ICE HYDROMETEOR MICROPHYSICAL PARAMETERISATIONS IN NWP

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ABSTRACT

Radiative transfer models capable of modelling scattering by ice hydrometeors are required in order to assimilate microwave data affected by cloud and precipitation in numerical weather prediction (NWP). Testing of a fast radiative transfer model for this purpose revealed high sensitivity to the assumptions made within the model about ice particle microphysics (size, shape, density, permittivity). This paper investigates density and size distribution parameterisations and the effect that they have on simulated microwave brightness temperatures for a number of case studies over the UK. It concludes that size distribution and density parameterisations which are functions of temperature, ice water content and particle size perform better than less flexible assumptions.

1. INTRODUCTION

Microwave frequencies above about 89 GHz are sensitive to scattering by ice hydrometeors. A satellite instrument sensing top of atmosphere radiation detects a decrease in brightness temperature, or brightness temperature depression, when ice is present in the field of view. The work presented in this paper is based on observations and simulations of the AMSU-B instrument, which has five channels between 89 and 183 GHz.

Currently at the Met Office no ice and precipitation affected microwave data is assimilated. Use of these data is desirable as it contains information important to NWP in data sparse regions. To use these data in NWP a fast forward model capable of modelling the scattering of microwave radiation by ice particles is required. RTTOV is investigated for this purpose.

RTTOV (Saunders *et al.*, 1999) is used operationally at the Met Office for assimilation of clear air infra-red (IR) and microwave radiances. The scattering modules of RTTOV were released in November 2005 with version 8[1]. In preparation for operational implementation RTTOV was tested using a number of case studies over the UK. Comparisons were made between observed brightness temperature (TB) and RTTOV simulated TB generated using Met Office forecast fields as input. This testing revealed a high sensitivity of the RTTOV simulated TBs to the assumptions made within the model about the ice particle microphysics.

[1] http://www.metoffice.com/research/interproj/nwpsaf/rtm/rtm_rttov8.html

Section 2 of this paper describes the RTTOV model and Met Office forecast model. Section 3 outlines the methodology and presents the results from the experiments using different microphysical parameterisations within RTTOV. Section 4 presents a summary and conclusions together with direction of future work.

2. MODEL DESCRIPTIONS

2.1 RTTOV

RTTOV is a fast radiative transfer model (RTM) developed by the Satellite Application Facility for NWP (NWP SAF)[2]. RTTOV8, released in November 2005 contains modules for solving the equation of radiative transfer (RTE) in scattering conditions (Bauer *et al.,* 2006). RTTOV has been developed under the SAF by a large collaborative effort, it is widely used and well supported and is therefore the natural choice for an operational system.

For input RTTOV requires profiles of temperature, humidity, fractional cloud cover, rain, snow, liquid and ice cloud contents and surface variables including a land/sea mask and wind speed and direction. It uses the delta-Eddington approximation (Kummerow, 1993) to solve the scattering RTE, this is a two stream solution allowing calculations to be carried out quickly. A fast geometric optics model is used to calculate the ocean surface emissivity (English, *et. al.,* 2003). Precipitating hydrometeors are assumed to have a Marshall-Palmer size distribution (Marshall and Palmer, 1948) and cloud hydrometeors a modified gamma distribution (Seifert & Beheng, 2006). Ice particles have diameters up to 100 microns and snow has a diameter range of 100-20000 microns. The density of ice and snow particles is constant set at 0.9 g/cm^3 for ice and 0.1 g/cm^3 for snow. Permittivity of the particles is dependent on the ice/water/air mixture within the hydrometeors and this is calculated by the Maxwell-Garnett mixing formula (Maxwell-Garnett, 1904).

2.2 Met Office Forecast Model

The Met Office Unified Model (UM) contains a large scale cloud and precipitation scheme which treats ice and liquid clouds as prognostic variables (Wilson & Ballard, 1999). Rain and liquid cloud are treated separately, but all ice hydrometeors are encompassed by one particle type, with no distinction between cloud ice and snow. Condensation and evaporation are parameterised using a diagnostic scheme and ice falls from layer to layer between time steps to simulate the effect of snow. All other transfer terms between water phases require information about the size distribution, density, fall speed and shapes of the hydrometeors.

The size distribution for ice particles is an exponential distribution of the form

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[2] http://www.metoffice.gov.uk/research/interproj/nwpsaf/index.html

$$N_{ice}(D) = N_{0\,ice} \exp(-0.1222\ T) \exp(-\Lambda_{ice} D)$$

Where D is the ice particle diameter, T is the temperature, $N_{0ice}=2.0\times10^{6}\ m^{-4}$ and Λ_{ice} is the slope of the distribution. The density is given by $0.132\ D^{-1}$.

