COMPARISONS OF RTTOVSCATT WITH OBSERVATIONS AND ARTS AT AMSU FREQUENCIES

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ABSTRACT

The evaluation of the use of current radiative transfer models and their interfaces to numerical weather prediction forecast models with a view to data assimilation of cloudy and precipitating radiances is being carried out at the Met Office. Output at Advanced Microwave Sounding Unit (AMSU) frequencies from RTTOV8, a radiative transfer model developed by the EUMETSAT SAF for NWP with the ability to simulate scattering by hydrometeors, is evaluated against AMSU observations, and also against output from the Atmospheric Radiative Transfer System (ARTS), a radiative transfer model developed at the University of Bremen.

The inter-comparisons suggest that RTTOV8 is able to produce qualitatively realistic AMSU-A brightness temperatures for which quantitative error characteristics are difficult to quantify but appear to be within expectation. At higher frequencies, RTTOV8 fails to simulate the lowest brightness temperatures that are seen in the corresponding AMSU-B observations, while ARTS shows a good agreement with the observations.

The discrepancy at higher frequencies seems to arise not from the radiative transfer, where RTTOV8 and ARTS give results consistent with no gross error in either model, but with the choice of microphysical parameterisations and particle size distributions in the interface between the outputs of the NWP model and the inputs to the radiative transfer model. Future work will concentrate on investigating the effect of more appropriate assumptions on these for simulations at these frequencies in the presence of ice crystals.

1. INTRODUCTION

Currently, NWP centres do not exploit satellite observations with information on precipitation. The Met Office is working towards the assimilation of cloud and precipitation information, which should improve NWP forecasts. The first step in achieving this goal is to utilise a radiative transfer model which is capable of simulating the effects of the scattering of radiation by atmospheric hydrometeors. The radiative transfer model currently in use at the Met Office is RTTOV8, a collaborative supported model developed under the EUMETSAT SAF for NWP by a consortium consisting of the Met Office, Météo-France and ECMWF. RTTOV8 is the latest in the RTTOV series of radiative transfer models (e.g. Saunders *et. al.* 1999a,b, further documentation available from NWP webpage: http://www.metoffice.com/research/interproj/nwpsaf/rtm/) and, among other new features, includes a delta-Eddington approximation to scattering by hydrometeors, developed at ECMWF. The work outlined in this paper is an evaluation of the new scattering version of RTTOV8 at AMSU frequencies by comparison with NOAA-16 observations and another radiative transfer model.

2. EVALUATION OF RTTOV8 AGAINST OBSERVATIONS

Several case studies have been used to carry out the evaluation of RTTOV8. For each case study, the RTTOV8 simulated brightness temperatures at AMSU frequencies (23.8-183.3GHz) have been compared to the observed brightness temperatures from the NOAA polar-orbiting satellites, and sensitivity tests carried out. In addition, RTTOV output at AMSU-B frequencies (89-183.3GHz) has also been compared with the output from the Atmospheric Radiative Transfer System (ARTS), a radiative transfer model developed at the University of Bremen (Sreerekha et al. 2002). A summary of the fundamental differences between the two models, and the differences in their inputs is given in Section 3.

For the purposes of this paper, one case study is presented. This consists of a frontal case over the UK on 25th January 2002 at 12UTC with significant rainfall and large ice and liquid water contents.

2.1. SIMULATIONS AT AMSU-A FREQUENCIES

AMSU-A is a 15-channel microwave radiometer with frequencies ranging from 23.8-89GHz. At these lower frequencies, the signal is dominated by absorption and emission, although at 89GHz scattering effects are starting to become important. Comparison of the RTTOV8 simulated brightness temperatures against observations demonstrate that RTTOV8 is able to produce qualitatively realistic brightness temperatures whose quantitative error characteristics are difficult to quantify but appear to be within expectation. As an example, the results for AMSU Channel 15 (89GHz) are shown in Figure 1. Figure 1a shows the NOAA-16 observed brightness temperatures, and Figure 1b shows the corresponding RTTOV8 simulated brightness temperatures. It can be seen that RTTOV8 not only reproduces the large scale observed features, but is also able to represent the amplitude of the signal.

