig. 1.

The hydrometeor inputs for RTTOV are cloud liquid water, cloud ice water, rain flux, snow flux and cloud cover. The cloud cover is derived from the relative humidity:

$$N = \left( \frac{f - f_0}{1.0 - f_0} \right)^b$$

Where,  $f$  is the relative humidity.  $f_0$  is the threshold of relative humidity that is the function of height. It takes 0.9, 0.5, 0.6 and 0.5 for under 600m, 600-1500m, 1500-2500m and above 2500m, respectively.  $b$  is a constant. Generally it is 2.

The input parameters for CRTM are cloud, rain, ice, snow, graupel profiles, effective radius and effective variance. The effective radius for cloud, rain, ice, snow and graupel are taken as 15, 200, 200, 600 and 600, respectively. At present, the effective variance is a constant in CRTM.

## 3 The influence of hydrometeors on the simulation of microwave satellite brightness temperature

The observation and simulated brightness temperature by using RTTOV and CRTM for AMSUA/B channel 1 are presented in Fig. 2 and Fig. 3, respectively. It could be seen that there exists large bias between the observation and simulated brightness temperature without hydrometeors. The inclusion of the radiative effects of hydrometeors in the rapid radiative transfer model makes the simulation match the observation closely. The use of 5 kinds of hydrometeor in CRTM decreases greatly the simulated

brightness temperature in typhoon core area that is also obvious in observation.

