RTTOV-91 Science and Validation Plan

Annex-A: RTTOV9 Cloud validation

Authors

O Embury

C J Merchant

The University of Edinburgh

Institute for Atmos. & Environ. Science

Crew Building

King’s Buildings

Edinburgh

EH9 3JN

Draft Version: 20 March 2007

Introduction

This work was undertaken as an extension to an NWP SAF Associated Scientist Mission initiated in November 2005, and should be read in conjunction with the resulting report “RTTOVCLD version 8: Independent Assessment” (Merchant, Embury and Old, 2006).

The objective is to validate new cloudy radiance code, RTTOV9, by cross-comparison of RTTOV8 cloudy radiance simulations against and independent scattering model.

DISORT

As with the previous independent assessment of RT8C, the DISORT computer code is used to calculate control radiances. Due to the enhancements introduced in RTTOV9, incorporating DISORT as the radiative transfer solver was more straightforward than in the previous study. RTTOV9 now calculates all the parameters necessary for scattering calculations so DISORT can effectively be used as an alternative to the rttov_integrate subroutine. Modifications to the different parts of RTTOV9 to facilitate the comparison are listed in further detail below.

Scattering parameters and code modifications

RTTOV9 makes use of four scattering parameters: absorption optical depth, scattering optical depth, backscatter parameter, and phase function. RTTOV9 uses the phase function only for solar radiance calculations, so the phase function is only stored for near infrared channels. DISORT uses the full phase function for all calculations; therefore new scattering coefficient files were necessary, including the phase function for all channels. Furthermore DISORT requires that the phase function is expressed as Legendre polynomial coefficients rather than tabulated as a function of scattering angle.

The optical properties of aerosols and water clouds used in RTTOV9 are taken from the Optical Properties of Aerosols and Clouds (OPAC) package. Thus, for consistency, we extracted phase function data for the thermal channels from the OPAC package.

The scattering coefficient files were also altered to contain the asymmetry parameter, rather than the backscatter parameter. The asymmetry parameter is not actually used in the current version of the DISORT code, but was used for early tests which assumed a Henyey-Greenstein phase function.

rttov_opdpscattir
The subroutine rttov_opdpscattir was modified to extract the phase function for all channels rather than just the solar-affected channels. Code previously used to calculate the azimuthally averaged phase function was removed as it was no longer required and relied on the phase function being tabulated as a function of scattering angle. Finally the phase function moments were saved in the transmission_scatt_ir structure for passing to the rttov_integrate subroutine.

rttov_integrate
This subroutine was replaced with a wrapper around the DISORT computer code. As with the RT8C comparison it is necessary to 'correct' the RTTOV9 calculated optical depths to equivalent nadir optical depths. With RTTOV9, however, there is no need to interpolate optical depths / radiances to model pressure levels as all calculations are performed on the same fixed pressure levels. The optical properties of each layer are calculated from the gas, aerosol and cloud optical properties as:

$$\tau_e = \tau_a^{gas} + \tau_a^{cld} + \tau_s^{cld} + \tau_a^{aer} + \tau_s^{aer}$$

$$\omega = \frac{\tau_s^{cld} + \tau_s^{aer}}{\tau_e}$$

$$\eta_i = \frac{\eta_i^{cld}\tau_s^{cld} + \eta_i^{aer}\tau_s^{aer}}{\tau_s^{cld} + \tau_s^{aer}}$$

where η_i is the ith phase function moment.

Profile set

As with the RT8C validation, the 60L-SDr profile set (Chevallier 2001) was used to provide profiles of cloud water content. However, fixed profiles of temperature, water vapour and trace gases were used for all simulations. The example RTTOV9 profile (prof_101lev.dat) included with the code was used for this purpose.

Unlike RT8C which required input profiles on two different pressure grids, the new code uses only one grid. In the version of the code being tested this was limited to the 100 layers used by the coefficient files. Input cloud profiles to RTTOV9 can be specified as one of six different cloud types (five water cloud types or ice cloud) – different layers can contain different cloud types, but only one cloud type is allowed on a given layer.

RTTOV9 cloud profiles were generated for each of the 67 60L-SDr profiles including cloud liquid water data. The entire profile was assumed to be a single cloud type, although the cloud type chosen was varied for different simulations.

