COMPARISON OF SIMULATED RADIANCE FIELDS USING RTTOV AND CRTM AT MICROWAVE FREQUENCIES IN KOPS FRAMEWORK

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Abstract

The radiative transfer for television operational vertical sounder (RTTOV) and the community radiative transfer model (CRTM) are fast RTMs those are used as an observation operator in numerical weather prediction (NWP). With Advanced Microwave Sounding Unit-A (AMSU-A) data, RTTOV and CRTM are compared by the first-guess (FG) departures for both clear and cloud sky conditions within the framework of Korea Institute of Atmospheric Prediction Systems (KIAPS) Observation Processing System (OPS). For calculation of ocean surface emissivity, the FASTEM version 4 is used. Without cloud condition, RTTOV produces smaller FG departures (i.e. better results) in image channels compared to CRTM over ocean. By adding cloud water and ice particles, the TB bias between CRTM simulations and the observations at 31.4 and 89 GHz is substantially decreased compared to RTTOV. For sounding channels, the two models are comparable in their TB calculations, but RTTOV shows slightly better FG departures in mid- and upper-tropospheric sounding channels when cloud fields are included. CRTM takes marginally longer TB calculation time. Model run times are increased by 30% when cloud fields are added to the AMSU-A simulation.

1. INTRODUCTION

This study is a comparison of simulated radiances for AMSU-A by the two most widely used fast RTMs, RTTOV and CRTM within the framework of the KIAPS OPS (KOPS). For satellite radiance data, the AMSU-A and the Infrared Atmospheric Sounding Interferometer (IASI) data processing system is currently under development. These two satellite observations are known to have the most impact on NWP among other microwave and infrared sensors. The RTTOV-SCATT version 10.2 (Bauer et al. 2006; Saunders et al. 2011) is adopted as an observation operator in microwave data processing in KOPS.

Many NWP centers assimilate only the clear-sky radiance only, but satellite radiance observations in cloudy and precipitating regions can improve analyses and provide much information on weather forecasting. One of the most important factors in the use of radiance data associated with cloud and precipitation is effective RT modeling for scattering properties of cloud particles such as cloudiness assumption and uncertain information about hydrometeors together with a selection of a fast scattering solver (Geer et al. 2009).

For this comparative study, the CRTM version 2.1.1 (Han et al. 2006) has been installed. Simulated radiance fields for AMSU-A using the two fast RTMs are compared for clear and cloudy sky conditions on November 7, 2012. The FG departures for different surface conditions and scan positions are also compared and the comparison of computation times using the two RTMs are reported as well.

2. KOPS for AMSU-A

AMSU-A has 15 channels, 12 temperature sounding channels around the O₂ absorption band (50–60 GHz) and 3 image channels at 23.8, 31.4, and 89 GHz. It is cross-track scanning radiometer, which has an instantaneous field of view (IFOV) of 50 km at nadir and the swath width of about 2300 km.
The FOV size grows gradually to about 150 km at extreme scan position. Goldberg et al. (2001) reported that the variation of the measurement according to beam position can be as much as 30 K for the 23.8 GHz window channel and 15 K for the atmospheric temperature sounding channels (53-58 GHz) which is called by limb effect. From channel 3 to 14, the peak of the channel weighting functions is increased in altitude. The channel 5 has a weighting peak near 500 hPa level and observed TBs of channel 9 and 10 are mostly affected by atmospheric temperatures near the tropopause.

Figure 1 shows a flow chart of AMSU-A data processing in KOPS. AMSU-A level-1d data is extracted by European Organization for the Exploitation of Meteorological Satellites (ECMWF) (Binary Universal Form for the Representation of meteorological data) BUFR decoder. Since the level-1d data was mapped to a High Resolution Infra-Red Sounder (HIRS) footprint, it has 56 (not 30) scan positions. By the initial quality checks (QC), the pixels with gross errors are removed (6 - 7 %) and those contaminated by large amounts of cloud liquid water, heavy precipitation, and sea ice are removed with flagging (40 - 50 %). The unified model (UM) forecast is used as atmospheric background data, which provides initial atmospheric and surface fields to the forward operator. About 94 % of AMSU-A data after gross QC are used in this comparative study. Offline bias corrections for scan positions and air-mass corrections are performed based on the Harris and Kelly scheme (2001) using 1 month innovations statistics.