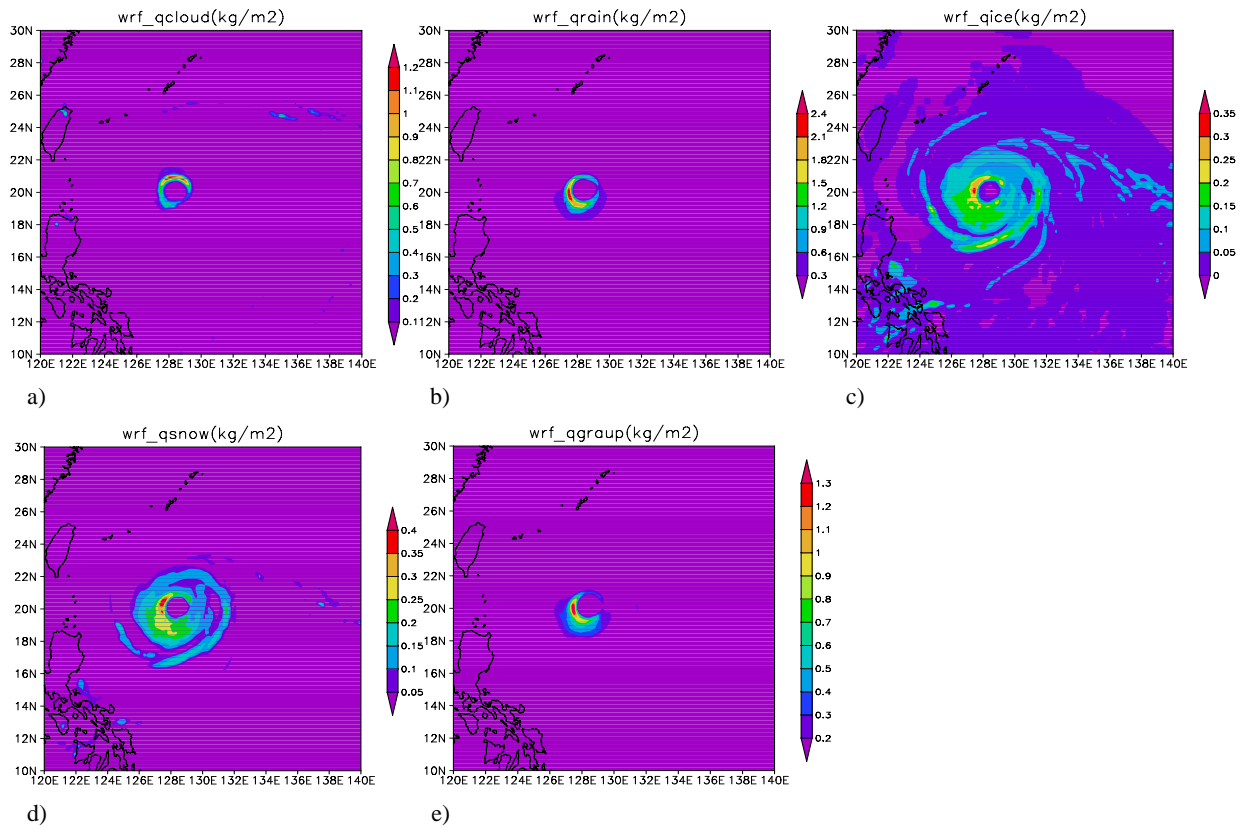


Fig.1 The total integrated hydrometeors output from WRF model. unit:  $\text{kg m}^{-2}$  (a: cloud; b: rain; c: ice; d: snow; e: graupel)

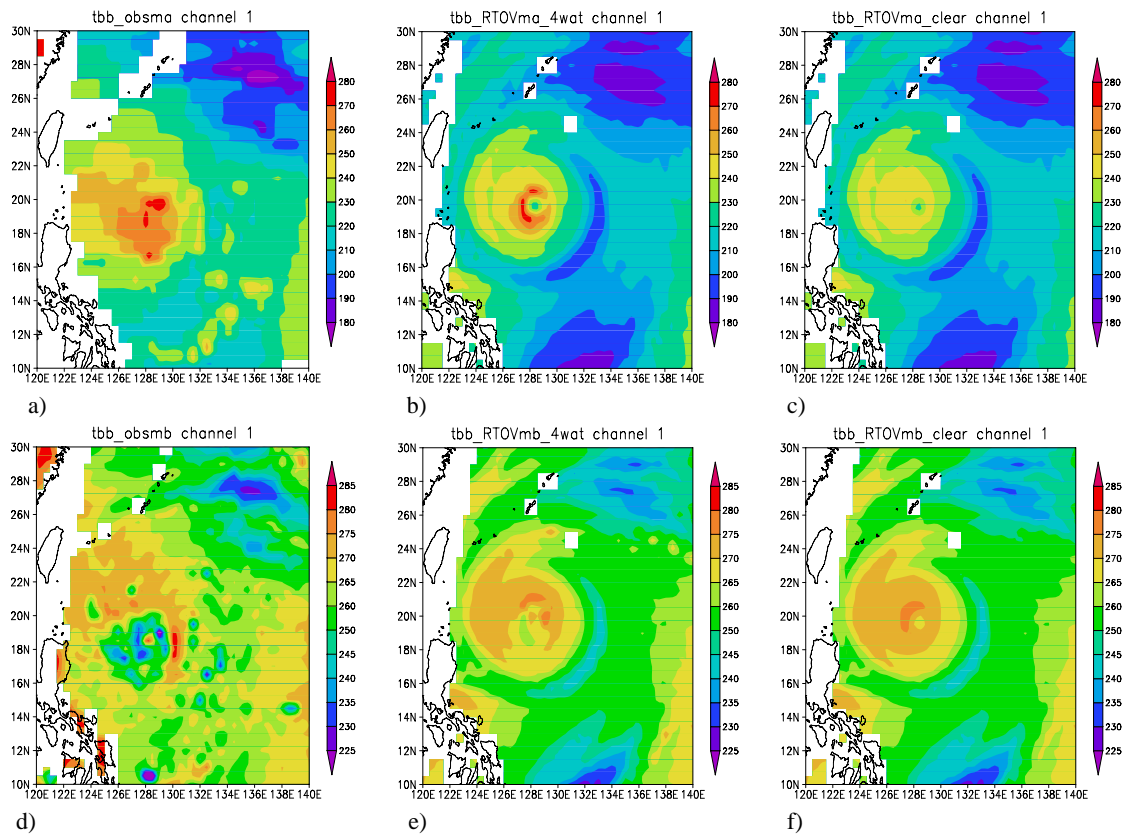


Fig. 2 Observation and RTTOV simulated brightness temperature for AMSUA/B channel 1 (a: AMSUA observation; b: AMSUA simulation with 4 kinds hydrometeor; c: AMSUA simulation without hydrometeor; d: AMSUB observation; e:

