A New Ice Cloud Parametrization in the Infrared for RTTOV-11: Model and Comparison with other RTTOV parametrizations against A-Train observations

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Abstract

A new ice cloud optical properties database in the thermal infrared has been parameterized for RTTOV version 11. The database combines an ensemble model of ice crystals, and a particle size distribution scheme that can predict the radiative properties of cirrus cloud without the need of a priori information on the ice particle shape and an estimate of the ice crystal effective dimension, obtained through empirical parametrization. The ice cloud optical properties (absorption and scattering coefficients and fraction of backscattering radiation) are estimated through linear parametrizations of in-cloud temperature and ice water content. We performed comparisons with infrared observations at 8.65, 10.6 and 12.05 microns (from IIR onboard CALIPSO) with RTTOV simulations in the presence of single-layer ice clouds by using the different RTTOV parametrizations and ice water content profiles retrieved from CLOUDSAT and CALIOP synergy (2C-ICE product). We also tested parametrizations from modified ensemble model ice cloud bulk optical property databases, based on different shapes of the particle size distribution, determined by assuming different pre-factors in the Mass-diameter law to improve the comparisons.

INTRODUCTION

The assimilation of cloudy radiances is considered a major issue for improving Numerical Weather Prediction models. Fast radiative transfer models, such as RTTOV, are key tools to achieve this goal and makes use of parametrization to simulate cloudy radiances. In the thermal infrared, a first step in that area involves the assimilation of radiances affected by ice clouds, since they are optically thin (as compared with liquid clouds), and some information may be retrieved below the cloud (Okamoto et al., 2013; Martinet et al., 2013).

To do so, a new database of bulk optical properties of ice cloud particles in the thermal infrared has been parameterized for RTTOV-11 (Saunders et al., 2013). This database combines an ensemble model of atmospheric ice particles and a particle size distribution scheme (Baran et al., 2013; Field et al., 2007) that can predict the radiative properties of cirrus cloud without the need for a priori information on the ice particles shape and an ice crystal effective dimension, obtained through empirical parametrization. The ice cloud optical properties (absorption and scattering coefficients and fraction of backscattering radiation) are estimated through linear parametrizations of in-cloud temperature and ice water content.

To evaluate this parametrization, we used 2 weeks of ice cloud profile retrieval products from combined CloudSat and CALIOP observations to simulate infrared TOA brightness temperatures, and compare then against IIR brightness temperature observations at 8.65, 10.6 and 12.05 microns.

THE RTTOV ICE CLOUD PARAMETRIZATION AND THE BARAN DATABASE

The TOA brightness temperature (BT) of satellite-based observations affected by ice cloud in thermal infrared is simulated by RTTOV using the Chou-scaling approximation (Chou et al., 1999) with
different parametrizations of ice cloud optical properties (absorption and scattering coefficients, backscattering fraction) from cloud temperature ($T_c$) and ice water content (IWC).

In RTTOV-10 (Saunders et al., 2012), ten different parametrizations were provided. These parametrizations come from four different empirical relationships named OL95 (Ou and Liou, 1995), W98 (Wyser, 1998), B02 (Boudala et al., 2002) and MF03 (McFarquhar et al., 2003) - that relate the ice crystal effective diameter ($D_e$) to IWC and/or $T_c$ - times two shapes of the ice crystals (Hexagonal or Aggregates) - that allow calculating the optical properties from $D_e$ and IWC (see Matricardi, 2005 for details). These previous parametrizations developed for RTTOV are based on particle size distributions which are highly likely to be biased towards smaller ice crystals due to ice shattering on or at the inlets of microphysical probes (Korolev et al. 2011). Two more parametrizations were also provided when directly inputting $D_e$ profiles to RTTOV for each shape.

