Inter-comparison of CRTM and RTTOV in NCEP Global Model

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Objectives and Information

The capability of using RTTOV in GSI, in addition to CRTM, has been implemented in NCEP global model for the following purposes:

- To have a more consistent and flexible way in comparing radiative transfer (RT) models by using the same model input
- To better understand differences in optical properties, radiances, and Jacobians between the two
- To help in spotting errors by cross validating each other
- To establish symbiotic relationship between the two RT models by exploring new features in each one

Current NCEP global forecast model (GFS) does not generate precipitation (rain and snow) profiles, therefore the experimental GFS (Fig. 1), which includes cloud water, cloud ice, rain, and snow as prognostic variables are used for the validation. The goal is not to focus on the forecast skills, but to aim at the RT model differences.

CRTM release 2.2.3 and RTTOV v11.2 are used in the comparisons for AMSU-A on board of MetOp-B over the ocean. Issues found in comparison, possible solution for improvement and work plan are summarized and discussed.

Method

The comparison between CRTM and RTTOV are performed on point-by-point bases at the observation location (footprint). The variables evaluated are surface emissivity, optical depth, brightness temperature, and Jacobian. The simulations are performed within NCEP's global data assimilation system from 6-hour forecasts using the both RTTOV and CRTM over two 6-hour cycles for AMSU-A data on board of MetOp-B over the ocean. The 6-hour forecasts are originating from a T1534, 64 levels setup of the GFS. Since the same short-term forecasts are used in both CRTM and RTTOV, the differences in simulated variables are those between the two observation operators.

