Inter-comparison of CRTM and RTTOV in NCEP Global Model

Emily H. C. Liu[1], Andrew Collard[2], Ruiyu Sun[2], Yanqiu Zhu[2], Paul van Delst[2], Dave Groff[2], John Derber[3]

[1]SRG@NOAA/NCEP/EMC [2]IMSG@NOAA/NCEP/EMC [3]NOAA/NCEP/EMC

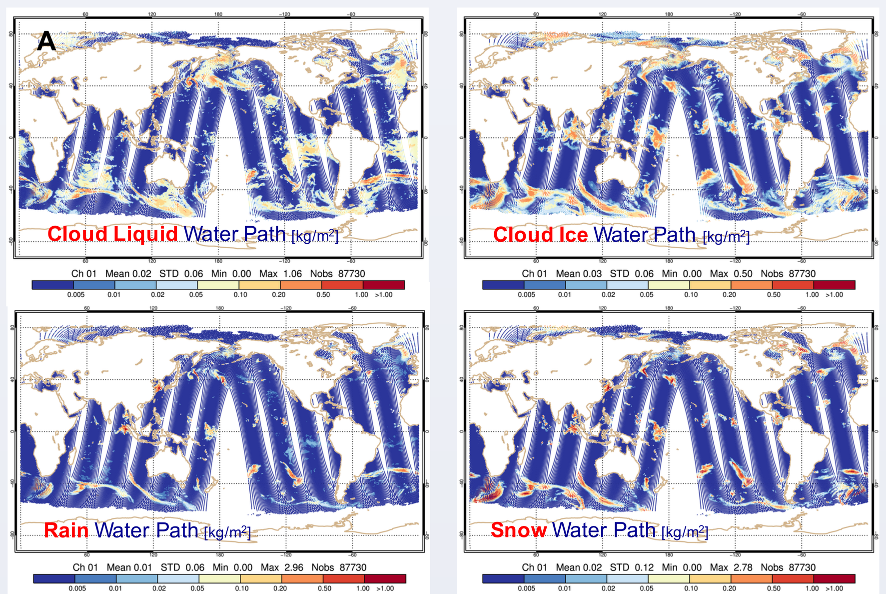
Objectives and Information

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

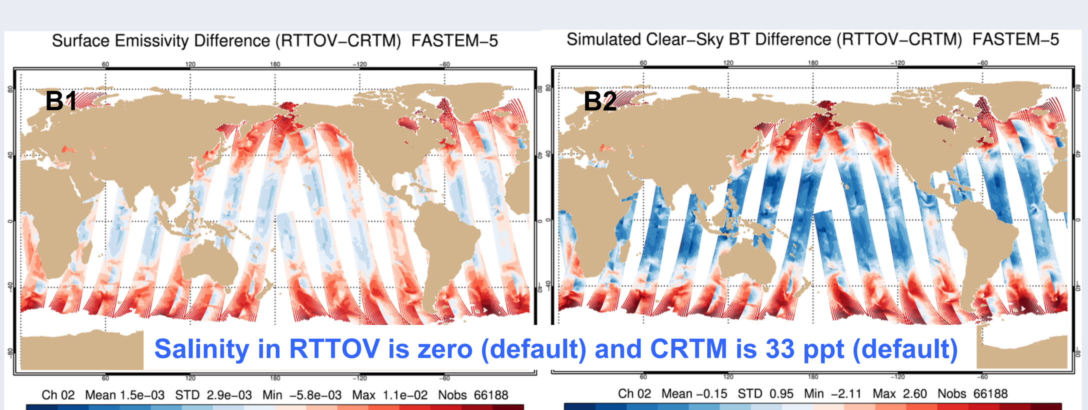
- To have a more consistent and flexible way in comparing radiative transfer models (RTMs) by using the same model input
- To better understand differences in optical properties, radiances, and Jacobians between the two
- To help in spotting errors by cross validating each other
- To establish symbiotic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