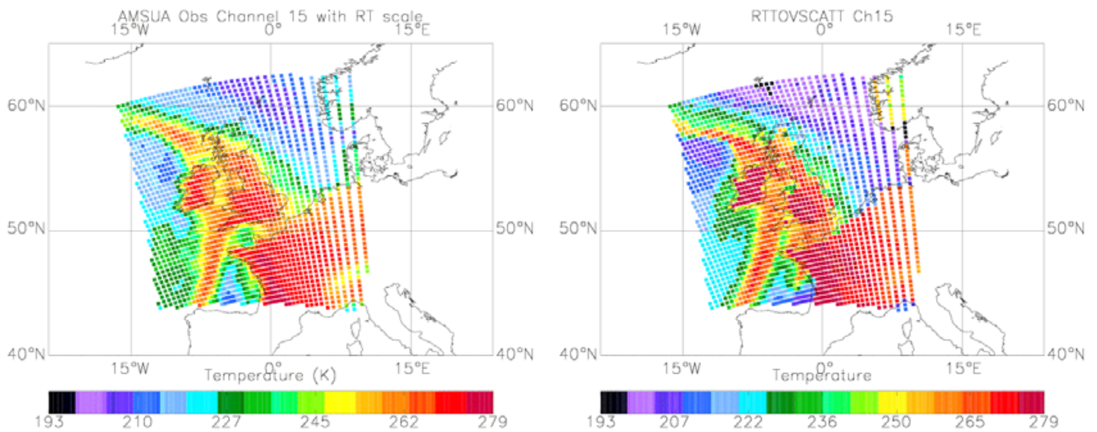

Figure 1a (left). NOAA-16 observed brightness temperatures at 89GHz over the UK on 25th January 2002 at 12UTC. **Figure 1b (right).** Corresponding brightness temperatures simulated by RTTOV8.

2.2. SIMULATIONS AT AMSU-B FREQUENCIES

AMSU-B is a 5-channel microwave radiometer with frequencies ranging from 89-183.3GHz. These frequencies are more sensitive to scattering by ice hydrometeors than the lower frequency channels. Figure 2 shows the comparison between the observed NOAA-16 brightness temperatures for AMSU channel 20 (183.3±7GHz) (Figure 2a) and the corresponding RTTOV8 output (Figure 2b). Again, RTTOV8 demonstrates an ability to simulate the large scale features of the precipitating system. At this frequency, however, the amplitude of the signal is not reproduced as it was for the lower frequencies, with the RTTOV8 simulated brightness temperatures being too warm compared to observations over the front, where scattering will be strong. This demonstrates that the scattering effect simulated by RTTOV8 is not strong enough to reproduce the lower temperatures. Figure 3 is a scatter plot of observed brightness temperatures against simulated brightness temperatures for AMSU Ch 20, with the colour of the points representing various values of model ice water content in each field of view. The red and pink points are the fields of view with the highest ice water content. Figure 3 again shows that RTTOV8 fails to reproduce the coolest brightness temperatures seen in the observations, and it can be seen that the majority of the points where this occurs are the fields of view with the highest ice water content. This indicates that the scattering effects from the largest ice particles in RTTOV8 are not large enough to reproduce observations in strongly scattering fields of view. There are many possible reasons for the observed discrepancy. In order to reduce the possibilities, a three-way comparison was carried out between RTTOV8, observations and ARTS. This comparison is discussed in the next section.

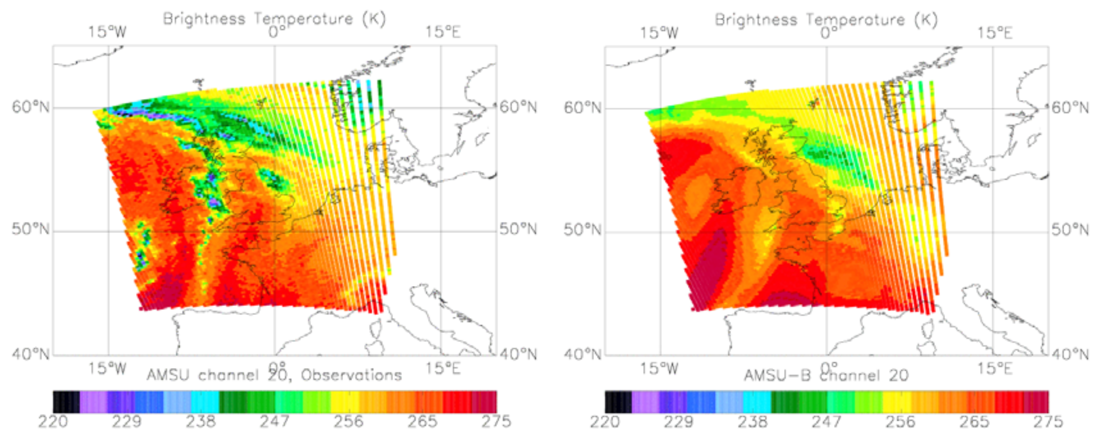

Figure 2a (left). NOAA-16 observed brightness temperatures at 183.3±7GHz over the UK on 25th January 2002 at 12UTC. **Figure 2b (right).** Corresponding brightness temperatures simulated by RTTOV8