AMSUB simulation with 4 kinds hydrometeor; f: AMSUB simulation without hydrometeor)

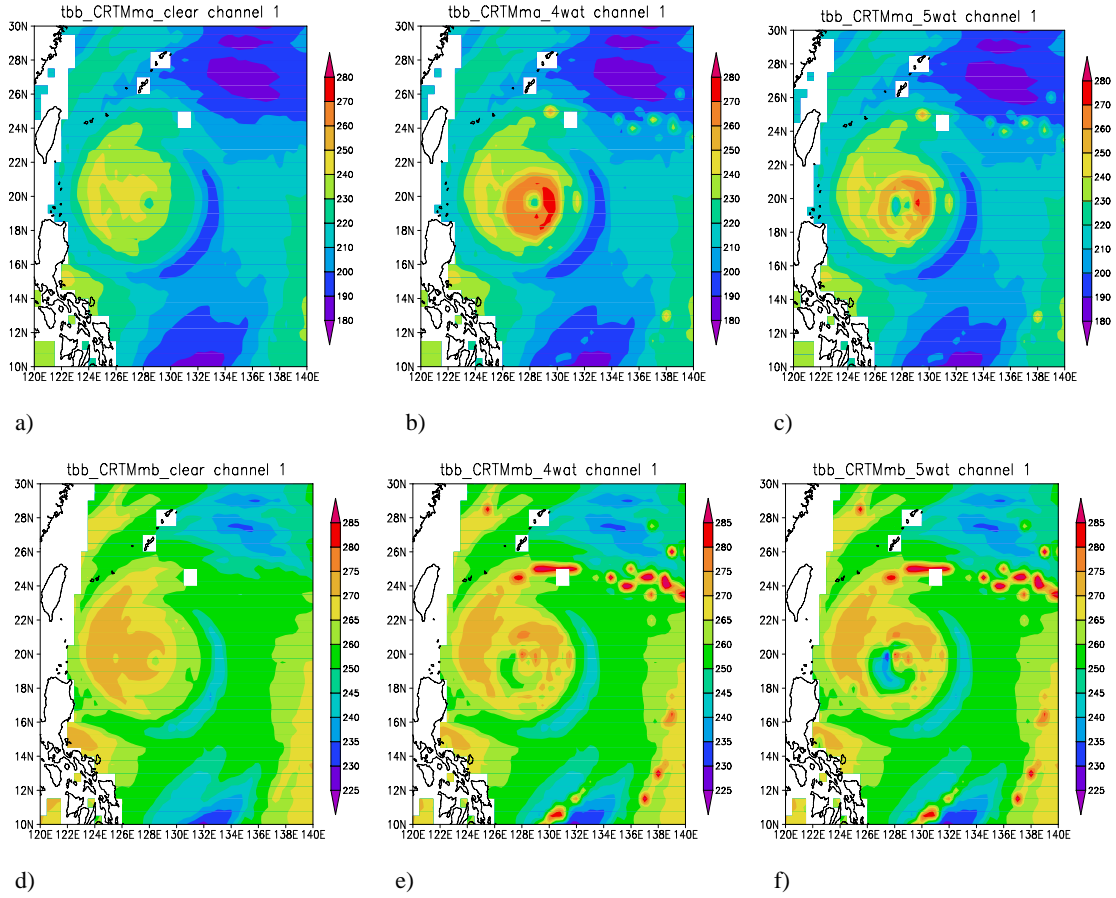


Fig. 3 CRTM simulated bright temperature for AMSUA/B channel 1 (a: AMSUA simulation without hydrometeor; b: AMSUA simulation with 4 kinds hydrometeor; c: AMSUA simulation with 5 kinds hydrometeor; d: AMSUB simulation without hydrometeor; e: AMSUB simulation with 4 kinds hydrometeor; f: AMSUB simulation with 5 kinds hydrometeor)

