Modifying CRTM with Microphysics-Consistent Cloud Optical Properties for All-Sky Microwave Satellite Radiances

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Introduction

The ***Community Radiative Transfer Model (CRTM;*** Han et al. 2006) is a product of the Joint Center for Satellite Data Assimilation (JCSDA). Users specify cloud and precipitation by position, species, water path, and effective radius. Cloud absorption and scattering properties are in lookup tables and based on calculations for homogeneous spherical particles.

The radiative transfer community defines effective radius as the ratio of the third and second moment of the particle size distribution (PSD). Hansen and Travis (1974) derive this by assuming geometric optics. But scattering of microwave by cloud and precipitation is Rayleigh or Mie scattering. Consequently, effective radius can fail to describe different PSDs which have the same microwave scattering.

Effective Radius (microns)	Water Content (g m^{-3})	Monodisperse: Scattering Optical Depth	Monodisperse: Brightness Temperature (K)	Exponential ($N_0 = 4 \times 10^6$): Scattering Optical Depth	Exponential ($N_0 = 4 \times 10^6$): Brightness Temperature (K)
0	0	0	276.18	0	276.18
103.7	1.15×10^{-4}	4.03×10^{-6}	272.96	1.74×10^{-5}	272.96
184.3	1.15×10^{-3}	2.24×10^{-4}	272.91	8.79×10^{-4}	272.79
327.8	1.15×10^{-2}	1.21×10^{-2}	270.57	3.49×10^{-2}	267.94
582.9	1.15×10^{-1}	5.54×10^{-1}	204.09	$1.00 \times 10^{+0}$	200.35
1037	$1.15 \times 10^{+0}$	$1.16 \times 10^{+1}$	75.57	$2.05 \times 10^{+1}$	74.74

Table 1. Scattering optical depths and brightness temperature output of CRTM simulations with the same water content, effective radius, and particle properties but with different particle size distributions. The CRTM is configured to simulate the 91.665 GHz horizontal polarization channel of the SSMIS aboard satellite DMSP-16. The particle used is an ice sphere of bulk density 500 kg m^{-3} at 91.665 GHz.

The PSDs of the CRTM cloud optical property lookup table are not documented to users, but WRF microphysics schemes can differ in assumed PSDs, in which case it must not be consistent with all. There are other known inconsistencies with microphysics schemes, including the bulk density of graupel (400 vs 500 kg m^{-3} in WSM6/WDM6), and assuming all ice cloud particles have effective radius of just 5 µm. We explore the impacts of these inconsistencies on simulated T_B fields of a tropical cyclone in WRF.

Modifying the CRTM ("CRTM-DS")

Particle Properties

- Mie theory, spheres of radius 1 µm to 10 cm
  - All species of studied MP schemes have spherical particle mass-size relationship
  - Scattering phase functions exactly described by Mie theory
- Maxwell-Garnett mixing formula for different ice bulk densities
- Turner et al (2016) supercooled liquid dielectric constants

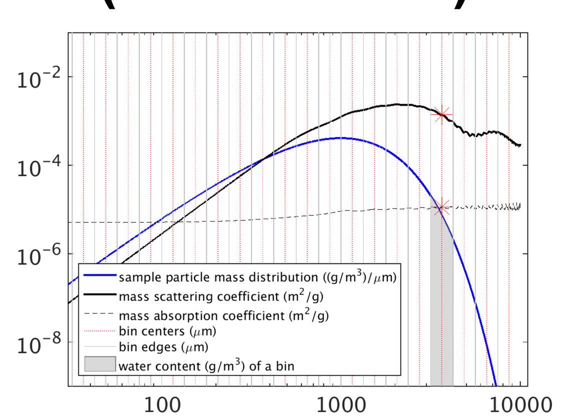


Figure 1. Sample relationship of mass scattering coefficients, mass absorption coefficients, and particle mass distribution, and demonstrating principle of integration.