2.3 Compatibility of the Models

The interface between the RTM and the model providing the input profiles is very important. What the UM and RTTOV define as snow, ice, rain and liquid cloud are subtly different, as described above. In order to use the UM fields in RTTOV the snow profiles had to be set to zero at all times and all frozen hydrometeors treated under the label of ice. This meant the built in RTTOV assumptions for ice (diameter < 100microns, density = 0.9 g/cm^3 and modified gamma size distribution) were no longer appropriate since large snow flakes were also now included in this hydrometeor class. Consistency between the RTM and the model providing the input profiles is of utmost importance.

3. METHODOLOGY AND RESULTS

A variety of combinations of ice density and size distribution assumptions from the literature were implemented within RTTOV and the simulations using these compared to observations for a number of case studies. The combinations examined are outlined in Table 1.

Experiment	Density	Size distribution
1	$0.1\ g/cm^3$	Modified Gamma
2	$0.5\ g/cm^3$	Modified Gamma
3	$0.5\ g/cm^3$	Field *et al.* (2005)
4	$8.74 \times 10^{-4} \exp\{-0.625D^{2}\} + 4.5 \times 10^{-5}$ [3]	Modified Gamma
5	$0.132\ D^{-1}$	Modified Gamma
6	$0.132\ D^{-1}$	Field *et al.* (2005)

***Table 1**: Microphysical assumptions for each experimental set up of RTTOV*

The case study for which results are presented here is a frontal system over the UK on the 25th January 2002 at 13 UTC. The AMSU-B observations used are from 1332 UTC and the mesoscale model fields are from 13 UTC, so there is a discrepancy of 32 minutes between observed and simulated TB.

The AVHRR visible (channel 1) and IR (channel 4) images for the case study are shown in Figure 1 and illustrate the strong cold frontal cloud that was present in this case.

[3] Jones (1995)

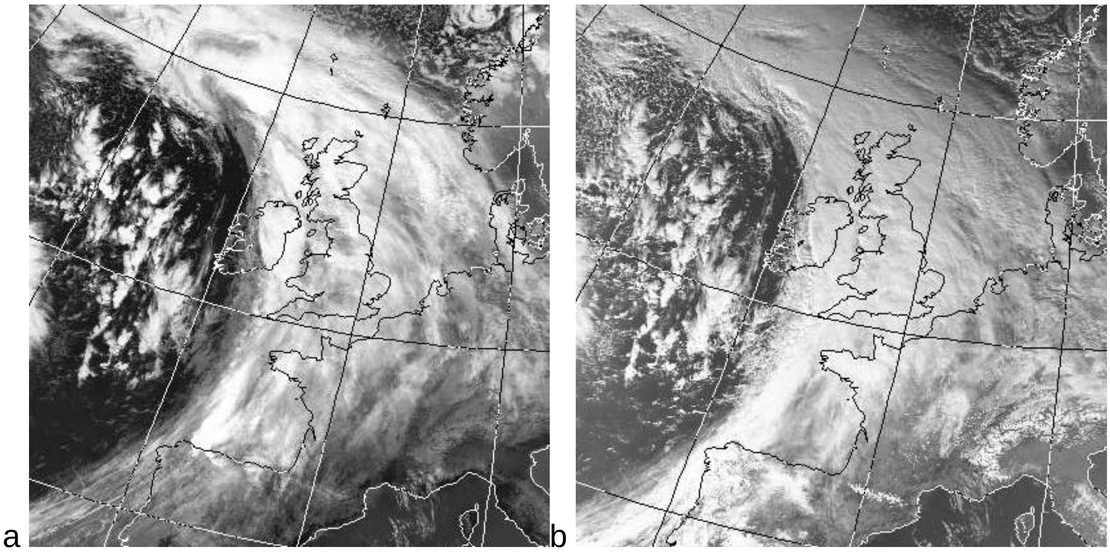

Figure 1*: AVHRR a) IR and b) visible images for case study showing strong frontal system across the UK.*

Comparison of RTTOV8.7 as released with observations for the case study is shown in Figure 2.