In RTTOV-11 (Saunders et al., 2013), we have implemented a new parametrization based on a new database of ice cloud optical properties. This database was assembled by combining an ensemble model of six ice crystal elements (hexagonal ice column, six-branched bullet rosette, 4 three to ten elements hexagonal ice aggregates) described in Baran and Labonnote (2007) and a moment estimation parametrization of the particle size distribution (PSD) (Field et al., 2007). The Field et al. (2007) PSD parametrization is based on in-situ PSDs, which have been filtered to remove ice artefacts due to shattering, and in-situ measurements of ice crystal size less than 100 µm were ignored. The parametrization assumes an exponential PSD to represent ice crystal size less than 100 µm, and this is added to a gamma function, for sizes greater than that, to complete the PSD. The ensemble model is able to simulate passive and active measurements of ice clouds, from UV to the microwave (Baran et al., 2013). The database consists of 20662 PSDs, that were generated from the F07 parametrization, using different in-situ measured $T_c$ and estimated IWC observations, and their distribution is shown in Figure 1. The database provides for each PSD, the simulated volumetric extinction and scattering coefficients, and asymmetry parameter at 57 wavelengths between 3 and 18 microns. The phase function P is given by an analytical formulation of g and is used to calculate the backscattering fraction coefficient (Baran et al., 2001).

![Figure 1: Ice water content versus in cloud temperature of the Baran database.](image)

The new parametrization developed for RTTOV-11 allows estimating the ice cloud optical properties from $T_c$ and IWC, without the need to estimate $D_e$ and is given by the following equations:

\[
\log_{10}[\beta(\lambda)] = A_\beta + B_\beta T_c + C_\beta \log_{10}(IWC) + D_\beta T_c^2 + E_\beta \left(\log_{10}(IWC)\right)^2 + F_\beta T_c \log_{10}(IWC) \quad (1)
\]

\[
\beta(\lambda) = A_\beta + B_\beta T_c + C_\beta \log_{10}(IWC) \quad (2)
\]

Where $\beta$ is the absorption or the scattering coefficients and $b$ is the backscattering coefficient. The coefficients were calculated by using a non-linear least squares fitting procedure over the Baran
database. More details can be found in Saunders et al., 2013. The ensemble model is able to predict a mass-Diameter relationship of the form \( M = \alpha D^2 \), with \( \alpha = 0.04 \) (Baran et al., 2011). We call this parametrization BARV11. We also tested different databases of ice cloud optical parameters by generalizing the integration over the PSDs (named B004), and for two different values of \( \alpha \) (0.06 and 0.08 named B006 and B008 respectively). A further database was also tested assuming a pre-factor value of 0.0257, which corresponds to the value proposed by Cotton et al. (2012) and named hereafter B00257. The use of this pre-factor convolved with the Field et al. (2007) parametrization is microphysically consistent with the current cloud scheme used in the operational Met Office high-resolution numerical weather prediction model. We finally tested a last database, where the scattering and absorption coefficients of the B00257 database were scaled by a fixed value of 0.4901 (named B00257RW), in order to re-weight the ensemble model and obtain a database between B004 and B006.

**SELECTION OF ICE CLOUDS**

To evaluate the different RTTOV ice cloud parametrizations, we used 2 weeks of ice cloud profiles 2C-ICE products (Deng et al., 2010) retrieved from combined Lidar Caliop (onboard CALIPSO) and Radar CPR (onboard CloudSat) instruments. We compared the RTTOV TOA simulated BT with the TOA BT, observed by the IIR instrument onboard CALIPSO, at 8.65, 10.6 and 12.05 microns. The radiometric uncertainty of the IIR channels is ±1K. Thanks to the low spatial resolution of IIR (~1 km), we assume a cloud fraction of unity in any cloud layer. We also used collocated ECMWF meteorological profiles (for P, T, H2O, O3) and surface information (P_s, T_s).