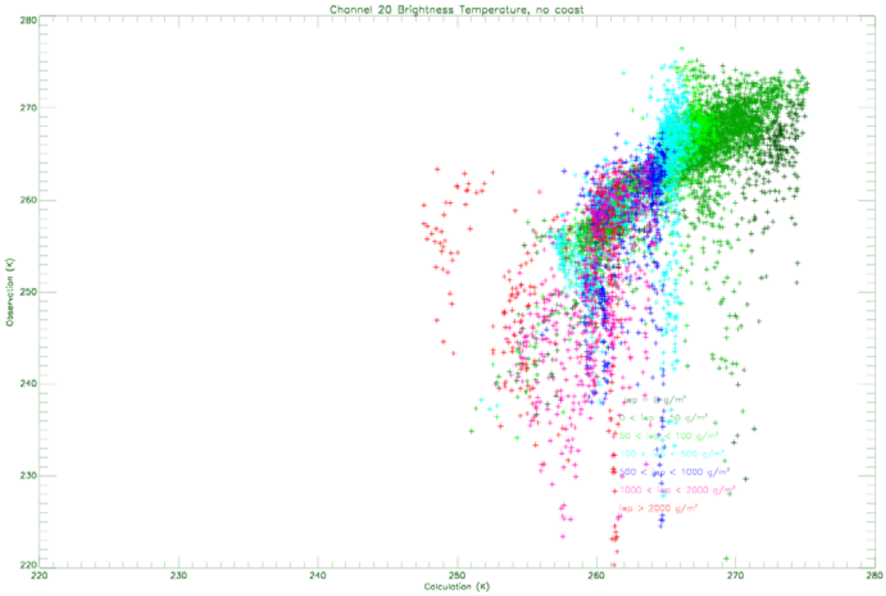

Figure 3. Scatterplot of 183.3±7GHz observed brightness temperatures (y-axis) against RTTOV8 simulated temperatures. The colour scale indicated the amount of ice water content in each field of view.

3. EVALUATION OF RTTOV8 AGAINST ARTS

3.1. RTTOV8/ARTS DIFFERENCES

RTTOV8 and ARTS differ in their approach to the approximation of scattering by hydrometeors. RTTOV8 uses the Eddington approximation, a fast and accurate two-stream approximation, while ARTS employs a multi-stream radiative transfer, which is accurate but slow to run. There were also differences in other areas. RTTOV8 uses a FASTEM-3 ocean surface emissivity; for this test case study, the ocean emissivity used in ARTS was set to a constant. The size distributions used to calculate the scattering parameters differ: RTTOV8 uses a Marshall-Palmer drop size distribution (DSD) for precipitating hydrometeors and a modified gamma DSD for cloud hydrometeors, while ARTS uses a gamma DSD for all hydrometeor types. The microphysics input to ARTS is easily tuneable via a variable effective radius.

3.2. 3-WAY COMPARISON RTTOV8/OBSERVATIONS/ARTS

Figure 4 is a scatter plot for Channel 20 (183±7GHz) for the case study, this time showing RTTOV8 simulated brightness temperatures against those simulated by ARTS. It can be seen that RTTOV8 underestimates the brightness temperatures compared to ARTS for the fields of view containing the highest ice water contents.