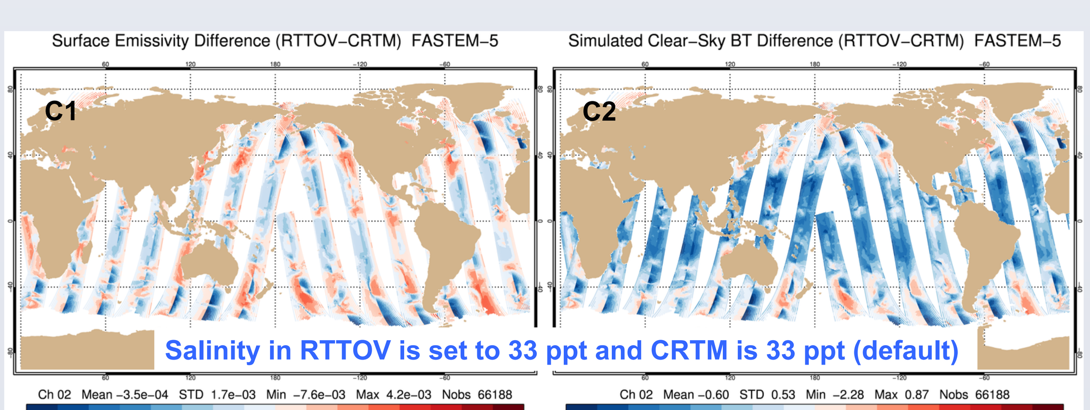


Validation for Surface Emissivity



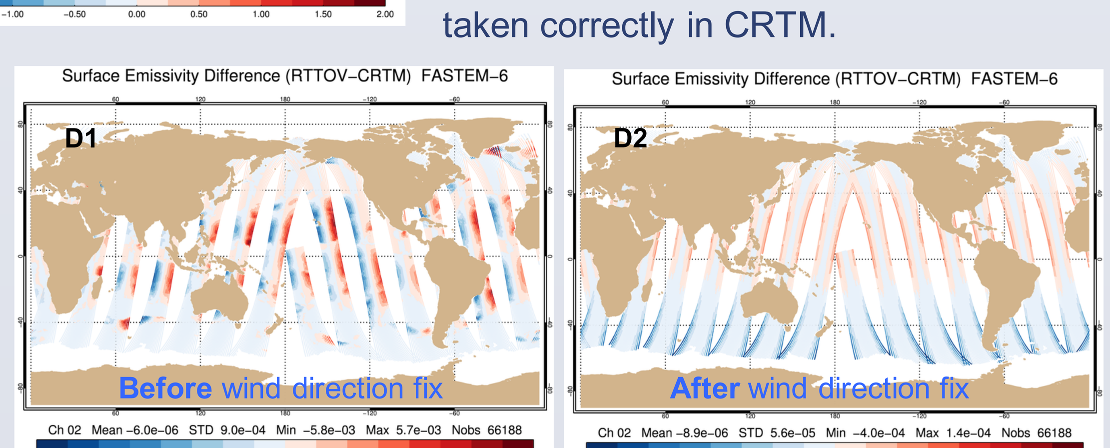
Systematic differences are observed in emissivity from **FASTEM-5** between CRTM and RTTOV:

- 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)