Profiles of mixed cloud types are not considered here. However, as the cloud type is simply used to determine the optical properties the presented results here can be used as a guide to mixed cloud conditions. Under these conditions, the RTTOV error is expected to be no worse than that for the cloud-type modelled “least well”

Clear-sky comparison

A cloud free comparison was performed to verify the DISORT model was functioning correctly. BT difference spectra are shown in Figure 1 for zenith angles of 0 and 60 degrees. The agreement is very good – differences are less than 0.1K for surface viewing channels and an order of magnitude smaller for sounding channels.

The differences between RTTOV and DISORT are due to differeing surface reflectivity assumptions: RTTOV assumes specular reflection, while Lambertian reflection was assumed for the DISORT simulations. This means the reflected downward radiance in the DISORT simulations is independent of zenith angle, while the RTTOV reflected radiance increases with zenith angle (as emissivity decreases). If a surface emissivity of 1.0 is used, then all RTTOV – DISORT differences are reduced to ~0.001 K

As the surface emissivity is the primary source of bias between the RTTOV and DISORT models in the clear-sky case, a surface emissivity of 1.0 was used for all cloudy-sky comparisons.

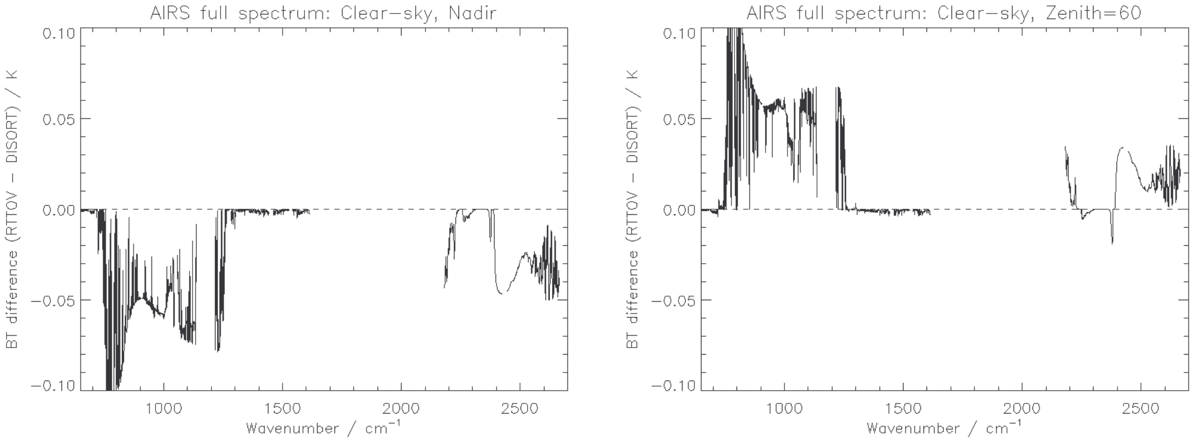

Figure 1 Comparison of RTTOV9 and DISORT calculated clear-sky spectra.

Water clouds

There are 67 profiles in the reduced Chevallier dataset containing cloud liquid water. For the purposes of this comparison they were assigned to one of three cloud types: stratus continental, stratus maritime, or cumulus maritime. The cumulus continental clean and continental polluted were not tested; however results from Matricardi (2006) can be used to infer their behaviour from results presented here for other water cloud types.

Figure 2 shows the radiative impact of two different cloud profiles assuming the stratus continental cloud type, and the differences between the RTTOV and DISORT calculations. The maximum BT decrease in these simulations is ~40K – roughly twice that reported in Matricardi (2006) due to the larger range of cloud profiles considered. However the RTTOV errors are consistent with those reported by Matricardi – less than 1 K for thermal infrared and less than 5 K in the near infrared.

Figure 3 shows the RTTOV error against cloud optical depth for two channels corresponding to wavelengths of 11.85 microns and 3.75 microns (chosen to be close to the AATSR 12 and 3.7 micron channels used in the RTTOV8 cloudy validation report). The thermal infrared channel shows excellent agreement – at nadir the bias is ~0.1 K for thick clouds (optical thickness greater than ~3), while at a zenith angle of 60 degrees the bias reaches only 0.5 K. For the near infrared channel, where scattering dominates, the biases are larger – reaching ~3.5 K at nadir and 6 K at zenith angle of 60 degrees.

