Resolving modeled microwave radiance biases resulting from microphysics-consistent cloud scattering properties: a role for non-spherical particles and modified particle bulk densities

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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 clouds and precipitation by their location, species, water path, and effective radius. Since most of the microwave scattering is by particles of size close to or larger than the wavelength, effective radius can fail to describe different PSDs which have the same microwave scattering.

In Sieron et al (2017; JGR), cloud scattering lookup tables were constructed that are entirely consistent with the particle properties and size distributions specified by the microphysics schemes (CRTM-DS).

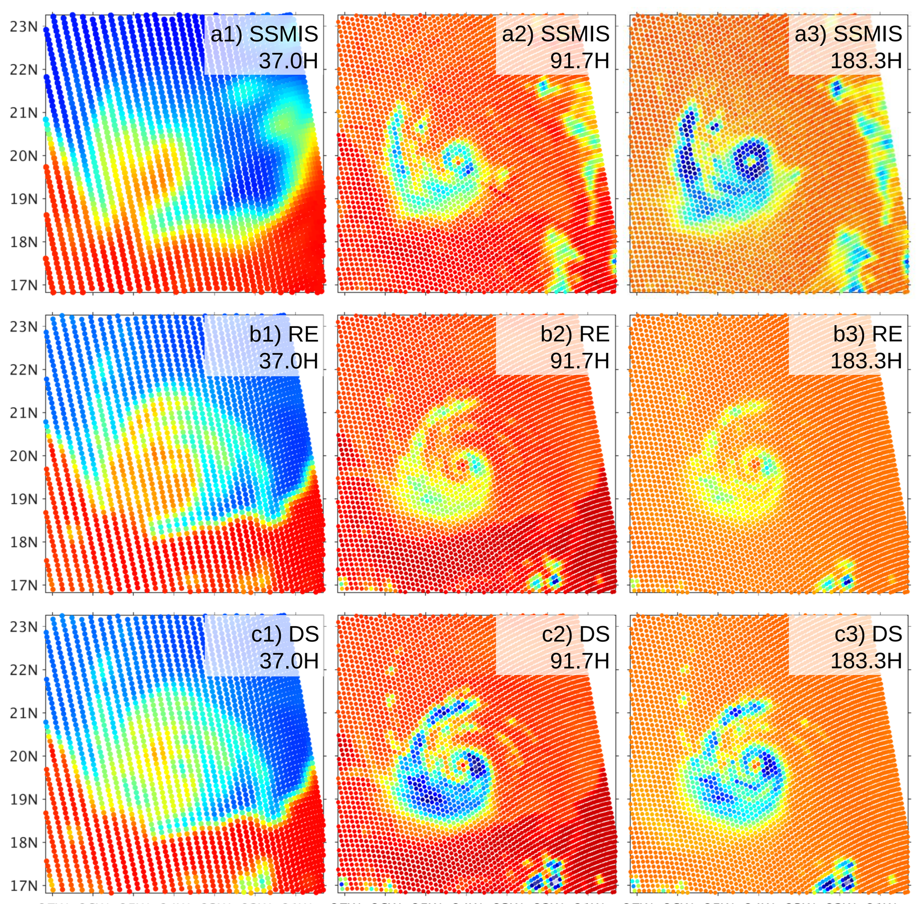

Figure 1. Brightness temperatures from (a) observations, (b) CRTM as-released using effective radius (CRMT-RE), and (c) CRTM-DS from 3-hour WRF forecasts of Hurricane Karl using WSM6 microphysics.