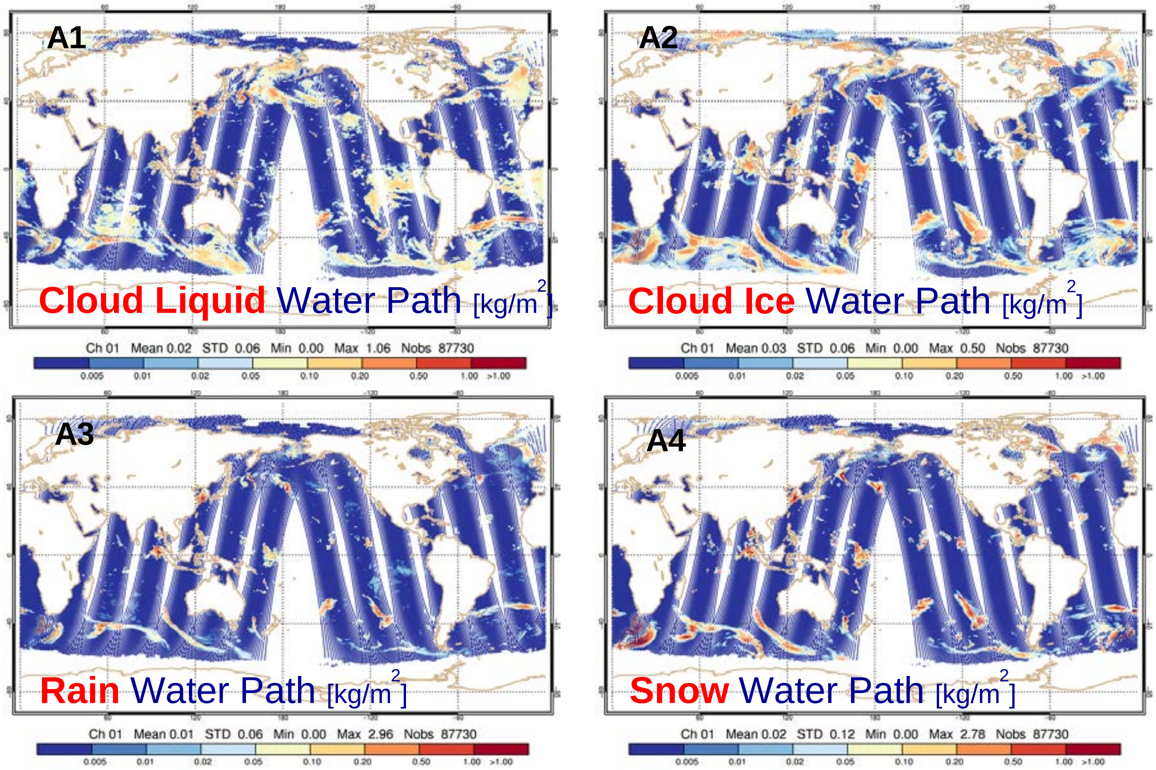


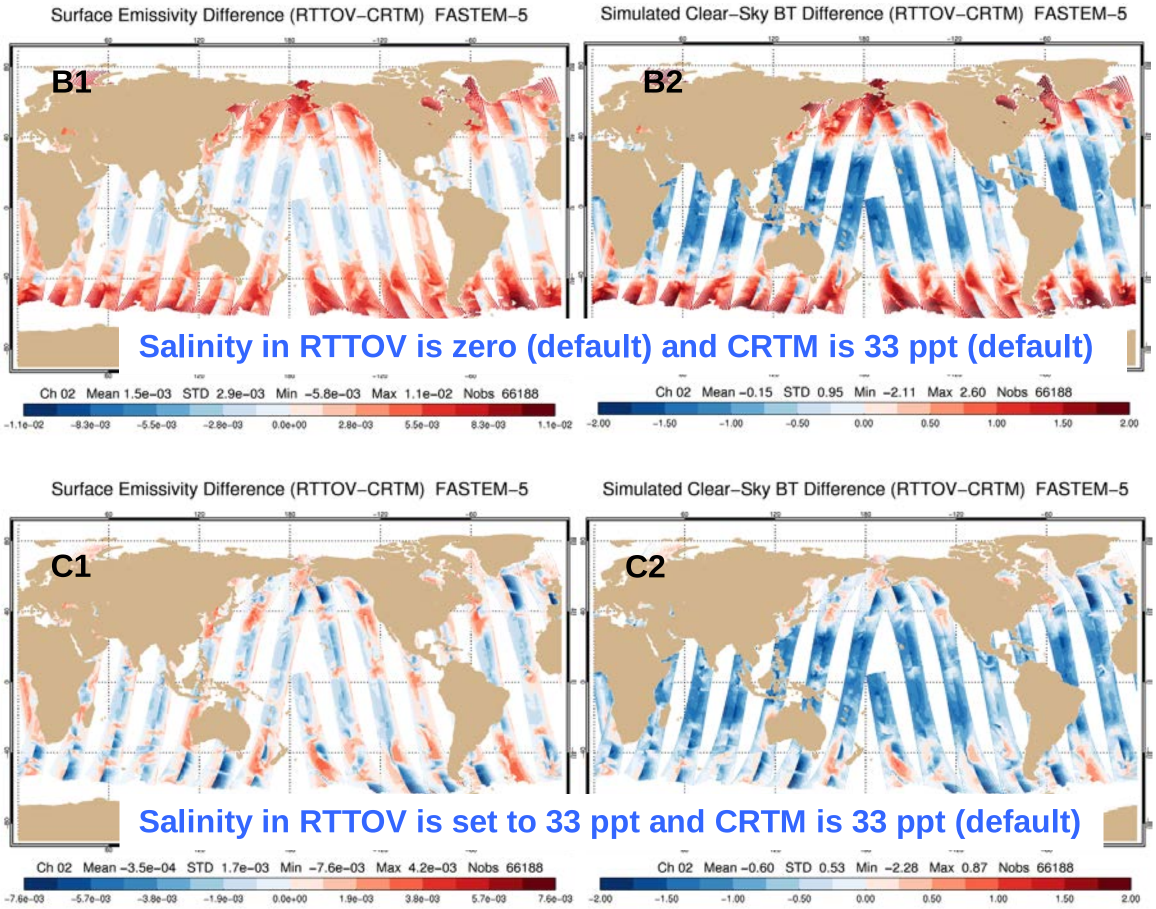
Fig. A The integrated (A1) cloud liquid water path, (A2) cloud ice water path, (A3) rain water path, (A4) snow water path at observation location.