Figure 4 through 7 show equivalent plots for the maritime stratus and maritime cumulus cloud types. The maximum error is less for these cloud types than stratus continental. Figure 8 shows optical properties of the three cloud types, showing that stratus continental has both higher backscatter coefficient and single scattering albedo than the maritime clouds, in the near infrared, meaning that scattering is more significant to the cloudy radiance.

The larger RTTOV-DISORT biases are associated with higher values of the single scattering albedo (ω) and backscatter parameter (b). This follows from the (absorptivity) scaling approximation used in RTTOV9 to define effective extinction optical depth:

$$\tilde{\tau}_e = \tau_a + b\tau_s$$

Where $\tau_s = \omega\tau_e$ and subscripts e, a, and s refer to extinction, absorption and scattering respectively.

Although in most cases, the scaling approximation leads to an overestimation of the ToA radiance, there are also cases where the radiance is underestimated. This is particularly noticeable for the thermal channels where the optical depth is between 0.1 and 10.0. All these cases are associated with very high clouds (clouds present between 600 and 400 mbar) whereas profiles with lower level clouds (lower than 600 mbar) give positive RTTOV-DISORT biases. This is a result of using (isotropic) thermal emission to approximate the scattered radiance which, in DISORT, is (correctly) non-isotropic.

The water cloud type used in RTTOV8 is closest to maritime cumulus – they would be virtually indistinguishable if plotted on Figure 8. Figure 9 shows RT8C-DISORT biases for the water cloud type. Clear-sky transmissions are calculated using the standard 43 level RTTOV8 coefficients, then interpolated to the 60 ECMWF model levels for cloudy calculations.

Comparing Figure 9 and Figure 7 we see that RTTOV9 has greatly improved the simulation in the thermal infrared – biases at nadir have been virtually eliminated while at higher zenith angles they have been reduced from ~1 K to ~0.3 K. In the near infrared the maximum bias (corresponding to optical depths of 10+) has not been substantially altered. However biases at lower optical depths (1 to 10) are improved compared against RT8C. Furthermore in both cases there is significantly less “scatter” in the RTTOV9 plots than the corresponding RT8C plots. This is primarily due to the different level and interpolation schemes employed by the models. In RT8C, Planck radiances are only calculated on the 43 fixed RTTOV levels, then interpolated to the model levels used for the cloudy calculations. RTTOV9, however, performs no such interpolation and therefore does not suffer from such interpolation artefacts.

Figure 10 shows the biases when RT8C is compared against RTTOV9. Again the water cloud type is used in RT8C and maritime cumulus in RTTOV9. The outlying point with cloud optical depth ~0.4 is due to an interpolation artefact when the 60-level cloud profile was interpolated to the 100 RTTOV9 levels. Note that at low cloud optical depths the differences in clear-sky BT due to the updated spectroscopy and larger number of variable gases is apparent.