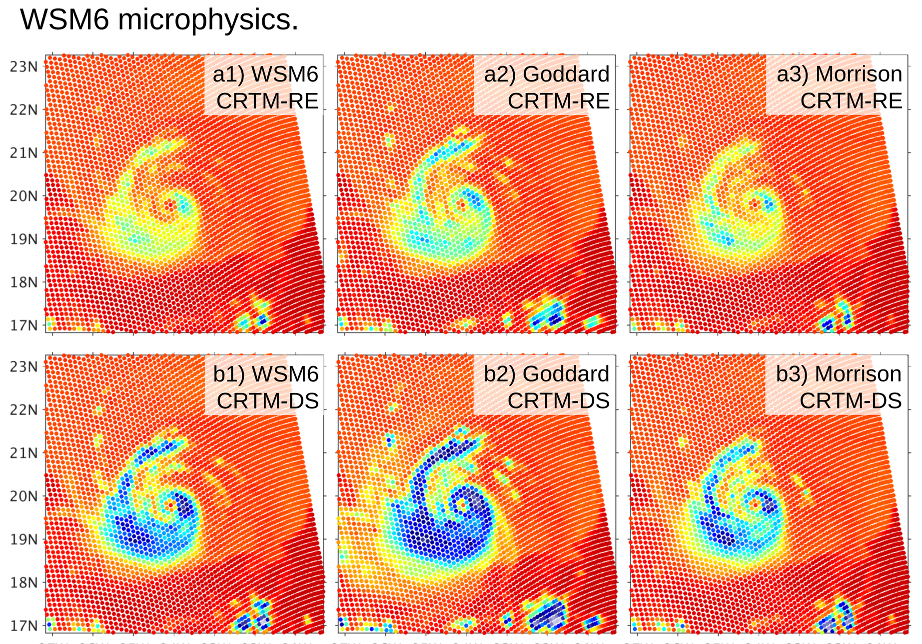

Figure 2. Brightness temperatures at 91.7 GHz from (a) CRTM as-released using effective radius (CRTM-RE) and (b) CRTM-DS. Simulations using (1) WSM6, (2) Goddard and (3) Morrison microphysics schemes.

In areas of precipitation:
1. CRTM-DS gives more variation in BTs across different microphysics schemes.
2. CRTM-DS produces lower BTs for all frequencies and microphysics schemes.
3*. All lookup tables produce 183 GHz BTs higher than 91.7 GHz BTs, contrary to observations.
4*. Changing graupel bulk density between 400 kg m^{-3} and 500 kg m^{-3} (WSM6) results in > 6 K difference in BT (not shown).

Bulk Density

(Sieron et al., in preparation)

There are three influences of particle bulk density on simulated brightness temperatures (BTs):
1. As a component of the microphysics scheme, which influences the evolution of snow and graupel water contents (e.g., fall speed*).
2. As a parameter in particle size distributions, which are integrated along with particle scattering properties to calculate microphysics-consistent cloud scattering properties.
3. As a physical factor in determining the scattering properties of particles of a given size/mass.

WSM6 default bulk densities: snow 100 kg m^{-3}, graupel 500 kg m^{-3}.