Results: Surface Emissivity

Systematic differences are observed in emissivity from FASTEM-5 between CRTM and RTTOV:

- Distinct variations between left and right side of each orbit (Fig. B1)
- Vary as a function of latitude; higher in polar areas. (Fig. B1)
- Cause up to 3K differences in brightness temperatures. (Fig. B2)

- Salinity in RTTOV is set to 33 ppt (default is zero), same as CRTM
- Large differences in higher latitudes disappear, but distinct variations between left and right side of each orbit still remain. (Figs. C1,C2)
- Discrepancies are found in regression coefficients for FASTEM-5 between CRTM and RTTOV. Some coefficients are not taken correctly in CRTM.



Figs. B and C Differences between RTTOV and CRTM (RTTOV-CRTM) for (B1) surface emissivity and (B2) brightness temperature when salinity in RTTOV and CRTM are set to different values. Differences between RTTOV and CRTM (RTTOV-CRTM) for (C1) surface emissivity and (C2) brightness temperature when salinity in RTTOV and CRTM set set to the same value (33 PPT).

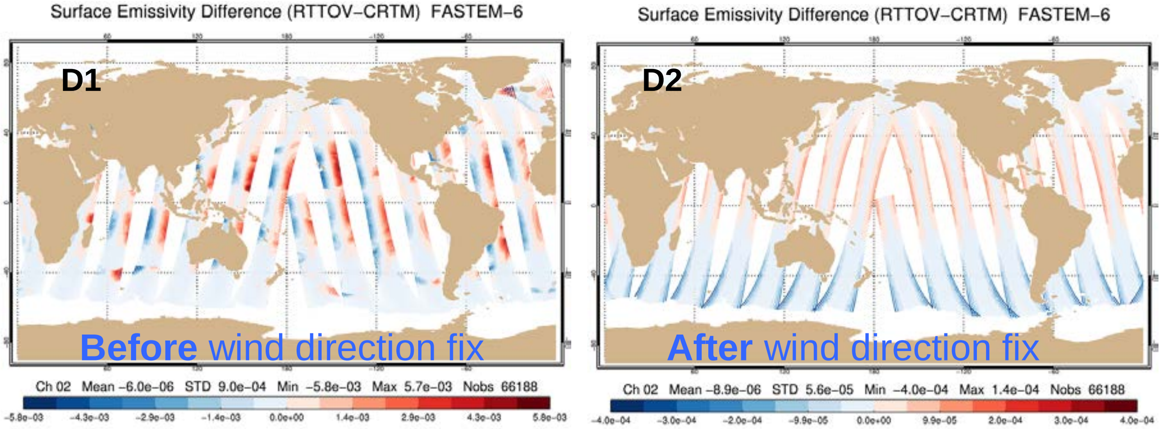


Fig. D Differences in surface emissivity between RTTOV and CRTM (RTTOV-CRTM) before (D1) and after (D2) wind direction fix.

In comparison of surface emissivity from FASTEM-6, paches of difference in emissivity can be observed, causing up to 3K differences in brightness temperature (Fig. D1). This is caused by the incorrect wind direction assignment in GSIin that westerly and easterly winds are assigned to have same angle. Correction has been made to follow Kazumoi (2015).

Results: Brightness Temperature (BT) and Optical Depth (OD)

The brightness temperature differences between RTTOV and CRTM under clear-sky condition are investigated. Fastem-6 is used in both RT models. Calculated channel 1 (channel 2) BTs from RTTOV are systematically warmer (colder) than CERM (Figs. E1 and E3). The differences in brightness temperature can be explained by the differences in total optical depth (for absorption dominant channels). The differences in optical depth most likely come from those in regression coefficients for water vapor and oxygen between CRTM and RTTOV. The are large enough to cause BT differences up up 3K at some spots (Figs. E1-E4).