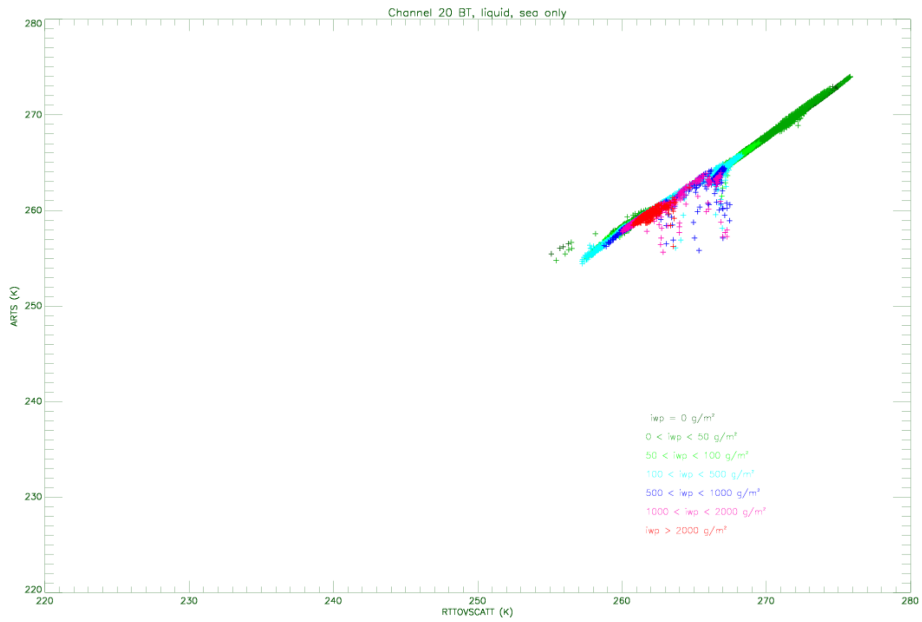

Figure 4. Scatterplot of 183.3±7GHz ARTS simulated brightness temperatures (y-axis) against RTTOV8 simulated temperatures. The colour scale indicates the amount of ice water content in each field of view.

Figure 5 shows histograms of brightness temperature for RTTOV8 (solid line), ARTS (dotted line) and observations (dashed line). There is good agreement between ARTS and observations at all temperature ranges, while the RTTOV8 simulations do not follow the tail of the distribution for the coldest brightness temperatures. The microphysical inputs to ARTS were tuned for this case study to achieve this agreement with observations. They can also be tuned so that the ARTS output agrees very closely with the RTTOV8 output (figure not shown), implying that, given the correct microphysics, the radiative transfer is quite capable of reproducing reality.

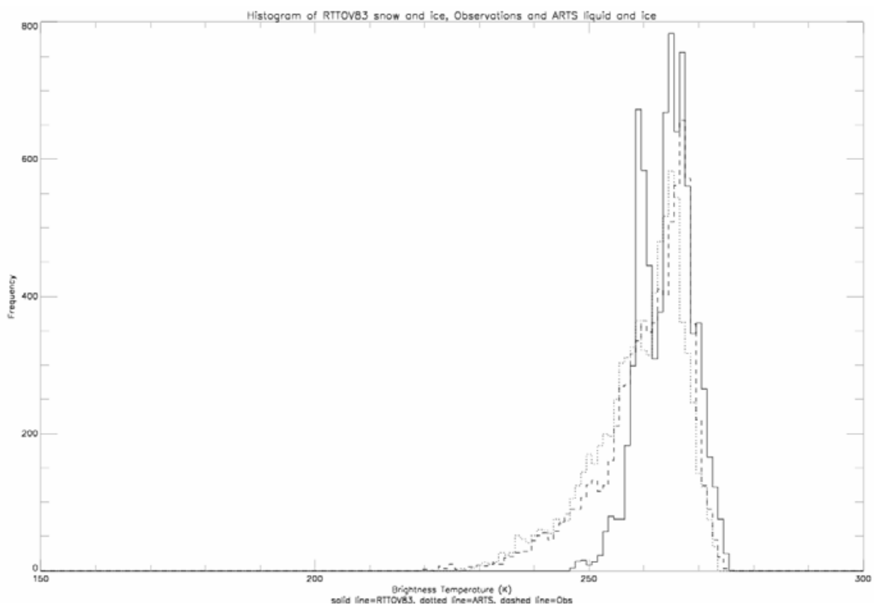

Figure 5. Histograms of brightness temperatures at 183.3±7GHz: Observed (dashed line), ARTS-simulated(dotted line) and RTTOV8-simulated (solid line).

As mentioned earlier, there are several possible explanations for the failure of RTTOV8 to correctly simulate the coolest brightness temperatures seen in the ARTS simulations and in the observations. The fact that the microphysical input to ARTS can be tuned either to agree with RTTOV8 or observations suggest that the radiative transfer itself is not the cause. The most probable explanation for the differences seen is the way in which the microphysics of ice is treated. It may be that the current parameterizations for ice particles used to calculate the scattering parameters are nor the most suitable for looking at scattering at these high (i.e., AMSU-B) frequencies.