The UM provides three cloud parameters for each atmospheric layer, which are cloud fraction, cloud liquid water, and cloud ice. The cloud liquid water distribution of the UM was compared the liquid water path (Grody et al. 2001) retrieved from AMSU-A observations (Fig. 2). For the UM, the general distribution and locations of cloud shows good agreement with observations, while AMSU-A retrieved liquid water over tropic regions shows more amount of water substances when compared to the simulations.

![Figure 1: A flow chart of AMSU-A data processing in KOPS.](image)
Figure 2: (a) Cloud liquid water mixing ratio [g kg\(^{-1}\)] from the UM forecast and (b) retrieved liquid water path [mm] from AMSU-A observations at 00 UTC November 7 2012.

3. RTTOV AND CRTM

The RTTOV-SCATT is developed by Met Office and NWP Satellite Application Facility for the calculation of cloud-affected radiance at microwave frequencies. The CRTM is developed by USA Joint Center for Satellite Data Assimilation (JCSDA), implemented using the OPTRAN transmittance algorithms. Both models are fast RTMs, which parameterize optical depth using atmospheric predictors by fitting to line-by-line model transmittance.

For atmospheric layer inputs, temperature, humidity, and pressure values are needed. The Information on the surface type, surface temperature, and salinity are common input variables of the two models. While the 2m level wind, humidity, and temperature are used for RTTOV TBs calculations, only the 10m wind speed is adopted for CRTM. For calculations of ocean surface emissivity, the Fast Emissivity Modeling (FASTEM) version 4 (Liu et al., 2011) is used in both models. The CRTM needs a viewing angle besides satellite and sun zenith angles for the calculations of geometry.

The additional variables for the level pressure and cloud particles are required for RT calculations under cloudy conditions. The information of n-levels of cloud cover (0-1), cloud liquid water [kg kg\(^{-1}\)], cloud ice water [kg kg\(^{-1}\)], total ice [kg kg\(^{-1}\)], and flux of rain and solid precipitations [kg m\(^{-2}\) s\(^{-1}\)] are used in RTTOV. The input parameters of the CRTM include cloud structures of water, ice, rain, snow, graupel, and hail using [kg m\(^{-2}\)] for water content and [µm] for effective radius. For cloud scattering properties, both models use pre-calculated tables for each hydrometeor type and density based on Mie theory.
The final TBs in RTTOV are obtained from linearly combined radiances of clear and cloud sky, i.e.
\[ T_B^{\text{Total}} = (1 - C)T_B^{\text{Clear}} + CT_B^{\text{Cloud}} \],
where C is the effective cloud fraction in the vertical profile, calculated internally. The scattering computation is based on the two-stream Eddington approximation model which produces mean errors of less than 0.5K at the targeted microwave frequencies between 10 and 200 GHz (Bauer et al. 2006). The CRTM adopted the advanced doubling-adding (ADA) method as a scattering solver. This method is about 60 times faster than the doubling-adding method, and is an accurate tool for detailed multiple-scattering calculations (Liu and Weng 2006).

4. Comparisons of FG departures

4.1 FG departures by surface type

Figure 3 shows a map of FG departures in channel 3 from both RTTOV and CRTM under the clear-sky condition. The AMSU-A observations within 6 hours (± 3hr) of 00 UTC on 7 November 2012 are used as a “truth” observation values of 00 UTC. The CRTM shows better FG departures (i.e. smaller FG departures) than RTTOV for the land and sea ice surface types due to different default values of surface emissivity for the surface types in the two models. The AMSU-A channel 3 is located in O₂ absorption line, but the effect of surface emissivity is also very large in this channel. Figure 4 compares FG departures of AMSU-A for three different surface types. Regardless of surface type, the results are very comparable from the mid tropospheric to upper stratospheric sounding channels (channel 5 to 14). The positive biases over land and sea ice and negative biases over ocean are combined to make smaller FG departure values over the globe with larger standard deviations for CRTM.

The correction of FG departures according to the scan position is done by removing the values (bch) between observed and simulated TBs of mid-point of beam positions on each channel. Figure 5 compares those offsets for ocean, land surfaces, and the globe. The trend of FG departures over ocean shows symmetry, which are similar for both models. The values from 89 GHz using CRTM are larger at the side of scan position than in RTTOV. Over land, the asymmetry for scan positions is appeared in image channels of CRTM simulation. The trend of FG departures toward extreme scan positions is reversed over ocean and land surface in RTTOV simulation of which the reason still needs further investigations.