Particle Size Distributions

- WSM6, Goddard and Morrison microphysics schemes
- Build space of parameters defining PSDs and particle properties
- CRTM-DS: integrate from 1 µm to 10 cm product of PSD and scattering/absorption cross-section

Why the CRTM?

- User community is focused on data assimilation
- Tangent linear, adjoint, K-matrix
- ADA and SOI solvers: many streams beneficial for high scattering profiles

CRTM Simulation Results

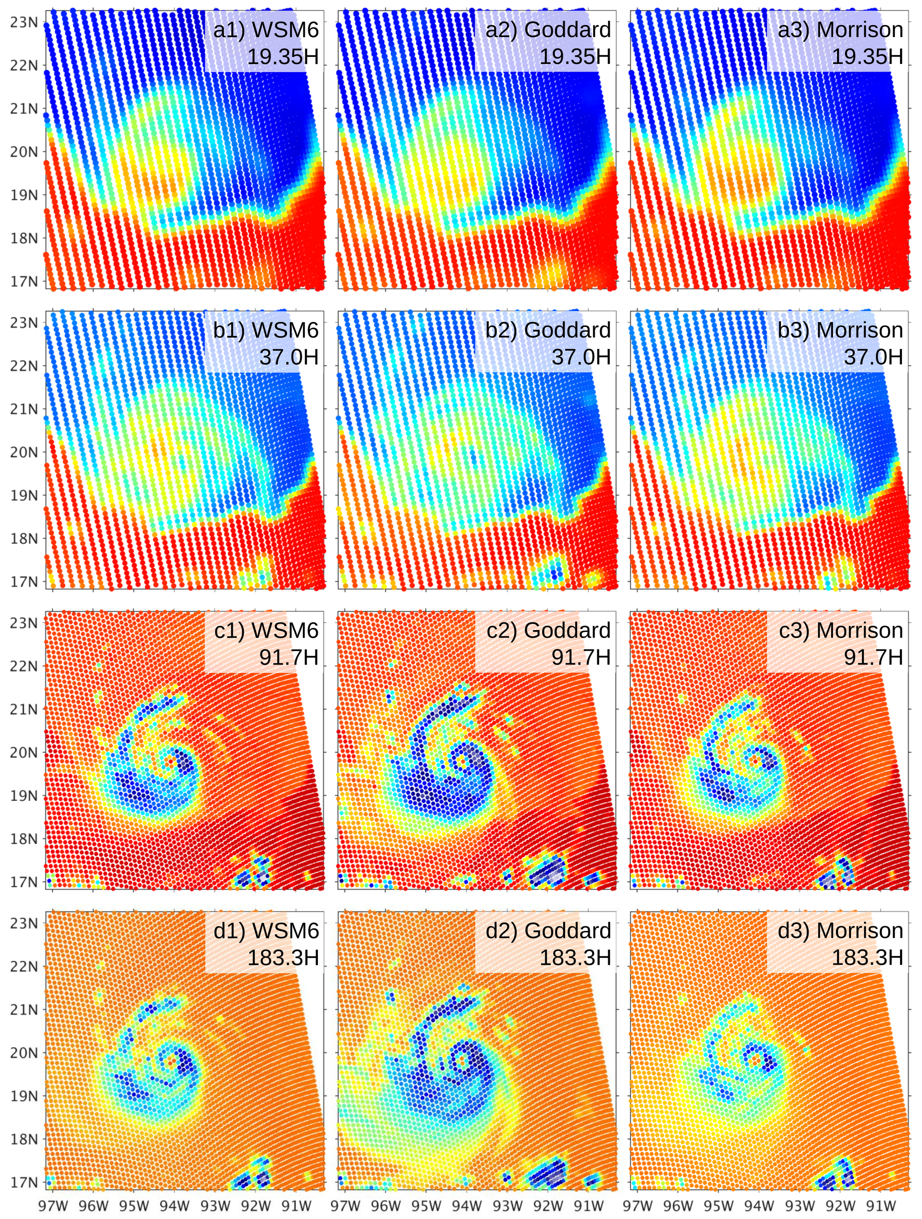


Figure 2. Brightness temperatures from CRTM-DS (microphysics-consistent cloud optical properties) from 3-hour WRF forecasts of Hurricane Karl using different microphysics schemes.