4. MICROPHYSICS AND SIZE DISTRIBUTIONS

Currently, the following is used in the calculations of Mie parameters for input to RTTOV8: a modified gamma distribution of ice, with a diameter range of 0-100 microns; and a Marshall-Palmer distribution for snow, with a range of 100-20,000 microns. There are also issues with the interface between the NWP forecast fields and the radiative transfer model in terms of how the ice and snow inputs are defined. At the Met Office, the ice and snow forecast fields that are output from the forecast model cannot be used directly as input to RTTOV8. In the forecast model, the snow field is the ice field 'tracked' between each model level at each time step, so using both fields equates to a double count of the ice. Currently, a scheme is in place which splits the forecast ice field into two size modes – smaller crystals and larger aggregates, which are then passed to RTTOV8 as the ice and snow input respectively. It is thought that the results discussed in the previous sections indicate that this treatment, along with the current size distributions, are not producing enough scattering at AMSU-B frequencies, i.e., there is not a large enough effect seen from the particles at the highest end of the size spectrum.

If this is the case, it is desirable to find a size distribution more appropriate for ice particles to fully represent the effect of scattering at high frequencies.

5. NEW SIZE DISTRIBUTION FOR ICE PARTICLES

A new method of calculating size distributions for ice particles has been developed at the Met Office from the analysis of a dataset of particle DSDs obtained during a recent UK C-130 aircraft campaign in ice stratiform cloud over the British Isles (Field *et al.* 2004).

The work done by Field *et al.* follows on from previous work which scaled size distributions for liquid droplet particle DSDs to a 'universal' distribution using two moments. Field *et al*. have demonstrated that a 'universal' size distribution is also applicable for a wide range of ice DSDs. The number of moments required to predict the particle size distribution is reduced from two to one through the use of power laws that vary as a function of in-cloud temperature that relate one moment to another. The second moment of the ice crystal distribution is assumed to be proportional to the ice water content and is used as a reference moment, allowing the estimation of ice particle size distributions from knowledge of the ice water content and the in-cloud temperature, both of which are available in the forecast fields.

The study by Field *et al.* was for mid-latitude weather prediction, and there was no test for the tropics or convective clouds. However, comparisons with TRMM data show good agreement in terms of the characteristic size as a function of temperature. Figure 6 demonstrates this agreement.

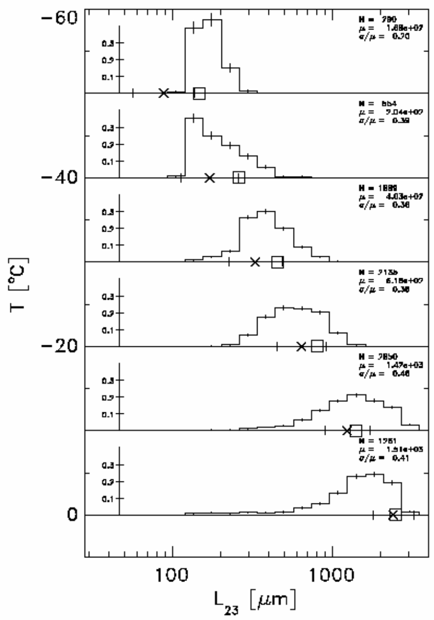

Figure 6. Taken from Field et al. 2004: Aircraft campaign observed probability density functions of L_{23} (mass weighted mean particle size). The x represents the estimated L_{23} obtained from parameterizations based on TRMM data (Heymsfield et al. 2002)

An advantage of testing this particular method in the calculations of the scattering parameters input to RTTOV8 is that there are plans to include the scheme within the Met Office large scale forecast model. Future work in this area will concentrate on evaluating the effects of this new size distribution on RTTOV8 simulations in the presence of ice.

6. CONCLUSIONS

Comparisons between outputs of RTTOV8 and ARTS with Met Office Mesoscale Model inputs and observations have highlighted that the current microphysics for ice at AMSU-B frequencies are not producing enough large particles to reproduce the brightness temperature depressions caused by scattering that are seen in observations. Current and future work will investigate the implications of using a new ice particles size distribution, based on aircraft data over the UK (Field *et al*. 2004). The radiative transfer itself is believed to be adequate but, until more is known about the correct microphysics and the interface between the radiative transfer model and the forecast model hydrometeor fields, no complete evaluation can be made.

At lower frequencies, where scattering by ice is less dominant, RTTOV8 is seen to be capable of producing quantitatively realistic brightness temperatures as compared to observations. This will allow work to continue towards the assimilation of liquid water and precipitation, to improve NWP forecasts.

7. REFERENCES

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