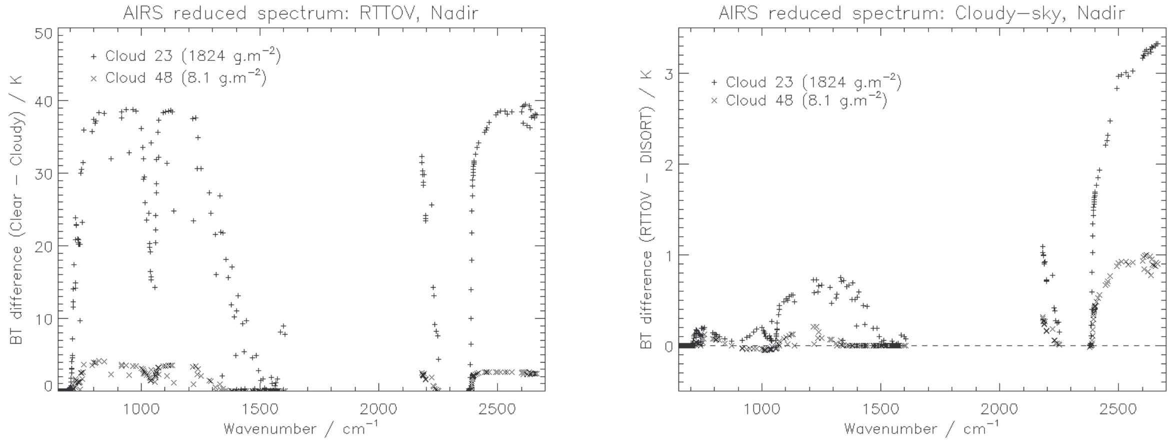

Figure 2 Radiative impact of stratus continental cloud type (left) and difference between RTTOV and DISORT calculations (right) for two different cloud profiles.

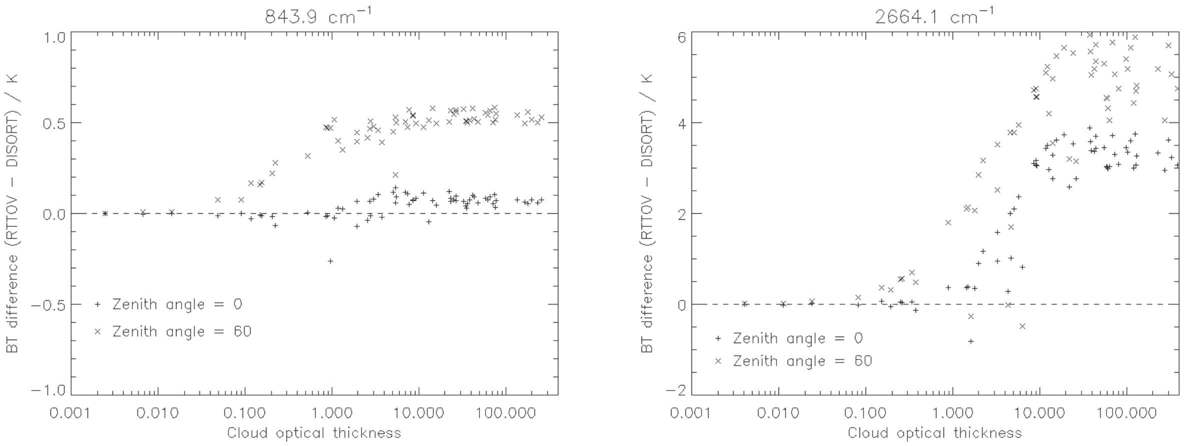

Figure 3 RTTOV-DISORT bias against cloud optical depth for stratus continental cloud type. Optical thickness is total cloud extinction at specified wavenumber.

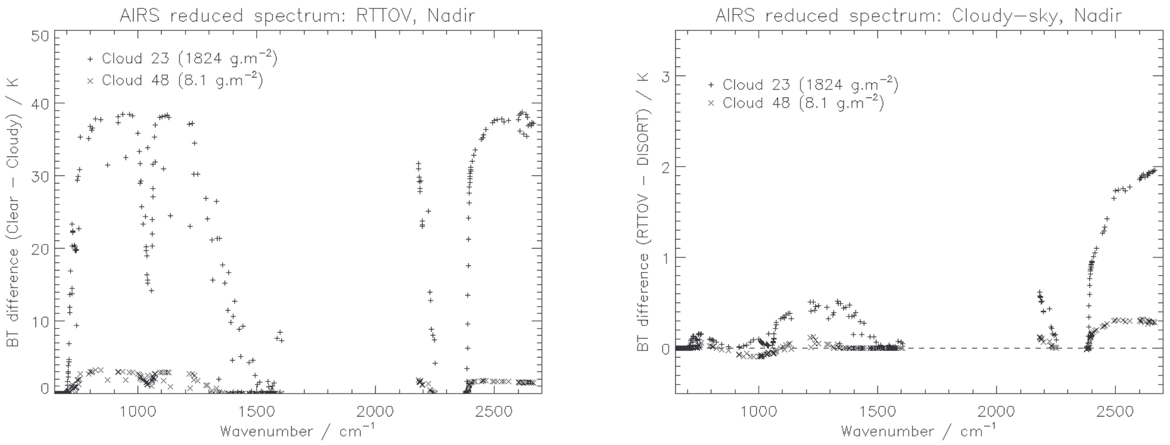

Figure 4 As Figure 2 for stratus maritime cloud type.