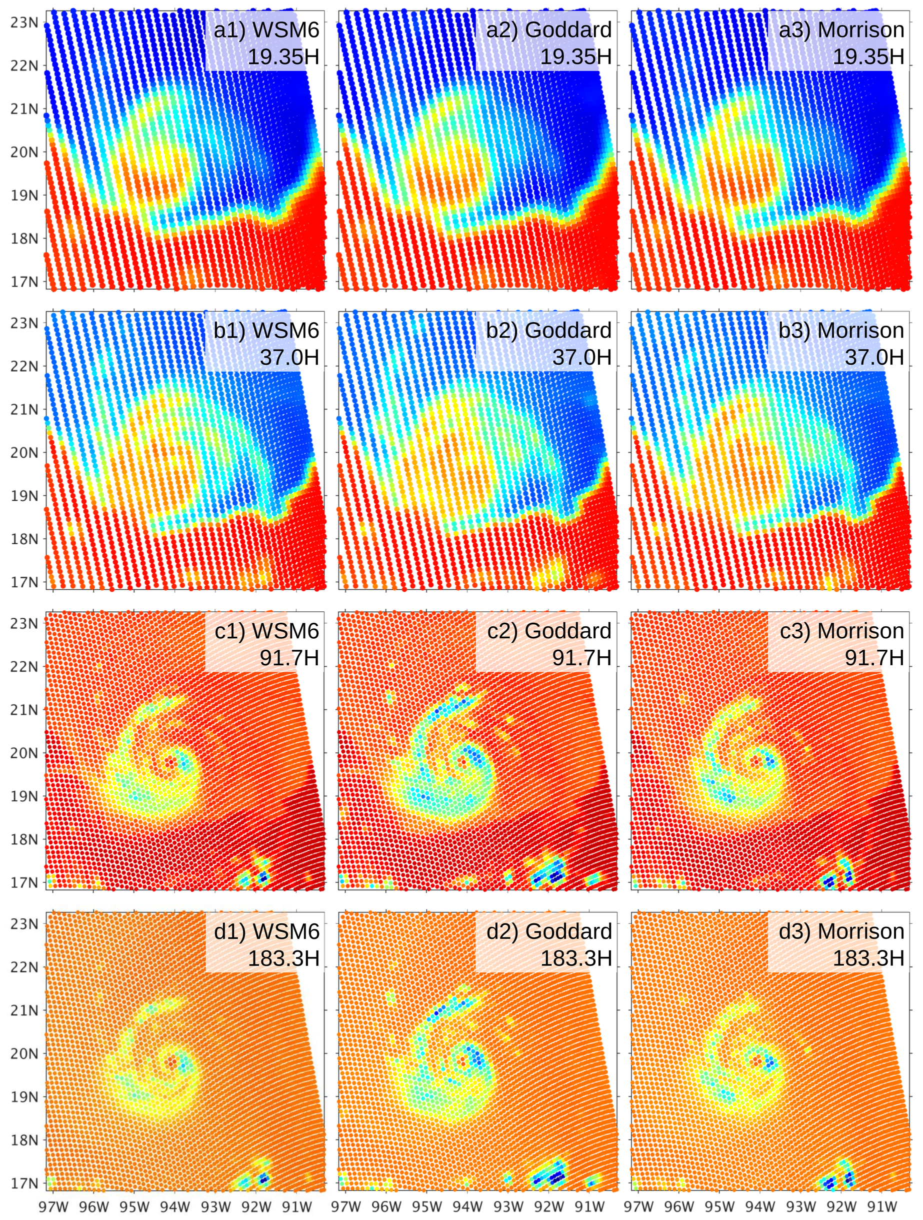


Figure 3. Same as Figure 2 but using CRTM-RE (as-released). Effective radii are ratio of third and second moment of microphysics-specified particle size distributions.