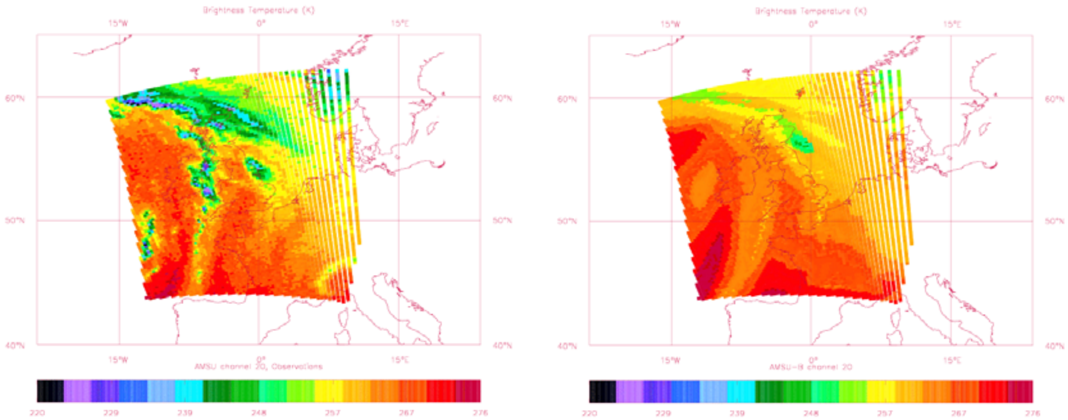

Figure 2*: Observed and RTTOV simulated TB for AMSU channel 20 (189 ± 7 GHz) for the case study*.

Variation of the assumed ice particle density or size distribution within RTTOV had a pronounced affect on the simulated signal. Larger in some cases than the signal for cloud itself which is of the order of 10 K. Figures 3 and 4 demonstrate this with Figure 3 showing two simulations with the same assumed size distribution but different densities (experiments 2 and 4) and Figure 4 showing two simulations with the same density but different PSDs (experiments 5 and 6).

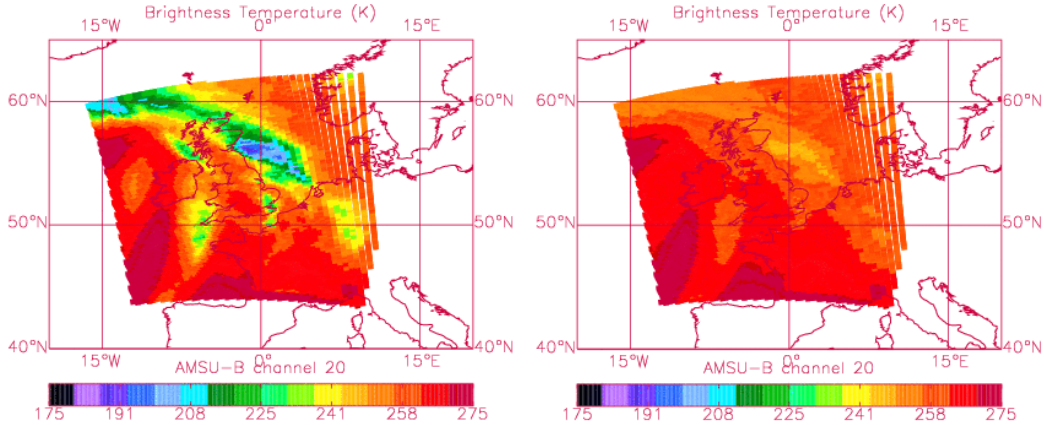

***Figure 3**: RTTOV TB simulations for experiments 2 (left) and 4 (right)*

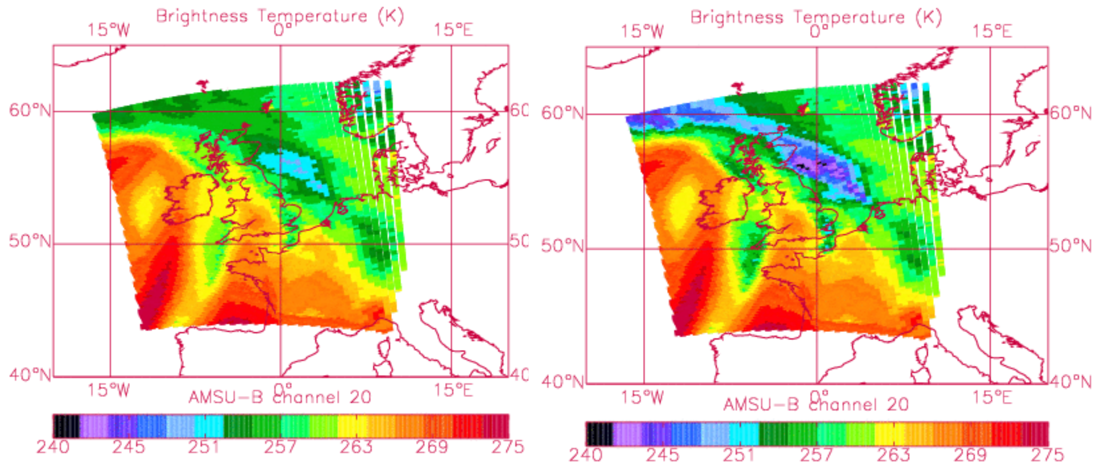

***Figure 4**: RTTOV TB simulation for experiment 5 (left) and experiment 6 (right).*

Figure 5 shows a brightness temperature histogram for all six experiments and observation.