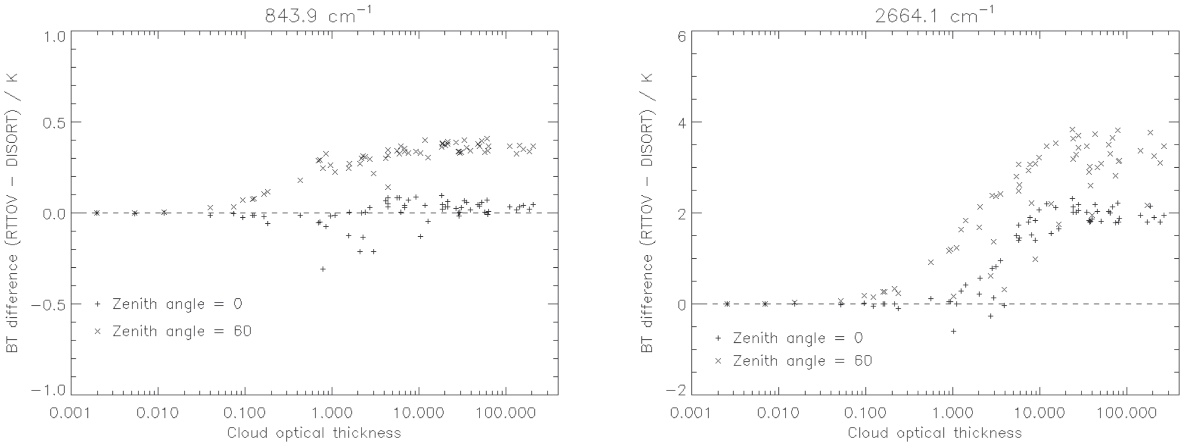

Figure 5 As Figure 3 for stratus maritime cloud type.

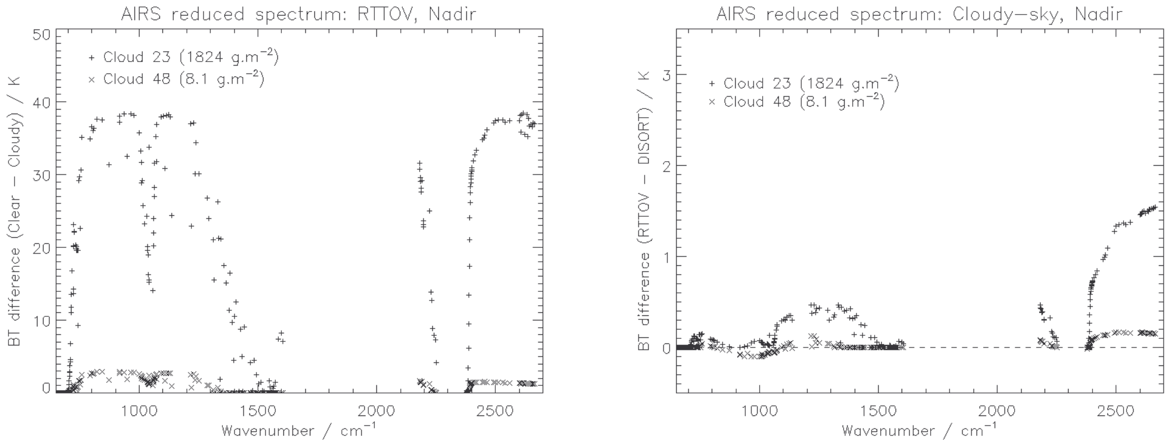

Figure 6 As Figure 2 for cumulus maritime cloud type.