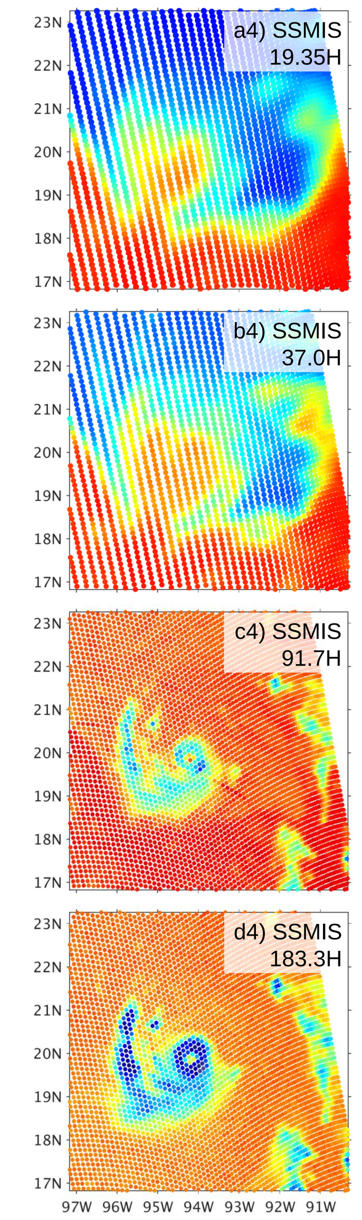
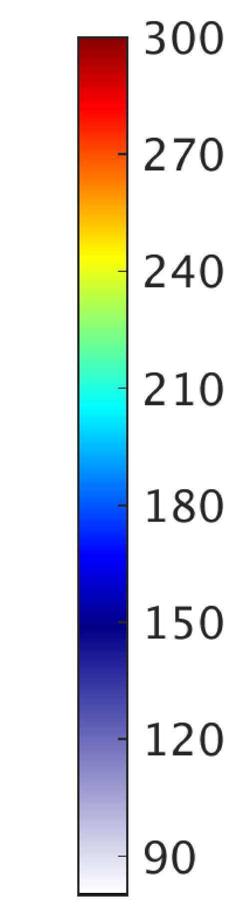


Figure 4. SSMIS pass over Hurricane Karl at 0117 UTC 17 September.



Brightness Temperature (K)

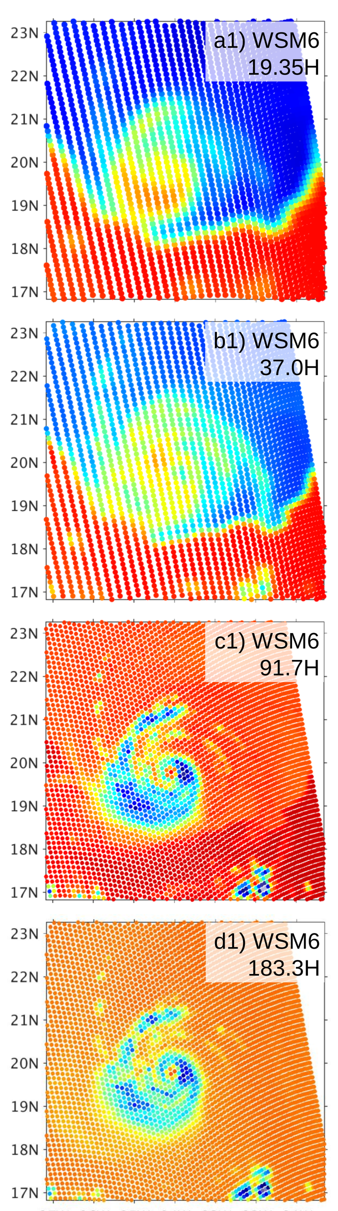


Figure 5. CRTM-DS WSM6 except with 400 kg m^{-3} bulk density for graupel.