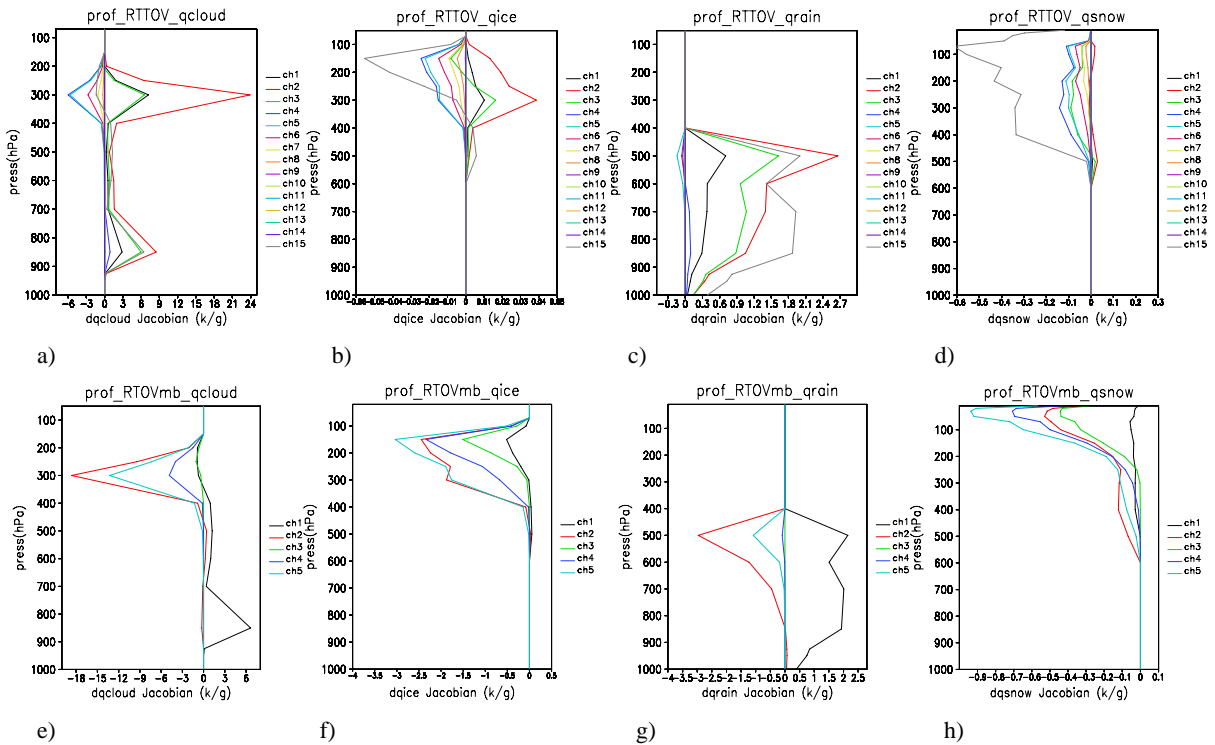


Fig. 4 AMSUA/B response function of hydrometeors in typhoon centre area obtained from RTTOV Jacobian model. (a、b、c、d: AMSUA cloud、ice、rain、snow, e、f、g、h: AMSUB cloud、ice、rain、snow)

## 4 The analysis and comparison of the simulated brightness temperature bias

### 4.1 The response functions of hydrometeors

The response functions of hydrometeors in typhoon centre area obtained from RTTOV and CRTM Jacobian models are given in Fig. 4 and Fig. 5, respectively. It could be found that the response functions of hydrometeors of RTTOV and CRTM present almost the same characteristics. It is corresponded well with the distribution of hydrometeors. The response functions of cloud and rain water concentrate on the lower and middle levels and that of ice and snow locate on the middle and higher levels. It is noticed that the response functions of cloud, ice and rain of CRTM for AMSUA are all larger than that of RTTOV, especially the result of ice water. For AMSUB, just the response function of cloud is a little larger than that of RTTOV.