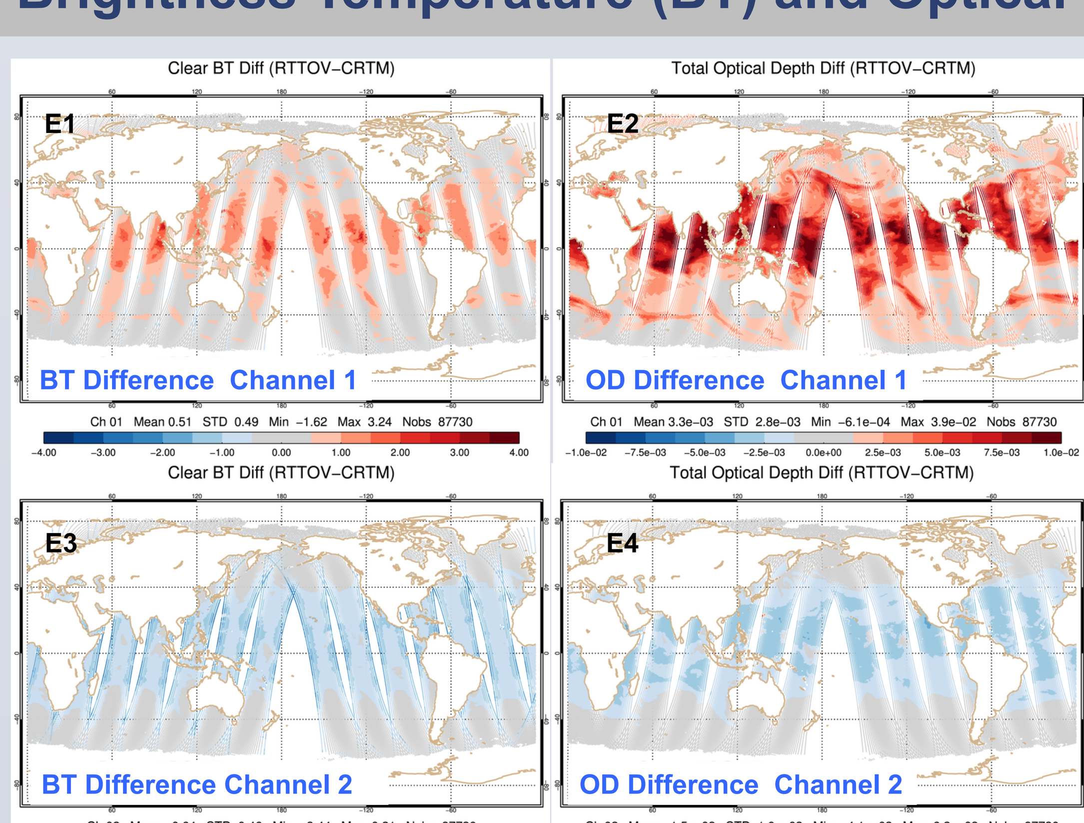
- **Salinity** in RTTOV is set to 33 ppt (default is zero), same as CRTM
- Large differences in higher latitudes disappear, but distinct variations between left and right side of each orbit still remain. (Figs. C1,C2)
- Discrepancies are found in regression coefficients for FASTEM-5 between CRTM and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

- **FASTEM-6** coefficients used in CRTM and RTTOV are identical.
- However, patches 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 GSI** in that westerly and easterly winds are assigned to have same angle. Correction has been made to follow Kazumori (2015).



- After correction for wind direction, the remaining differences in emissivity are small and they can be explained by differences in central frequency and in calculating the instrument viewing angle between CRTM and RTTOV (Fig. D2).

Brightness Temperature (BT) and Optical Depth (OD)