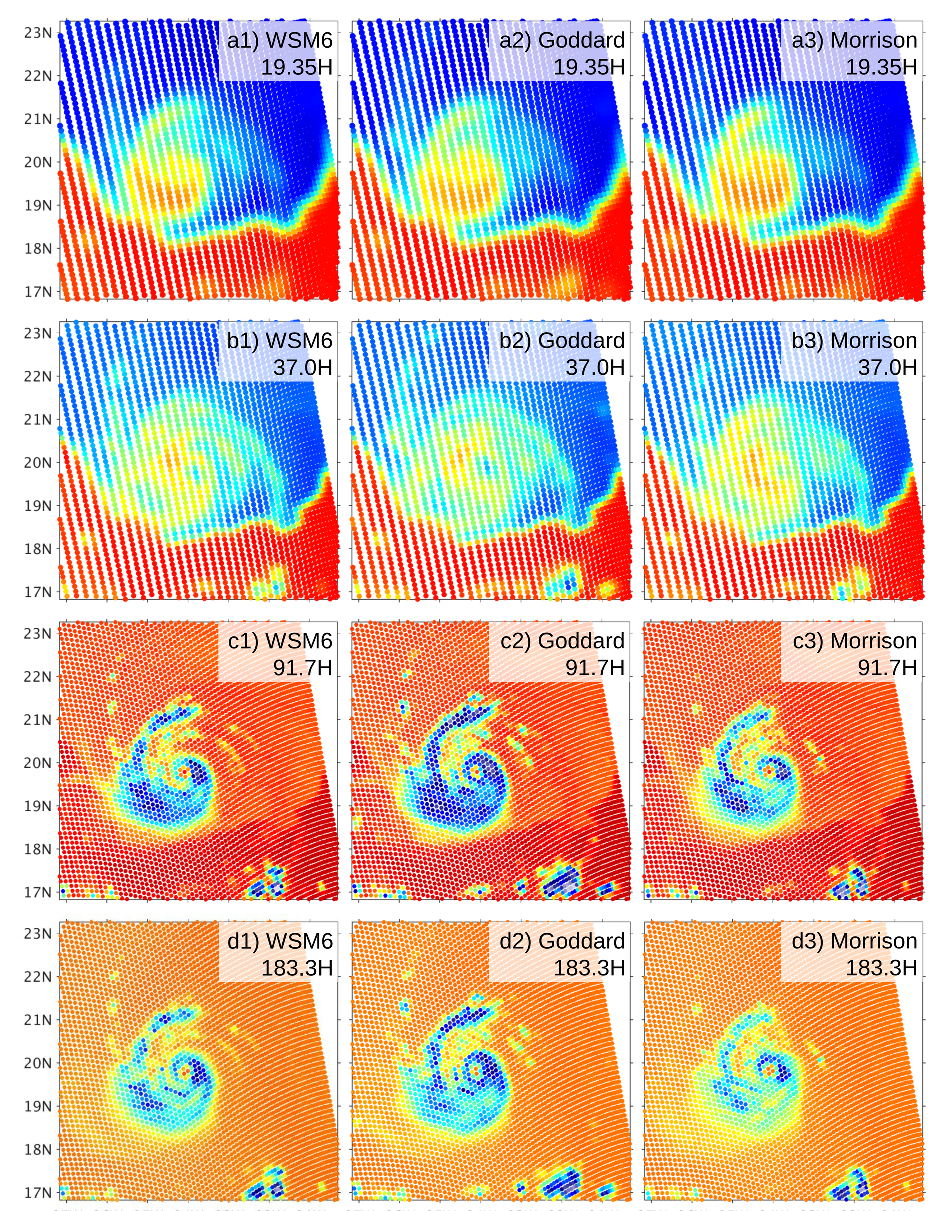


Figure 6. Same as Figure 2 but CRTM-DS ice cloud lookup table is modified to be monodisperse 5 µm radius 900 kg m^{-3} bulk density. (CRTM-DS 5CI)