We selected only ice clouds in each profiles by using the DARDAR cloud mask product (Delanoé and Hogan, 2010) that provides a better flag for aerosols affected profiles than the CloudSat product. We then separated the selection into two groups, one for “small” visible cirrus optical depth (COD), i.e. between 0.03 and 0.5 and one for “large” visible COD, i.e. between 0.5 and 4. We finally selected only profiles when ice cloud layer pressures are between 440 and 50 hPa.

Figure 2 represents the global location of profiles for small COD. The zonal number of profiles distribution is shown on the left side of the Figure 2. We separated the zonal areas into five: High Latitudes North (HLN) [90°N-60°N], Mid Latitudes North (MLN) [60°N-20°N], Tropics (TRO) [20°N-20°S], Mid Latitudes South (MLS) [20°S-60°S], High Latitudes South (HLS) [60°S-90°S]. Most of profiles are located between the tropics and decrease towards high latitudes. For large COD (Figure 3), much less profiles are located at high latitudes. The total number of profiles are almost similar (21033 for small COD and 20503 for large COD).

![Figure 2: Global maps of selected ice cloud profiles for small cirrus optical. Zonal number of profiles distribution are provided.](image)
RESULTS

Global results
On the panel of Figure 4 is represented the O-B PDF for all three IIR bands together, for small COD and for each of the parametrizations.

Figure 4: RTTOV TOA brightness temperature versus IIR measurements at 10.6 microns for all parametrizations. Statistical results are provided.
We did not evaluate the aggregates shape of ice crystals since the thermal infrared spectra for any cloud simulation show a non physical spectral behaviour between 10 and 12 microns (Faijan et al., 2012). All parametrizations underestimate observed BT with bias between –0.05K and -4.69K. Standard deviations are between 4.71K and 5.97K. For small COD, the B02-HEX gives the lower bias but the bigger standard deviation.

For large COD, the similar results are shown on the panel of Figure 5. Mean bias are between –6.52K (B008) and 20.64K (B02-Hex) and standard deviations between 6.8K (B008) and 10.7K (B02-Hex). The B00257RW parametrization gives the lowest bias of -0.29K.

Zonal results
We studied then the impact of the zonal areas on the evaluation at 10.60 µm. The panel Figure 6 show the bias and standard deviation values for the two groups of COD. The different colours represent the different zonal areas. For small COD, the B02-Hex parametrization shows clearly the better bias for all areas, except High Latitudes South, where it is less clear (Top left of Figure 6). The High Latitudes North are better simulated (in blue) than other regions, whatever parametrization is used. For large COD, (bottom of the Figure 6), the results are less clear, since W98-Hex, D0-Hex and B00257RW are closer to zero bias for different areas, but standard deviations are smaller for D0-Hex and B00257RW. In the NWP environment, the effective diameter of ice crystal is not a prognostic variable, and the previous RTTOV parametrizations are highly likely to be based on skewed PSDs; so the B00257RW is recommended, since it also satisfies the measurements over a greater range of COD. Also, it is interesting to see that the standard deviation is lower for High Latitudes North, and comparable with small COD.
CONCLUSION AND PERSPECTIVES

A new database of ice cloud optical properties in the infrared has been parameterized, and implemented in RTTOV-11. The new parametrization allow a direct estimation of the cloud optical properties from the IWC and the temperature profiles, avoiding the choice of an effective diameter parametrization and the shape of the ice crystals. The comparisons against observations show that the B02-Hex parametrization is recommended to use when COD are small, and the new physically consistent B00257RW parametrization should be used over a greater range of COD. Moreover, the apparent usefulness of the B02-Hex parametrization could be because of its physical inconsistency, due to artificially skewed PSDs. Furthermore, the hexagonal column geometry cannot be applied across the electromagnetic spectrum as demonstrated by Baran and Francis (2004). In the next version of RTTOV, we will replace the current BAR v11 parametrization with the B00257RW, and investigate improving the simulation of small COD, using the ensemble model of ice crystals by investigating the small mode of the PSD.

REFERENCES


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