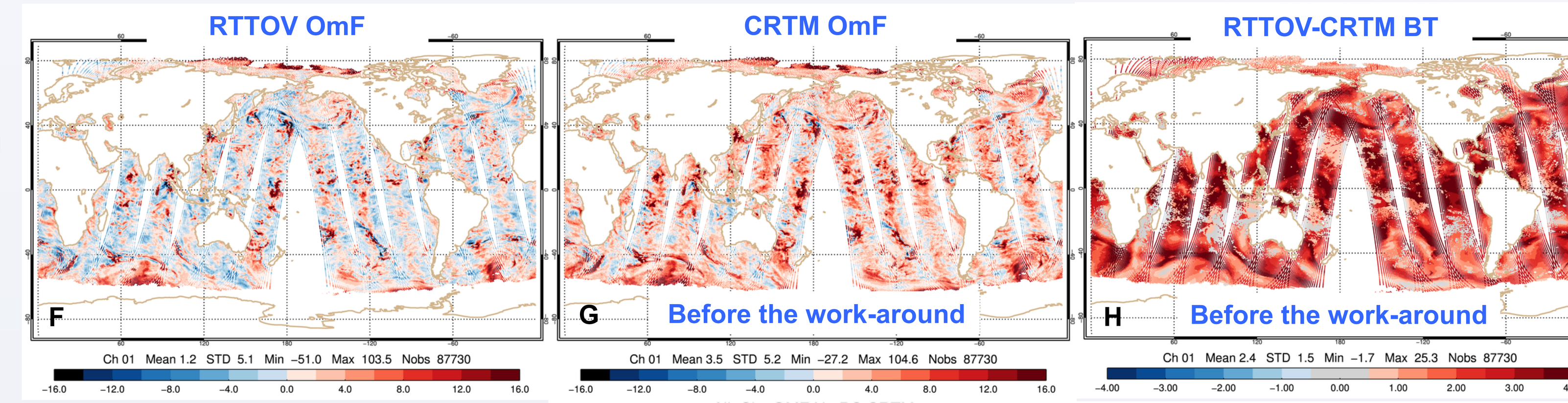


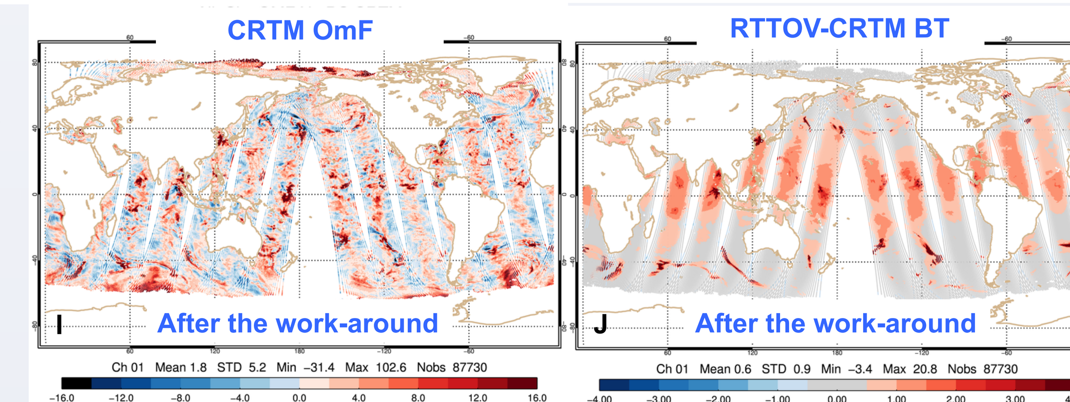
- Brightness temperature differences between RTTOV and CRTM under clear-sky condition are investigated.
- Fastem-6 is used in both RTMs.
- Calculated channel 1 (channel 2) BTs from RTTOV are systematically warmer (colder) than CRTM (Figs. E1,E3).
- The differences in brightness temperature can be explained 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. They are large enough to cause BT differences up to 3K at some spots (Figs. E1-E4).

Validation of Multiple-scattering for Clouds & Precipitation

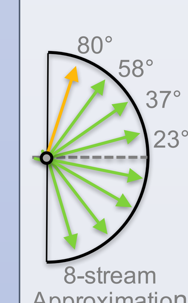
	CRTM	RTTOV (RTTOV-SCATT)
Algorithm	**Advanced Doubling-Adding (ADA) Scheme** Use Gaussian quadrature to calculate radiative transfer for specific up-welling and down-welling zenith directions (Liu and Weng, 2006)	**Delta-Eddington Approximation** Approximate the radiance vector and phase function to 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 ▪ 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	Cloud fraction profiles
Surface	FASTEM-6 without reflection correction	FASTEM-6 with reflection correction