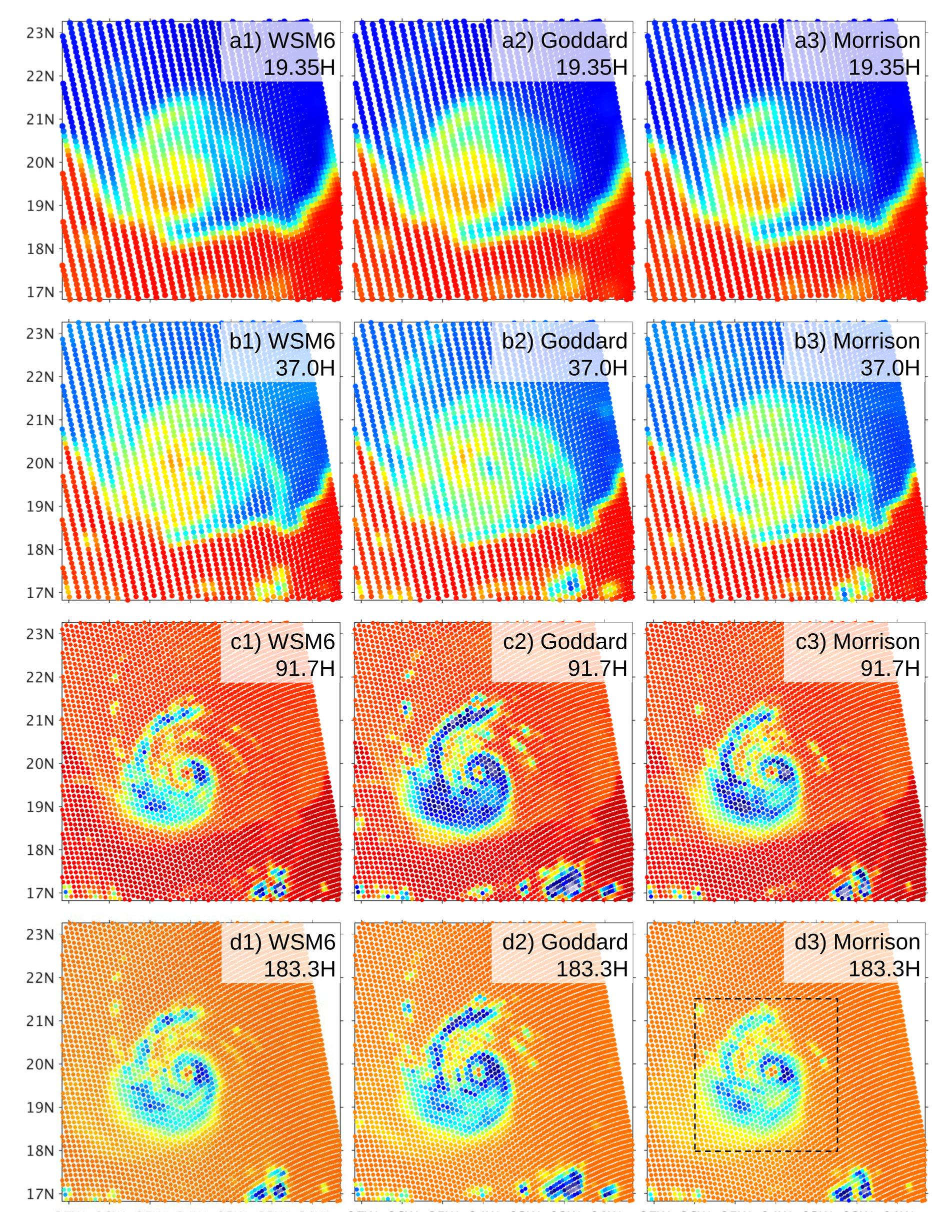


Figure 7. Same as Figure 2 but with a CRTM-DS lookup table that is Goddard liquid cloud, rain, snow, graupel, and WSM6 ice cloud. This lookup table is applied to all microphysics schemes (CRTM-Hybrid).