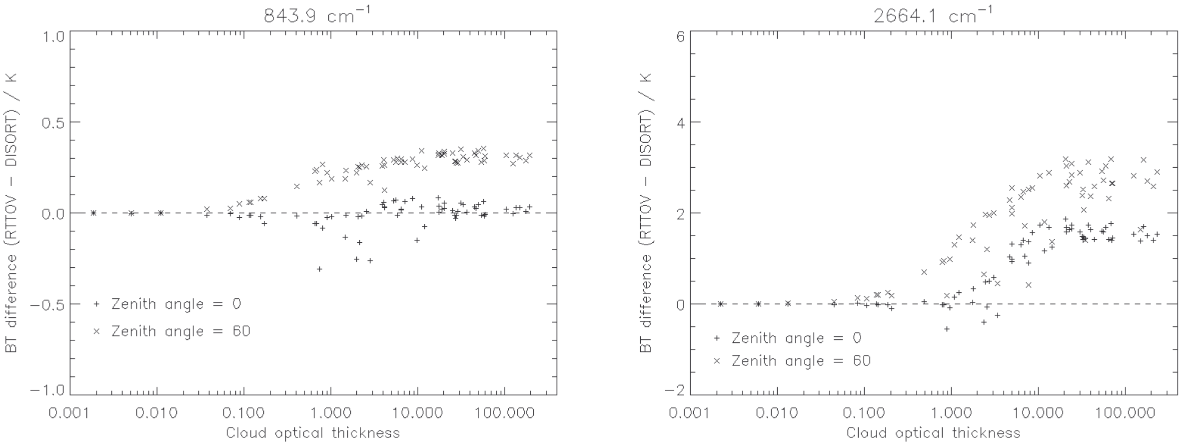

Figure 7 As Figure 3 for cumulus maritime cloud type.

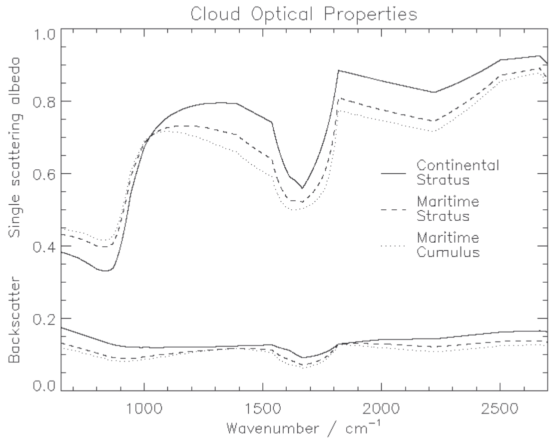

Figure 8 Optical properties of the three cloud types

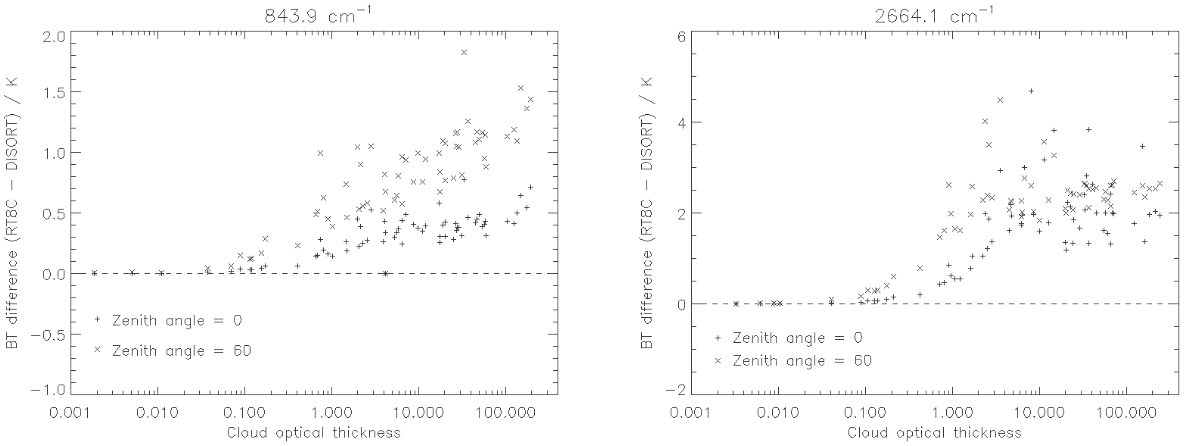

Figure 9 RT8C – DISORT biases for water cloud type. Clear-sky calculations performed on 43 RTTOV8 pressure levels; cloudy-sky calculations performed on 60 ECMWF model levels.