Multiple Scattering RTTOV vs. CRTM



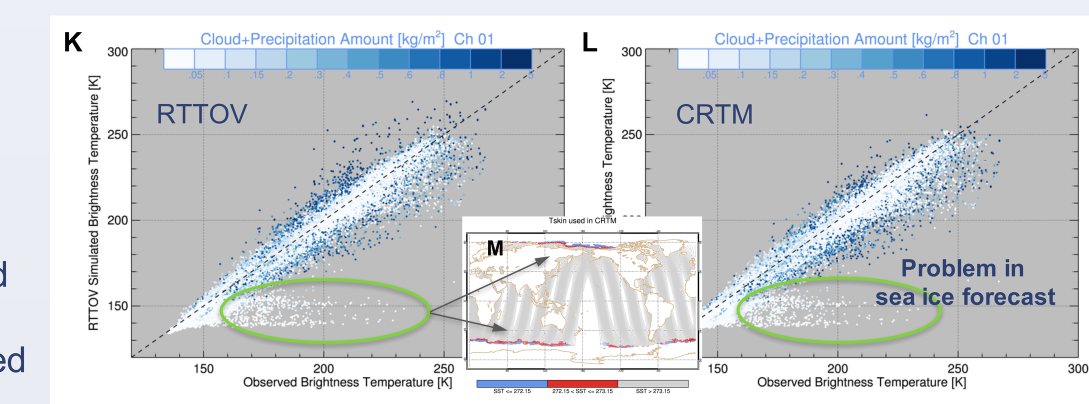


- The calculated CRTM BTs have systematic biases for surface sensitive channels (1-5, and 15) at locations where ADA solver is involved; channel 1 statistics are shown here to illustrate the biases (Figs. F,G,H).
- It is found that the off-diagonal terms of the surface reflectivity matrix is zero so that there is no diffuse radiation being reflected towards the viewing direction.
- The **work-around** - owing to the lack of proper surface reflectivity matrix for multiple-scattering radiative transfer, a work-around has been developed to reduce the bias:



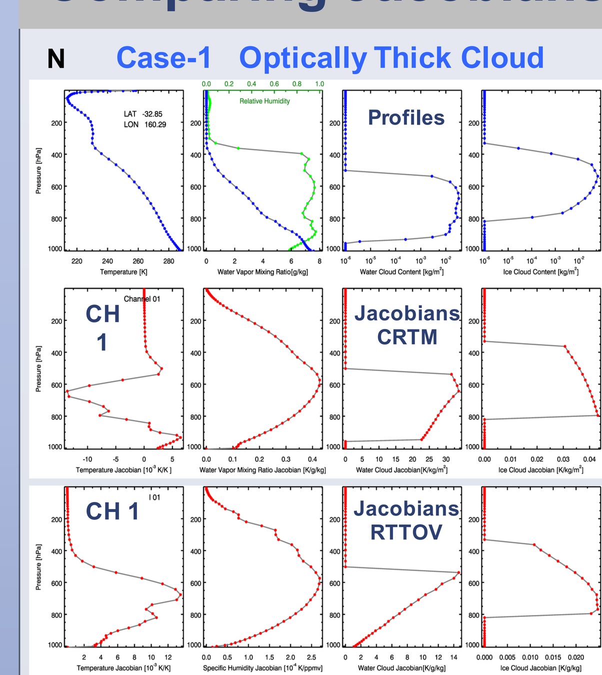
- Reflection correction is included in conjunction with ADA solver and the correction is only applied to stream angles less than 60°.
- Stream angles > 60° are taken as 60° in FASTEM-6 when multiple scattering is on.