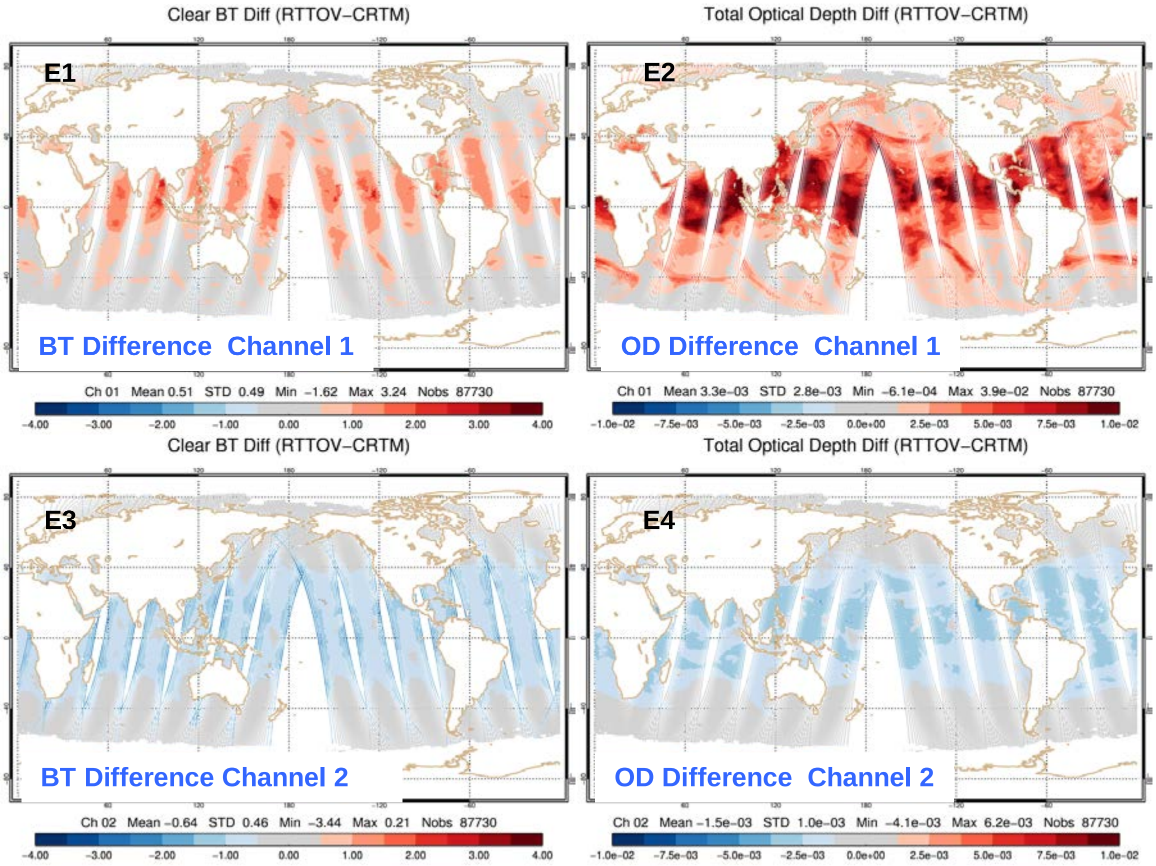


Fig. E Differences between RTTOV and CRTM for (E1) clear-sky brightness temperature, (E2) total optical depth for AMSU-A channel1, and for (E3) clear-sky brightness temperature, (E4) total optical depth for AMSU-A channel 2.