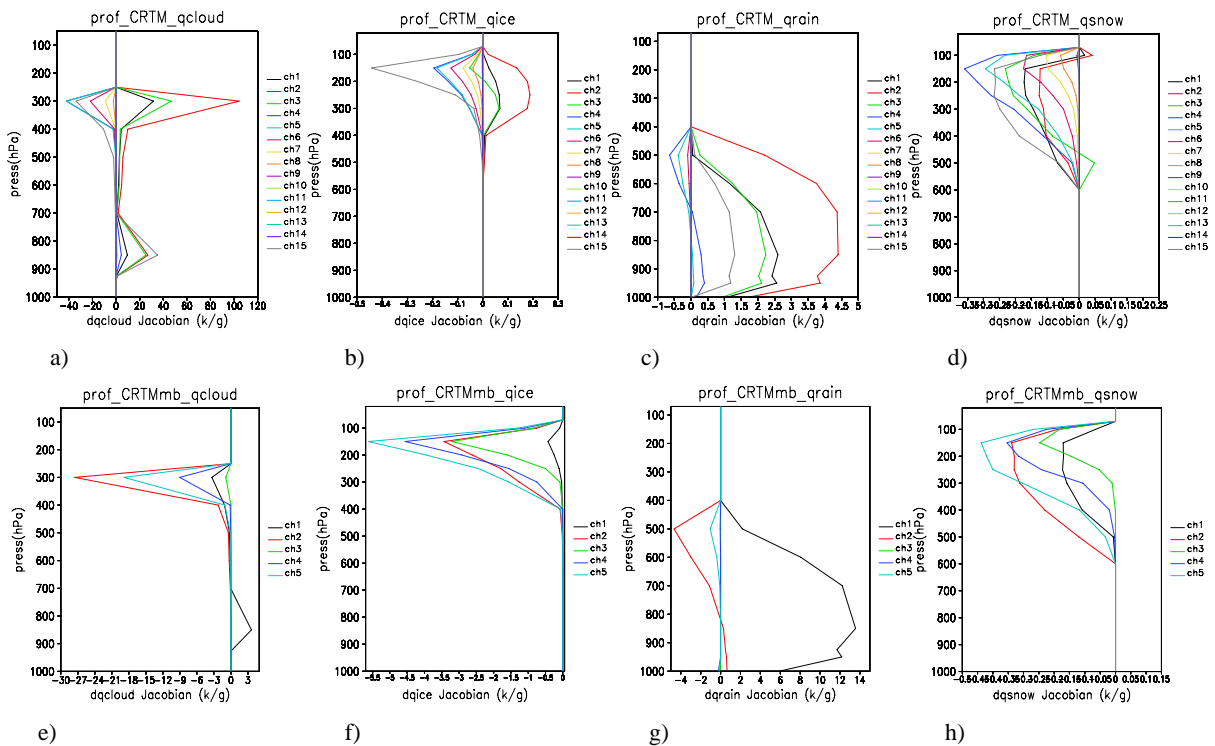


Fig. 5 AMSUA/B response function of hydrometeors in typhoon centre area obtained from CRTM Jacobian model. (a、b、c、d: AMSUA cloud、ice、rain、snow, e、f、g、h: AMSUB cloud、ice、rain、snow)

### 4.2 The simulated brightness temperature bias

Fig. 6 is the area average of simulated brightness temperature bias between the simulation with and without hydrometeors for AMSUA/B. The tag ice\*10 stands for the result of ice is multiplied by 10. Both the results of RTTOV and CRTM show that the radiative effect of all hydrometeors mainly increase the simulated brightness temperature in AMSUA low frequency channels 1-3 and decrease the simulated temperature in other AMSUA and all AMSUB channels. The maximum increment is in AMSUA channel 2 and the minimum decrement is in AMSUB channel 2. Cloud water mainly contributes to the increment of brightness temperature in AMSUA 1-3, 15 and AMSUB 1. Rain water makes the same contribution as cloud in AMSU-A channels with low frequency and has an opposite effect in AMSUA channel 15 and AMSUB channel 1. Ice, snow and graupel bring about the decrement of simulated brightness temperature in almost all AMSUA and AMSUB channels. The effects of snow and graupel are much obvious than that of ice. The magnitude of simulated brightness

temperature bias of CRTM is larger than that of RTTOV, especially in AMSUA channels 1-3.