Statistics below are calculated within the area enclosed by 18°N and 21.5°N, 96°W and 92.5°W.

Frequency (GHz) & Polarization	WSM6 RE	WSM6 Hybrid	WSM6 DS-5CI	WSM6 DS	WSM6 DS 400Gp	Goddard RE	Goddard Hybrid	Goddard DS-5CI	Goddard DS	Morrison RE	Morrison Hybrid	Morrison DS-5CI	Morrison DS
19.35 H	-2.3	-2.5	-2.7	-2.7	-2.6	0.3	-1.0	-1.0	-3.5	0.2	-5.1	-1.4	-1.4
37 H	0.1	-6.2	-7.0	-7.0	-6.2	0.3	-9.6	-9.6	-13.3	-0.8	-9.5	-7.3	-7.3
91.655 H	4.7	-11.4	-12.9	-13.0	-10.5	-2.1	-22.5	-22.4	-28.5	3.8	-12.3	-10.3	-10.5
183.31 +/- 6.6 H	18.2	4.1	2.9	2.3	4.3	12.8	-3.4	-3.3	-15.3	17.0	3.9	5.4	3.8

Table 2. Average error of CRTM simulated brightness temperature (Kelvin) to observed brightness temperature by DMSP-16 SSMIS.

Frequency (GHz) & Polarization	WSM6 and Goddard RE	WSM6 and Goddard Hybrid	WSM6 and Goddard DS-5CI	WSM6 and Goddard DS	WSM6 and Morrison RE	WSM6 and Morrison Hybrid	WSM6 and Morrison DS-5CI	WSM6 and Morrison DS	Goddard and Morrison RE	Goddard and Morrison Hybrid	Goddard and Morrison DS-5CI	Goddard and Morrison DS
19.35 H	6.5	5.9	5.9	6.3	8.5	6.5	7.3	7.3	6.4	7.6	6.4	7.8
37 H	7.7	10.9	10.2	12.6	7.9	8.4	8.4	8.4	8.7	10.6	11.8	14.2
91.655 H	13.5	22.2	21.0	24.8	8.1	15.2	15.7	15.7	13.7	23.4	24.8	28.5
183.31 +/- 6.6 H	12.3	18.3	17.3	25.6	6.6	11.7	14.4	14.3	12.4	20.4	21.5	28.6

Table 3. Root mean squared error of CRTM simulated brightness temperatures (Kelvin) between pairs of microphysics schemes.

	RE	Hybrid	DS-5CI	DS
Average RMSE	9.4	13.4	13.7	16.2

Results (continued)