Results: Multiple-scattering for Clouds and Precipitation

The simulated brightness temperature from CRTM under rainy and snowy condition are investigated and compared with RTTOV. The Advanced Doubling –Adding (ADA) scheme is implemented in CRTM to solve radiative transfer equation under scattering condition, while the Delta-Eddington approximation (two-steam approach) is used in RTTOV. The main differences between CRTM and RTTOV are summarized in Table 1.

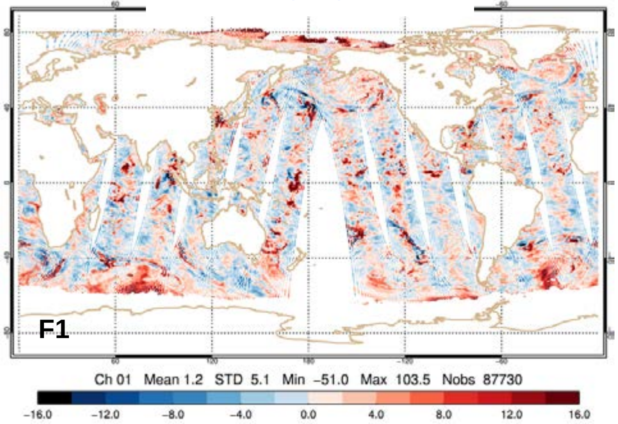
Table 1

	CRTM	**RTTOV (RTTOV-SCATT)**
Algorithm	Advanced Doubling-Adding (ADA) Use Gaussian quadrature to calculate radiative transfer for specific up-welling and down-welling zenith directions (Liu and Weng, 2006)	Delta-Eddington Approximation Approximate the radiance vector and phase function to the first order so that only the viewing/satellite zenith angle is needed (Bauer, 2002)
Scattering Properties	▪ Legendre polynomial expansion of the scattering phase function ▪ Pre-calculated lookup table: Mie theory for spherical particle DDA for non-spherical particle (underway) ▪ Function of frequency, temperature, hydrometeor type, density, effective radius	▪ Approximate phase function to the first order in viewing direction ▪ Pre-calculated lookup table: Mie theory for spherical particle and DDA for non-spherical particle (snow) ▪ Function of frequency, temperature, hydrometeor type, density
Cloud Types	water, ice, rain, snow, graupel, and hail	water, ice rain and snow
Cloud Cover	No handling yet (underway)	Cloud fraction profiles
Surface	FASTEM-6 without reflection correction	FASTEM-6 with reflection correction

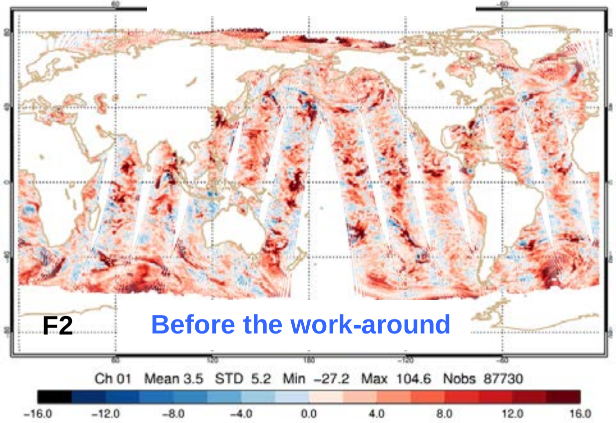
The calculated CRTM brightness temperatures have systematic biases for surface sensitive channels (1-5, and 15) at locations where ADA solver is involved. Channel 1 statistics are shown in Figure F. In is found that the off-diagonal terms of the surface reflectivity matrix are zero so that there is no diffuse radiation being reflected towards the viewing direction. A work-around to fix the problem found in surface reflectivity matrix is developed:

- Reflection correction is included in conjunction with ADA solver and the correction is only applied to stream angles less than 60°.
- Stream angles > 60° are taken as 60° in FASTEM-6 when multiple scattering is on.