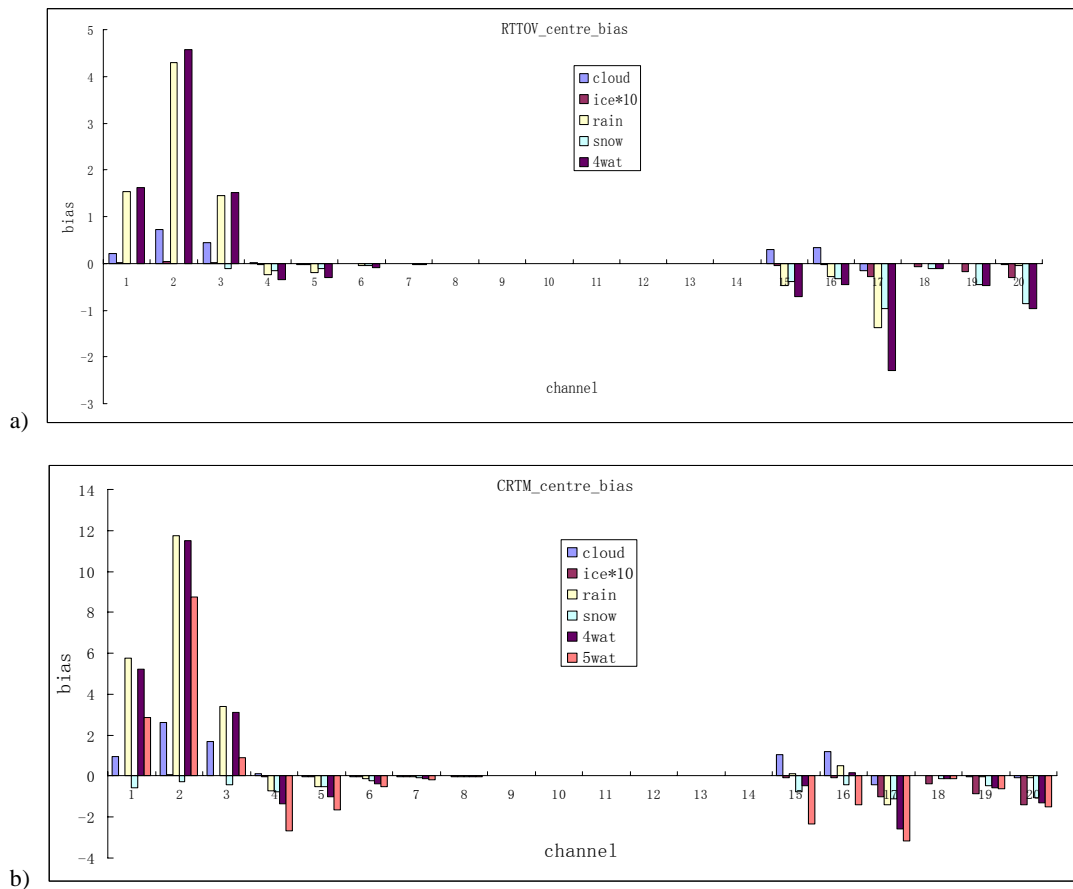


Fig. 6 Area average of simulated brightness temperature bias between the simulation with and without hydrometeors for AMSUA/B (a:RTTOV; b:CRTM)

### 4.3 The simulated brightness temperature RMSE

The Area average of simulated brightness temperature RMSE between the simulation with and without hydrometeors for AMSUA/B is shown in Fig. 7. It could be seen that the radiative effect of hydrometeor particles will bring about the simulated brightness temperature RMSE for AMSUA channels 1-6, 15 and AMSUB all channels. It is much obvious for AMSUA channels 1-5, 15 and AMSUB channels 1-2. The largest RMSE is all in channel 2 for both AMSUA and AMSUB when 4 kinds of hydrometeor, that is cloud, rain, ice and snow, are considered. Graupel is included in CRTM. It could be found that it contributes greatly to the RMSE of AMSUA channels 4-5 and AMSUB channels 1-3.