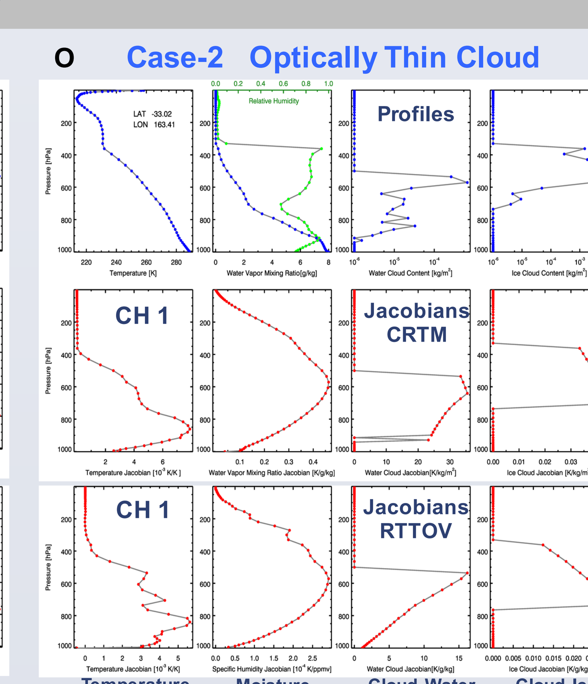
- The resulting CRTM BTs with the work-around are comparable to RTTOV BTs for non-precipitating regions (differences can be explained by those in OD (Figs. J,E).



- Larger BT differences between CRTM and RTTOV found in precipitating regions are likely due to discrepancies in approximations for cloud optical properties (Figs. J,K,L).
- Outliners in the scatter plots are associated with the scenes containing sea ice (higher emissivity) in the observations and only sea water (lower emissivity) in the forecast (Figs. K,L,M).

Comparing Jacobians



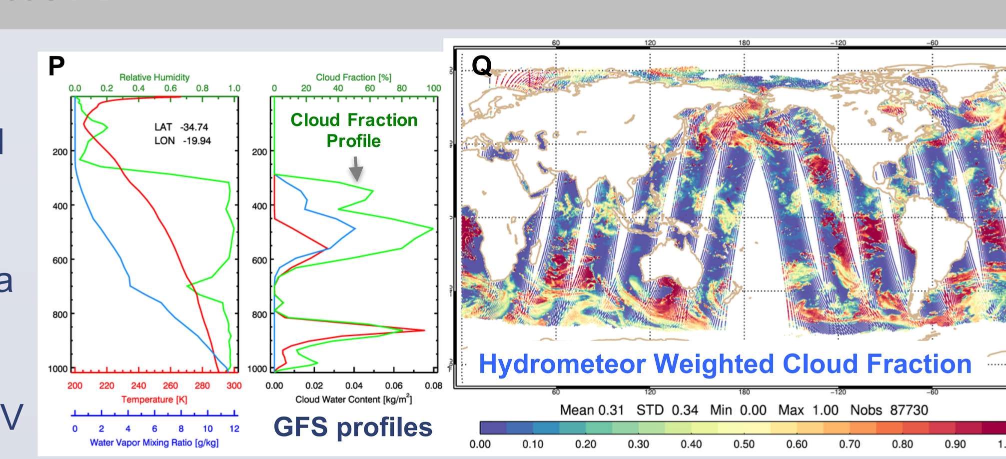


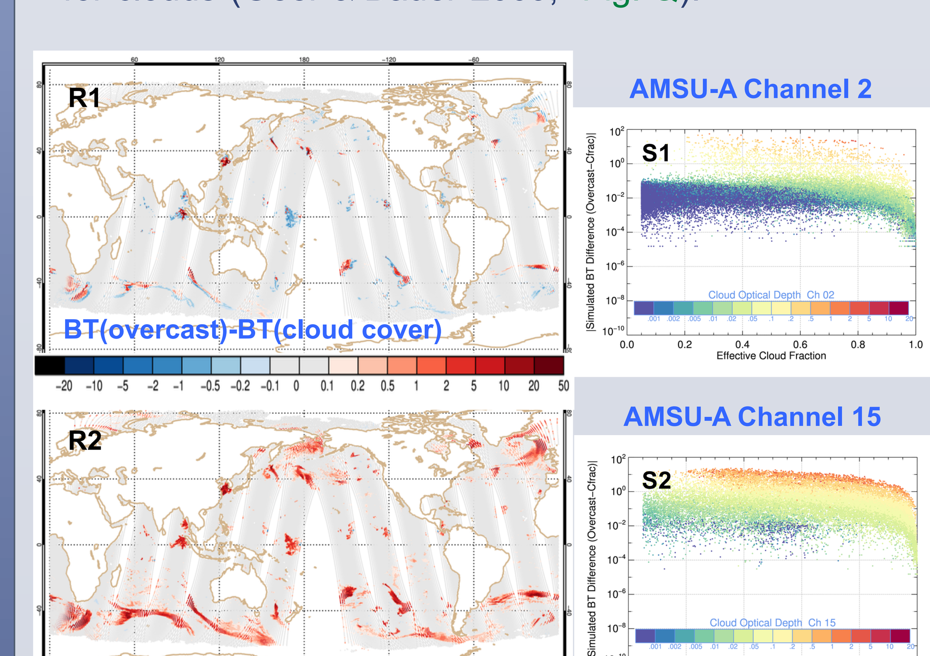
- Jacobians from profiles with non-precipitating clouds are compared.
- The responses of temperature Jacobians are similar for optically thin clouds (Fig. O), whereas the opposite responses are found for optically thick clouds (Fig. N).
- From a simplified MW RTE, sensitivity of BT to temperature is related to that of absorption coefficient to temperature.
- Need to investigate the difference in absorption between the two RTMs.