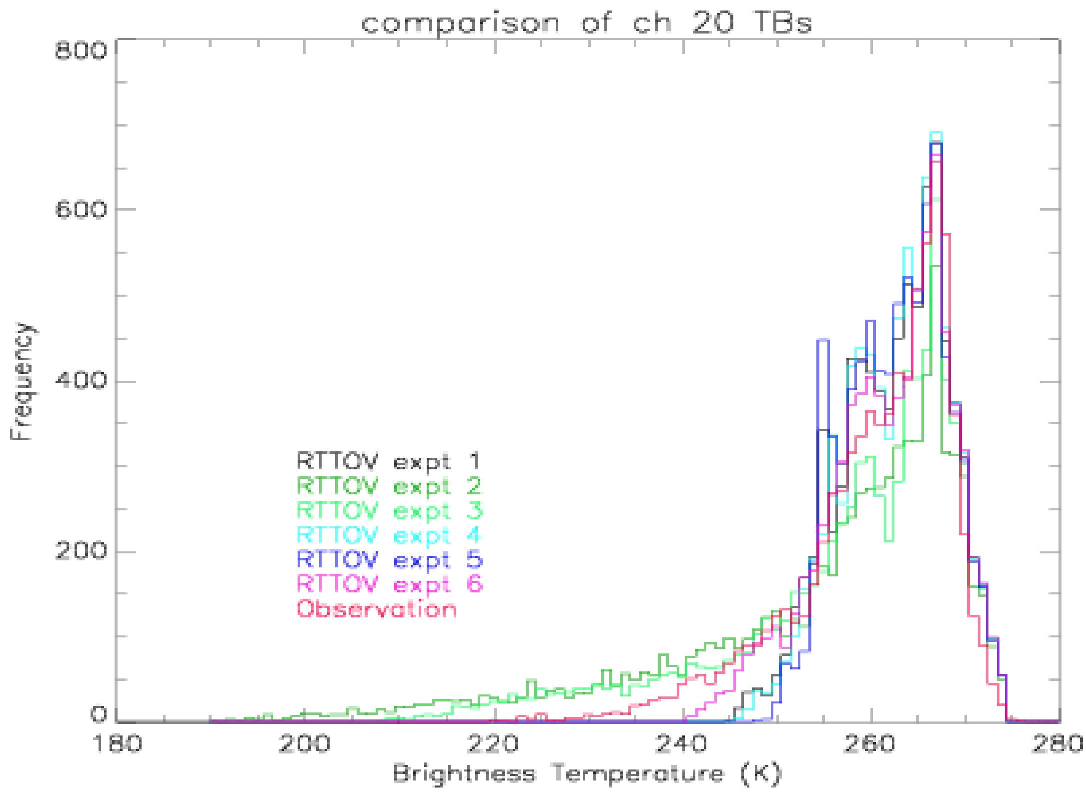

Figure 5*: AMSU channel 20 TB histogram showing frequency of occurrence of each 1 K bin for the case study for each of the six experiments and for observation.*

Figure 5 shows that experiment 6 TB matches most closely with observation, although still not reaching the very lowest brightness temperatures in the observations which are the areas of strongest scattering and highest ice content. Brightness temperature maps of observation and experiment 6 simulation for the case study are shown in Figure 6. Figure 7 shows a scatter plot of simulated against observed TB.