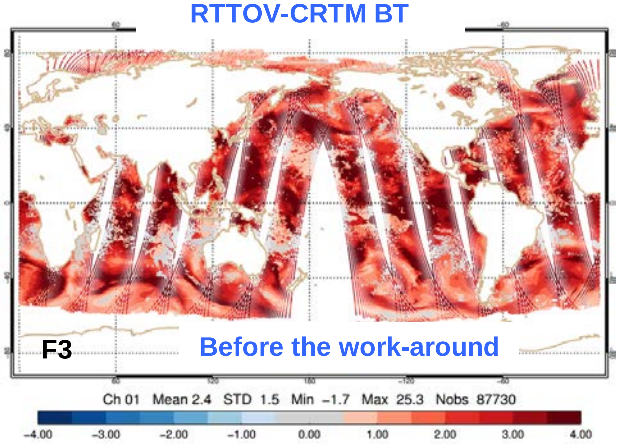
The resulting CRTM brightness temperature with the work-around are comparable with RTTOV (Figs 1 and 4). This work-around will be included in the next release of CRTM.


RTTOV OmF

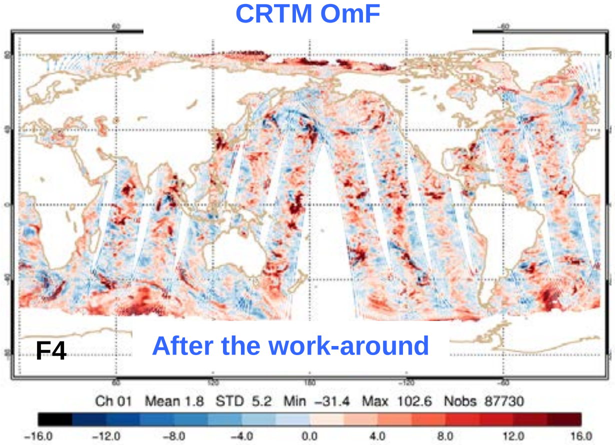
F1


CRTM OmF

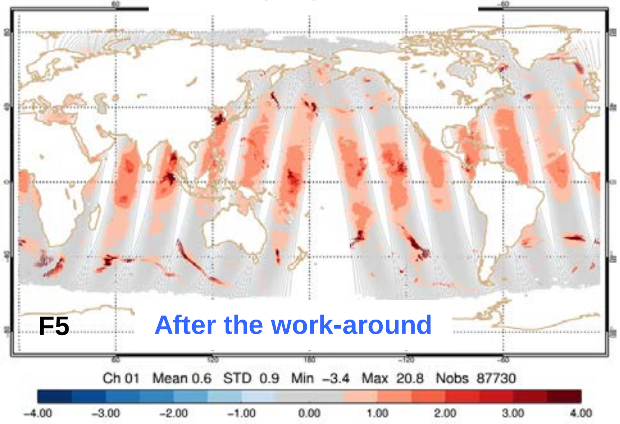
F2 **Before the work-around**


RTTOV-CRTM BT

F3 **Before the work-around**


CRTM OmF

F4 **After the work-around**


RTTOV-CRTM BT

F5 **After the work-around**

Fig. F The Comparison of observed and calculated brightness temperatures from RTTOV (F1), and from CRTM before the work-around (F2), and from CRTM after the work-around (F3). The differences in calculated brightness temperatures between CRTM and RTTOV before (F3) and after (F5) the work-around.

Results: Comparing Jacobians

Jacobians from profiles with non-precipitating clods are compared. The responses of temperature Jacobians are similar for optically thin clouds (Fig. G1), whereas the opposite responses are found for optically thick clouds (Fig. G2). From a simplified MW RT equation, sensitivity of brightness temperature to temperature is related to the sensitivity of extinction coefficient to temperature. There is a need to investigate the difference in hydrometeor extinction between the two RT models to explain the difference in Jacobians between RTTOV and CRTM.