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 profile** is diagnosed as a function of temperature and relative humidity (Randal and Xu 1996; Fig. P).
- **Hydrometeor weighted CF** is used in RTTOV for clouds (Geer & Bauer 2009; Fig. Q).





- Two experiments are compared: BTs from 100% cloud cover (overcast) vs. 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. S1,S2).
- The impact for non-precipitating clouds is small; it is justifiable to assimilate non-precipitating cloud affected AMSU-A radiances without considering cloud fraction (Session 7 poster by Yanqiu Zhu).
- BT differences can be as large as 50K and more in rainy and snowy regions (Figs. R1,R2).
- 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 (Session 5, Paul van Delst).

Work Plan

- For all cross-comparisons between CRTM and RTTOV, investigate to understand and explain the differences.
- MW Jacobian comparison for precipitating clouds
- BT and Jacobians comparison for more MW instruments (SSMIS, ATMS, MHS)
- Perform cross validation of IR instruments for both clear and cloudy calculations.
- Experiment with the Discrete Dipole Approximation (DDA) in RTTOV and compare with Mie approach (Geer and Baordo, 2014).
- Work with CRTM team to assess the impact of cloud fraction on simulated BTs and data assimilation.
- Work with CRTM team to explore the development of an emissivity model when performing multi-stream calculations.
- Discuss with the modeling group possibilities for better prediction of sea ice, cloud fraction, hydrometeor types and cloud microphysics parameters (e.g. size distribution).

References

- **Bauer, P.**, 2002: Microwave radiative transfer modeling in clouds and precipitation. Part I: Model description. NWP SAF Rep. NWPSAF-EC-TR-005, 27 pp.
- **Deblonde, G., and S. J. English**, 2000: Evaluation of the FASTEM-2 microwave oceanic surface emissivity model. Proc. Int. TOVS Study Conf., Budapest, Hungry
- **Geer, A., Bauer P., O'Dell C.**, 2009: A revised cloud overlap scheme for fast microwave radiative transfer in rain and cloud. J. Appl. Meteor. Climatol., 48, 2257-2270
- **Geer A., F. Baordo**, 2014: "Improved scattering radiative transfer for frozen hydrometeors at microwave frequencies", Atmos. Meas. Tech. Discuss. 1749-1805
- **Kazumori, M. and S.J. English**, 2015: Use of the ocean surface wind direction signal in microwave radiance assimilation, Q.J.Royal Met. Soc., vol. 141, No. 689
- **Liu, Q., and F. Weng**, 2006: advanced doubling-adding method for radiative transfer in planetary atmosphere. J. Atmos, Sci., 63, 3459-3465
- **Xu, K. M., and D. A. Randall**, 1996: A semi-empirical cloudiness parameterization for use in climate models. J. Atmos., Sci., 53, 3084-3102