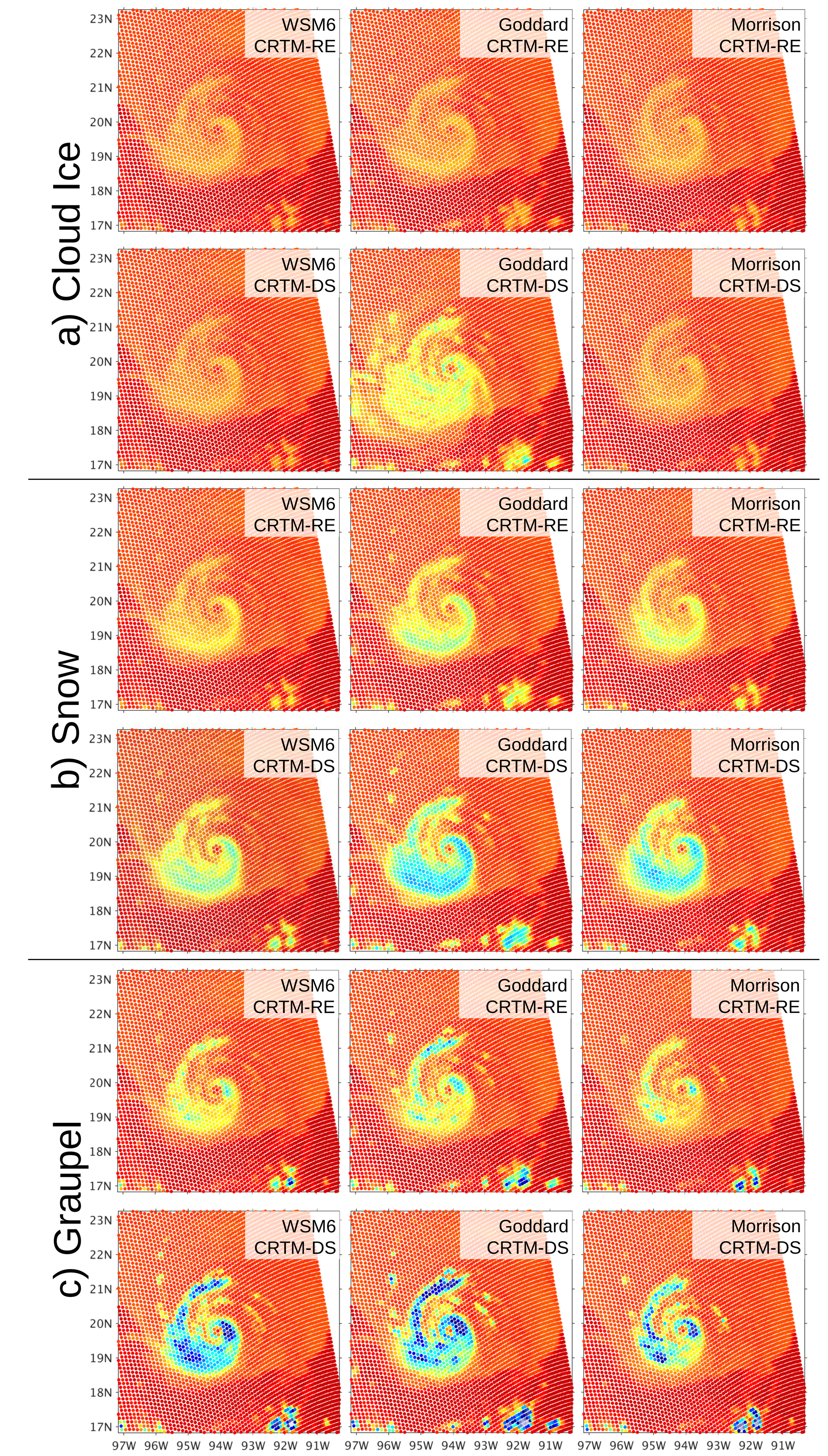


Figure 8. Comparing CRTM-RE and CRTM-DS simulations at 91.665 GHz using the model output of only the cloud liquid, rain and either a) cloud ice, b) snow, or c) graupel hydrometeor species.

Highlights

- DS gives lowest T_B and most variation between schemes
- RE gives highest T_B and least variation between schemes
- DS-5CI and Hybrid results in-between DS and RE; Hybrid is close to DS-5CI, Morrison has most difference
- Graupel bulk density inconsistency meaningful in T_B
- Goddard large ice cloud particles impact all frequencies

- T_B in DS lower than RE in all single-ice experiments
- T_B from Goddard lower than from WSM6 or Morrison in all single-ice experiments
- RE ice cloud T_B nearly equivalent to using just liquid species: 5 µm effective radius ice clouds are almost transparent
- Goddard DS is the only ice cloud experiment with T_B depressions at 91.665 GHz (Morrison does at 183.33 GHz)
- Lowest T_B and biggest T_B difference between RE and DS caused by graupel in WSM6 and Goddard, snow in Morrison

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