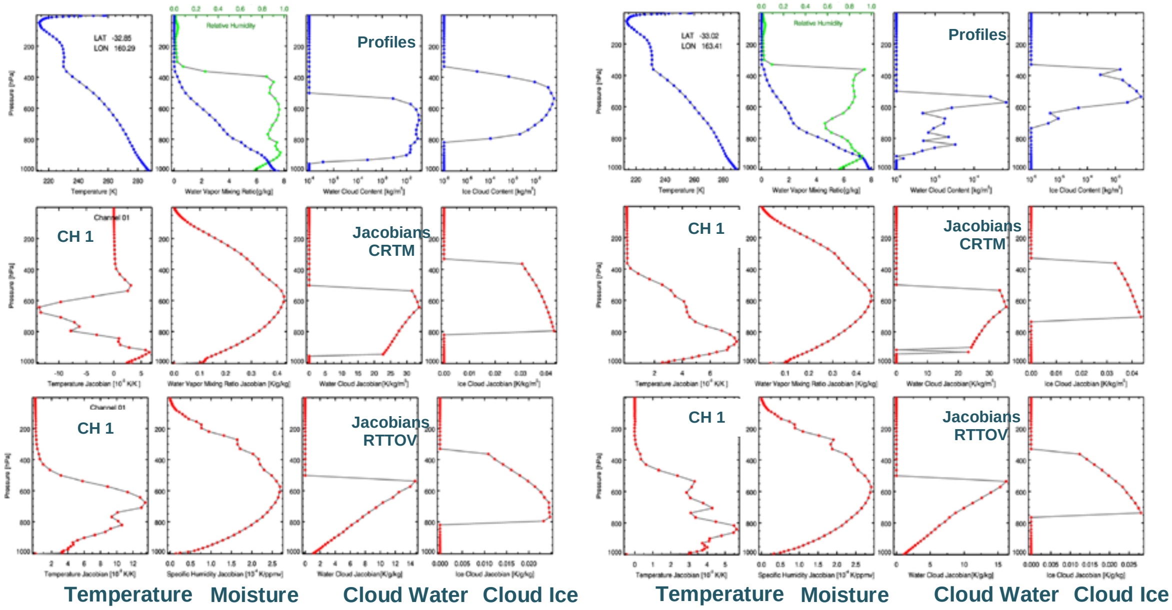
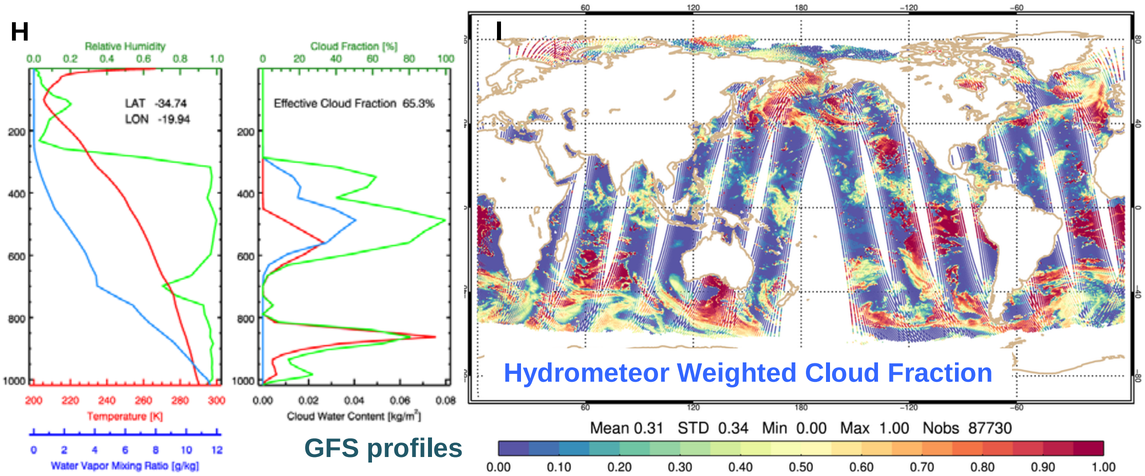


Figure G Jacobian comparison between CRTM and RTTOV for optically thin (left panel) and optically thick (right panel) clouds.