## 5 Conclusion and discussion

Study and comparison of simulation of satellite microwave observations in cloudy and rainy areas are presented in this talk. The conclusion and discussion are:

1) The inclusion of radiative effects of hydrometeors plays an important role in the simulation of satellite microwave observations in cloudy and rainy areas. The response function and the simulation of satellite brightness temperature for RTTOV and CRTM present almost the same characteristics, but with difference in magnitude.

2) The response functions of hydrometeors correspond well with the distribution of hydrometeors.

The magnitudes are slightly different between two fast radiative transfer models. It is suggested that Jacobian intercomparison of radiative transfer model should be carried out to figure out the uncertainties for hydrometeors.

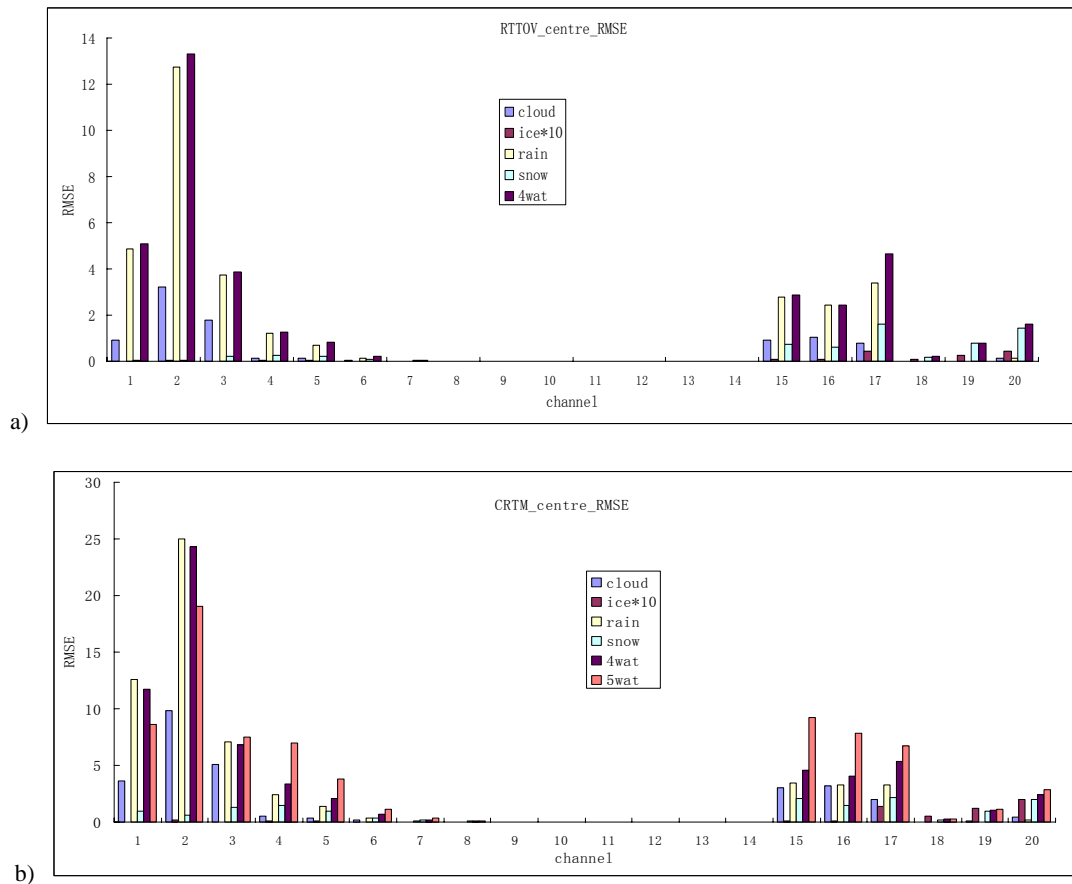


Fig. 7 Area average of simulated brightness temperature RMSE between the simulation with and without hydrometeors for AMSUA/B (a:RTTOV; b:CRTM)

3) The radiative effect of hydrometeors will bring about the bias of simulation of brightness temperature for AMSUA channels 1-6, 15 and AMSUB all channels. The magnitude of CRTM is larger than that of RTTOV.

4) Graupel plays an important role in the simulation of satellite microwave observation for certain channels. Its effect is taken in the radiative transfer model CRTM presently.

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