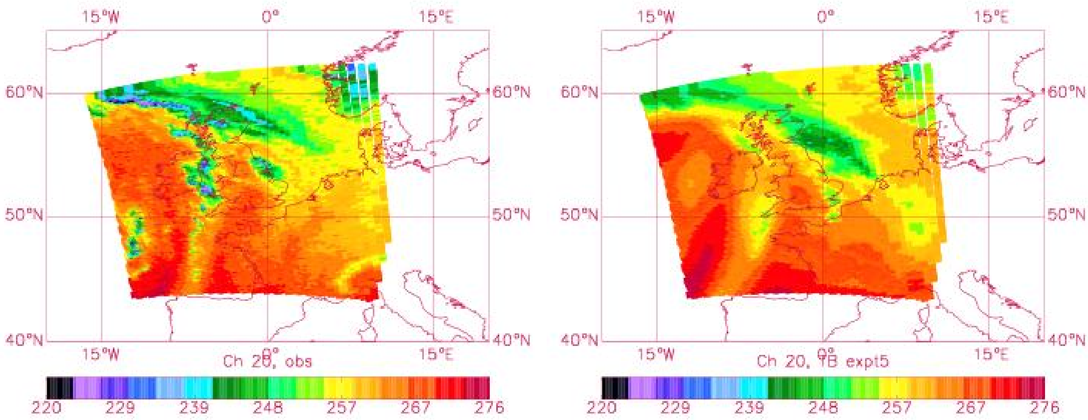

Figure 6*: Observed (left) and experiment 5 simulated (right) channel 20 TB.*

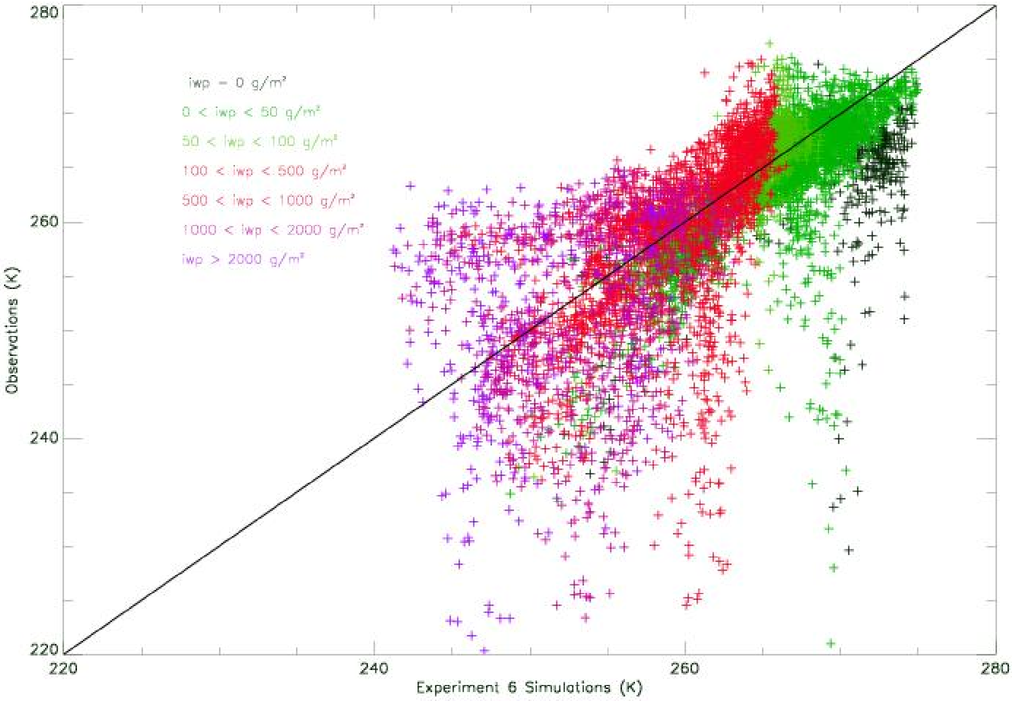

***Figure 7**: Scatterplot of experiment 6 simulated channel 20 TB against observation. Colours represent the different ice water paths with purple being the highest and black the lowest.*

4. SUMMARY AND CONCLUSIONS

A number of ice microphysical assumptions in RTTOV were examined by comparison of the simulated TB with observations. Experiment 6: the Field *et al* (2005) size distribution and a density inversely proportional to particle diameter, gave the best results for a number of case studies over the UK. The density parameterization is that used in the Met Office Unified Model which provides the input profiles for the RTM. There are plans to implement the PSD assumption in the Met Office operational forecast model in the near future. This combination of microphysical assumptions will also be included as an option in the next release of RTTOV (version 9).

The comparisons showed that more flexible approaches to ice microphysical parameterizations perform the best, with density treatments dependent on the ice particle diameter and PSDs dependent on temperature and ice water path giving the closest agreement to observations.

Consistency between the microphysics in the model providing the input fields for the RTM and the RTM itself was found to be very important.

Future work will expand this comparison to global cases. The use of different parameterisations in different meteorological conditions or latitude bands will be investigated. Other microphysical parameterisations can also be examined to see if an improved agreement with the very low TB observations in conditions of strong scattering can be obtained. The best parameterisations will then be implemented operationally at the Met Office to allow assimilation of cloud and precipitation affected microwave radiances in the NWP system. This should improve forecasts in these areas.

5. References

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