Results: Does Cloud Fraction (CF) Matter?

To evaluate the impact of cloud fraction on simulated brightness temperature, RTTOV and the GFS diagnosed cloud fraction are used in the investigation to answer the question. GFS cloud fraction profiles is diagnosed as a function of temperature and relative humidity (Randal and Xu 1996; Fig. H). The corresponding hydrometeor weighted cloud fraction is used in RTTOV for clouds (Geer & Bauer 2009; Fig. I).

Two experiments are compared: BT from 100% cloud cover (overcast) versus hydrometeor weighted cloud fraction (cloud cover) for cloudy scenes. Impacts of cloud fraction are within 0.1K for optically thin clouds and increase drastically for optically thick clouds (Figs. J1 and J2). The impact of non-precipitating clouds is small. Therefore, it is justifiable to assimilate non-precipitating cloud affected AMSU-A radiances without considering cloud fraction. The BT differences can be as large as 30K and more in rainy and snowy regions. To prepare for the assimilation of precipitation-affected radiances, the capability of handling cloud fraction in CRTM is in the pipe line for the next release.



Figs. H and I: GFS profiles (H) and the corresponding hydrometeor weighted cloud fraction (G).

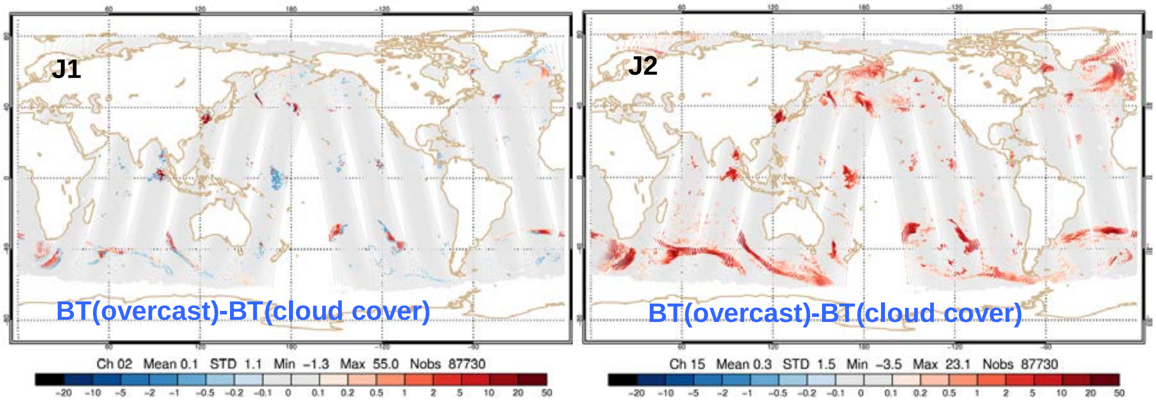


Fig. J Differences between brightness temperature calculated with and without considering cloud cover for channel 1 (J1) and channel 15 (J2).

Future Work Plan

The work plan is summarized as follows:

- Extent the BT and Jacobians comparison to MW instruments, such as SSMIS, ATMS, MHS with higher frequency channels.
- Perform cross validation of IR instruments for both clear and cloudy calculations.
- Investigate differences in hydrometeor optical properties between CRTM and RTTOV
- Investigate the sensitivity of RT solutions to the hydrometeor size distribution and habit.
- Work with CRTM team to assess the impact of cloud fraction on simulated BTs and data assimilation.
- Work with CRTM team to test the use of bi-directional reflectance distribution function (BRDF) at surface for MW.
- Discuss with the modeling group possibilities for better prediction of sea ice, cloud fraction, hydrometeor types and cloud microphysics parameters (e.g. size distribution).

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