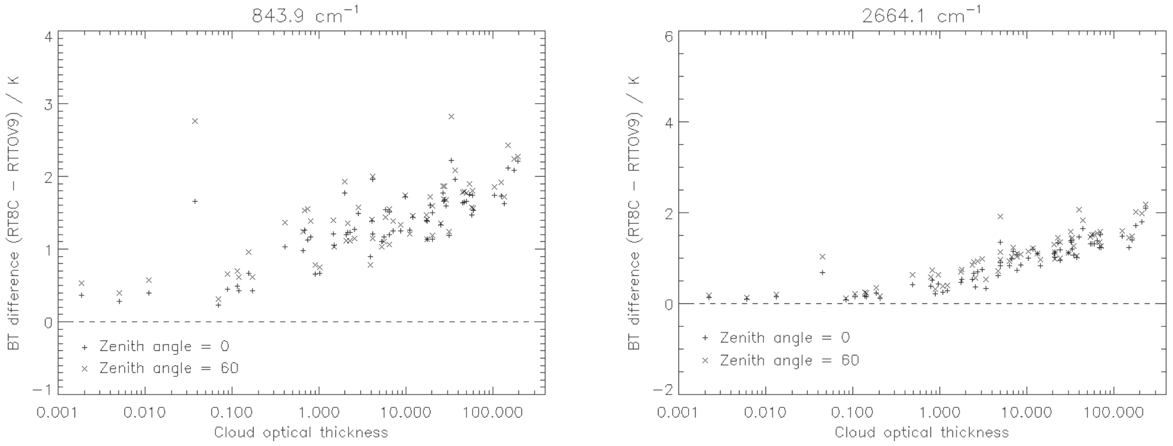

Figure 10 RT8C – RTTOV9 differences. RT8C run using water cloud type; RTTOV9 run using cumulus maritime cloud type.

Ice clouds

DISORT simulations were not run for ice clouds as full phase function data were not available. However, the results in Matricardi 2006 are consistent with the water cloud comparisons here. Cirrus clouds have a very low backscatter parameter, therefore we except only small difference between RTTOV and DISORT (Matricardi reports typical errors of less than 0.2 K).

Furthermore Matricardi notes that RTTOV9 tends to underestimate the radiance from cirrus clouds while clouds and aerosols are overestimated. We have identified a similar behaviour for water clouds above ~600 mbar. As the RTTOV9 scaling approximation represents scattered radiance with thermal emission it follows that the biases will be dependent on the cloud temperature.

Conclusion

RTTOV9 is a significant improvement on RT8C for simulating cloudy radiances compared to DISORT (full scattering model) run with equivalent optical properties. This is particularly true for thermal infrared wavelengths, where biases seen in RT8C are all but eliminated. Partly, this improvement will arise from the fact that, with RTTOV9, all calculations are performed on a consistent set of 100 levels. Nonetheless, scattering is significant at thermal wavelengths and the very low biases indicate that the parameterisation of scattering is effective.

At near-infrared wavelengths, biases are significantly improved up to cloud optical depths of about 10. At greater optical depths, the biases found relative to DISORT were similar in magnitude to those with RT8C, but are, perhaps, rather more consistent between clouds.

A pattern of over-estimation of radiance for warm clouds and under-estimation for cold clouds is evident, which fits with the method of parameterisation of scattering, in which the absorption optical depth (and thus the thermal emission) is scaled independently of incident radiance.

Future suggestions

One less obvious, but significant, advantage of the RTTOV9 code compared with RT8C is the ease with which an alternative radiative transfer equation solver (i.e. DISORT) could be incorporated. With RT8C it was easier to write a separate computer program which called RTTOV8 to calculate the clear-sky transmission, then calculated the cloud optical properties before calling DISORT. However, with RTTOV9 it was possible to make the call to DISORT directly from RTTOV9 itself, after making, comparatively, minor modifications to some of the optical properties which RTTOV9 stores internally.

If the various RTTOV modules were to have a more generic interface then it would be possible to implement new / alternative RTE solvers without modifying the rest of the RTTOV code.