Figure 3: (a) AMSU-A channel 3 FG departures using (a) RTTOV and (b) CRTM at 00 UTC on 7 November 2012.
Figure 4: AMSU-A FG departures using (a) RTTOV and (b) CRTM for different surface types: ocean (blue), land (red), sea ice (green), and globe (black).

Figure 5: AMSU-A FG departures for different scan positions and surface types using RTTOV (first row) and CRTM (second row).
4.2 FG departures with cloud information

The UM cloud information are used as additional inputs to compare the agreement between FGs and observations under all-sky conditions over ocean. Figure 6 shows the mean of FG departures using the two models without and with cloud conditions. Figure 7 illustrates the agreement between the observed and simulated TBs for CRTM and RTTOV over ocean. When cloud particles are considered, FG departures of image channels and low tropospheric sounding channels are reduced in both models. Especially for channel 2 (31.4 GHz) and 15 (89.0 GHz), statistics of bias and standard deviation of CRTM are getting much lower than those of RTTOV. These channels are particularly sensitive to cloud liquid water and cloud ice. If other variables related to cloud and precipitation (rain water, snow, and graupel) are considered, the means of FGs are expected increase and the bias would be reduced by emitted TBs from those precipitation particles.

For the upper troposphere to stratosphere sounding channels (channel 6 to 14), FG departures for all channels of RTTOV become smaller, although the changed amount (0.1 - 0.3 K) is not so significant. For CRTM, such changes did not show at all.

Table 1 compares the computation times of the two models for clear and cloudy RT calculations. CRTM calculation takes marginally longer, which is comparable to AMSU-A calculations. When cloud scattering is considered, model calculation times are increased about 30 % in both models.

![Figure 6: AMSU-A FG departures using RTTOV and CRTM (a) without and (b) with cloud conditions over ocean.](image)
Figure 7: Two-dimensional histograms of the observed and simulated TBs for CRTM and RTTOV over ocean for AMSU-A channel 1 (23.8 GHz), 2 (31.4 GHz), and 15 (89 GHz) observations: (a) RTTOV without cloud conditions, (b) RTTOV with cloud conditions, (c) CRTM without cloud conditions, (d) CRTM with cloud conditions.

Table 1: Comparison of model computation times for one time step, when 16 CPU are used. The number of profiles is about 1,200,000 from NOAA-15, 18, 19 and MetOp-A platforms.

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<th>RTTOV</th>
<th>CRTM</th>
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<td>Total time</td>
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5. Summary and ongoing work

This study introduces AMSU-A processing in KOPS, where the RTTOV-SCATT and CRTM are installed as an observation operator for microwave radiance data processing for data assimilation. The CRTM and RTTOV are compared by the FG departures of AMSU-A radiances for different surface types, scan positions, and cloud conditions. The agreement between the FGs and observations is good in sounding channels (channel 5 to 14) with error standard deviations around 2 K. Image channels have large dependency of the surface emissivity, so those values are increased to 20 K in CRTM and 15 K in RTTOV for all surface types with no cloud condition.

The comparison of different cloud conditions is shown only for ocean since both RTTOV and CRTM adopt the FASTEM version 4 of ocean surface emissivity scheme. Without cloud, RTTOV shows lower bias between model and observations at image channels simulations. When three cloud inputs (mixing ratio of cloud liquid water, cloud ice, and cloud cover) are considered, FG departures from CRTM are substantially reduced, especially at 31.4 GHz and 89 GHz channels. Both RTMs demand more cloud information such as rain and solid precipitations, so it is difficult to draw a conclusion of which model is better. Another thing to note is that FG departures from RTTOV in mid- and upper-tropospheric sounding channels are slightly decreased when cloud fields are included since the final TBs in RTTOV are combined radiances of both clear and cloud sky.

More theoretical studies on the characteristics of multiple-scattering in microwave radiative transfer and the differences in realization methods of the two models are in progress. To provide more accurate land surface emissivity, an estimation tool for Land Surface Emissivities at Microwaves frequencies (TELSEM) atlas datasets in RTTOV will be used in KOPS.

REFERENCES