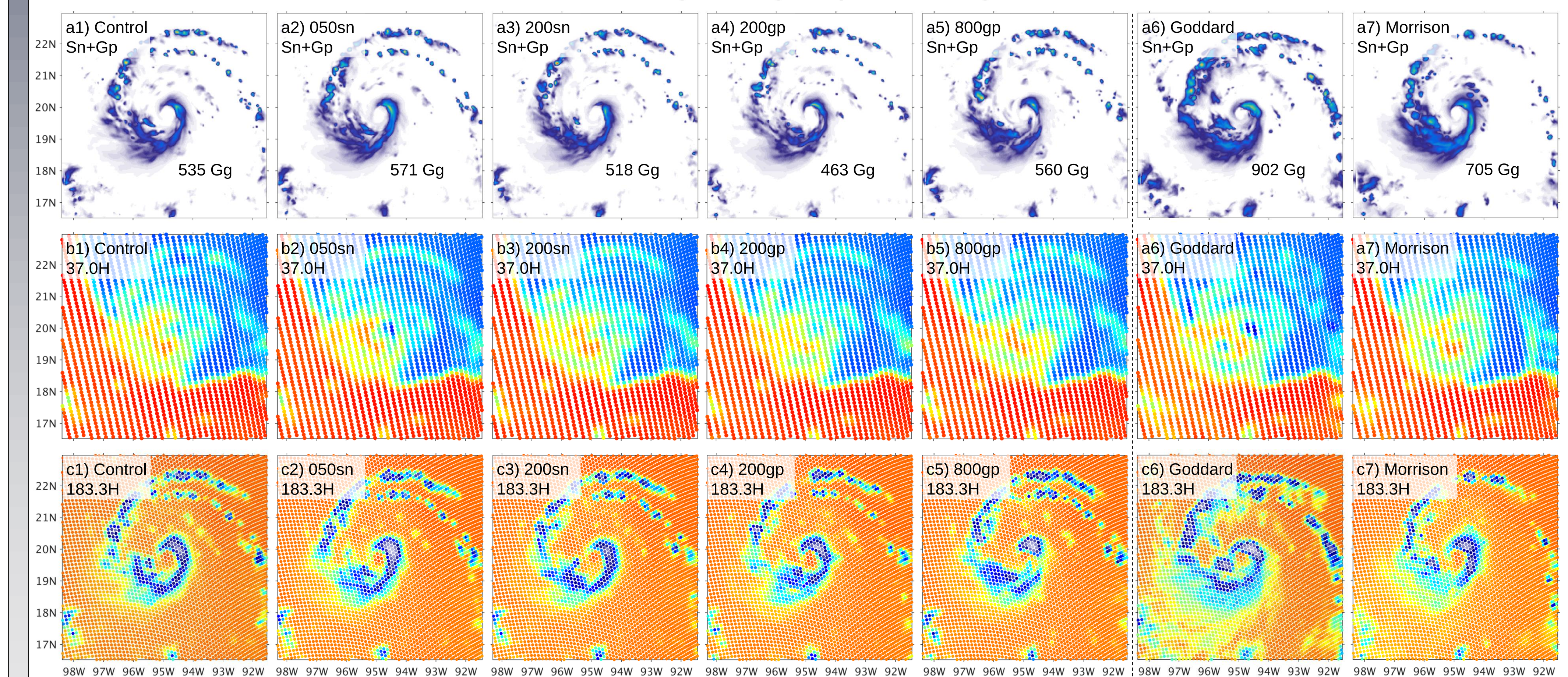

Figure 4. (a) Water path of all precipitation ice (snow and graupel; domain total mass shown in text), and simulated brightness temperatures at (b) 37 GHz and (c) 183 GHz using CRTM-DS lookup table for the unmodified WSM6 microphysics scheme, from 8-hour simulations using WSM6 with (1) unmodified bulk densities, (2) snow density of 50 kg m^{-3}, (3) snow density of 200 kg m^{-3}, (4) graupel density of 200 kg m^{-3}, and (5) graupel density of 800 kg m^{-3}. Also compared to using unmodified (6) Goddard and (7) Morrison microphysics schemes with the respective CRTM-DS lookup table.

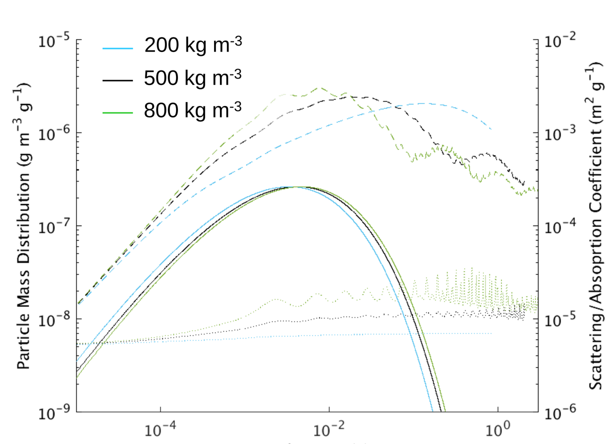

Figure 5. Influence of bulk density on particle mass distribution (solid lines), and the scattering (dashed) and absorption (dotted) coefficients of a sphere.

Exponential particle size distribution (emphasis on bulk density, $\boldsymbol{\rho_g}$):

$$N_g(D_g) = N_{0,g}e^{-\lambda_g D_g}$$

$$M_g(D_g) = \frac{\pi}{6}\boldsymbol{\rho_g} D^3 N_{0,g}e^{-\lambda_g D_g}$$

$$M_g(m_g) = \left(\frac{2\pi}{9}\frac{m_g}{\boldsymbol{\rho_g}}\right)^{1/3} N_{0,g}e^{-\lambda_g a}, \text{ with } a = \left(\frac{6m_g}{\pi\boldsymbol{\rho_g}}\right)^{1/3}$$

$$\lambda_g[m^{-1}] = \left(\frac{\pi\boldsymbol{\rho_g} N_{0,g}}{\rho_a q_g}\right)^{1/4}$$

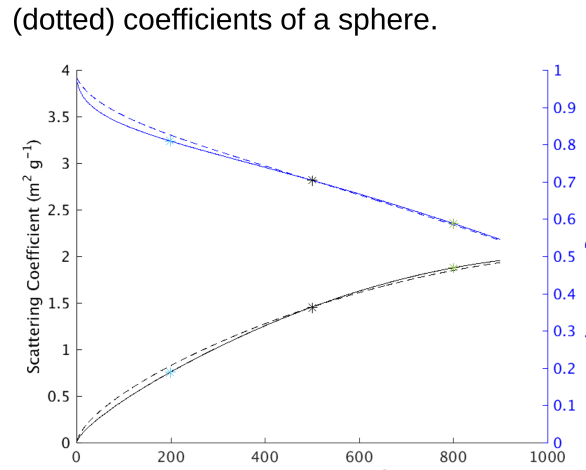

Figure 6. Influence of bulk density on cloud scattering coefficient and asymmetry parameter (1 g m^{-3} of WSM6 graupel), whether using particle mass distribution consistent with specified bulk density (solid line), or using the particle mass distribution consistent with 500 kg m^{-3} bulk density (dashed line).

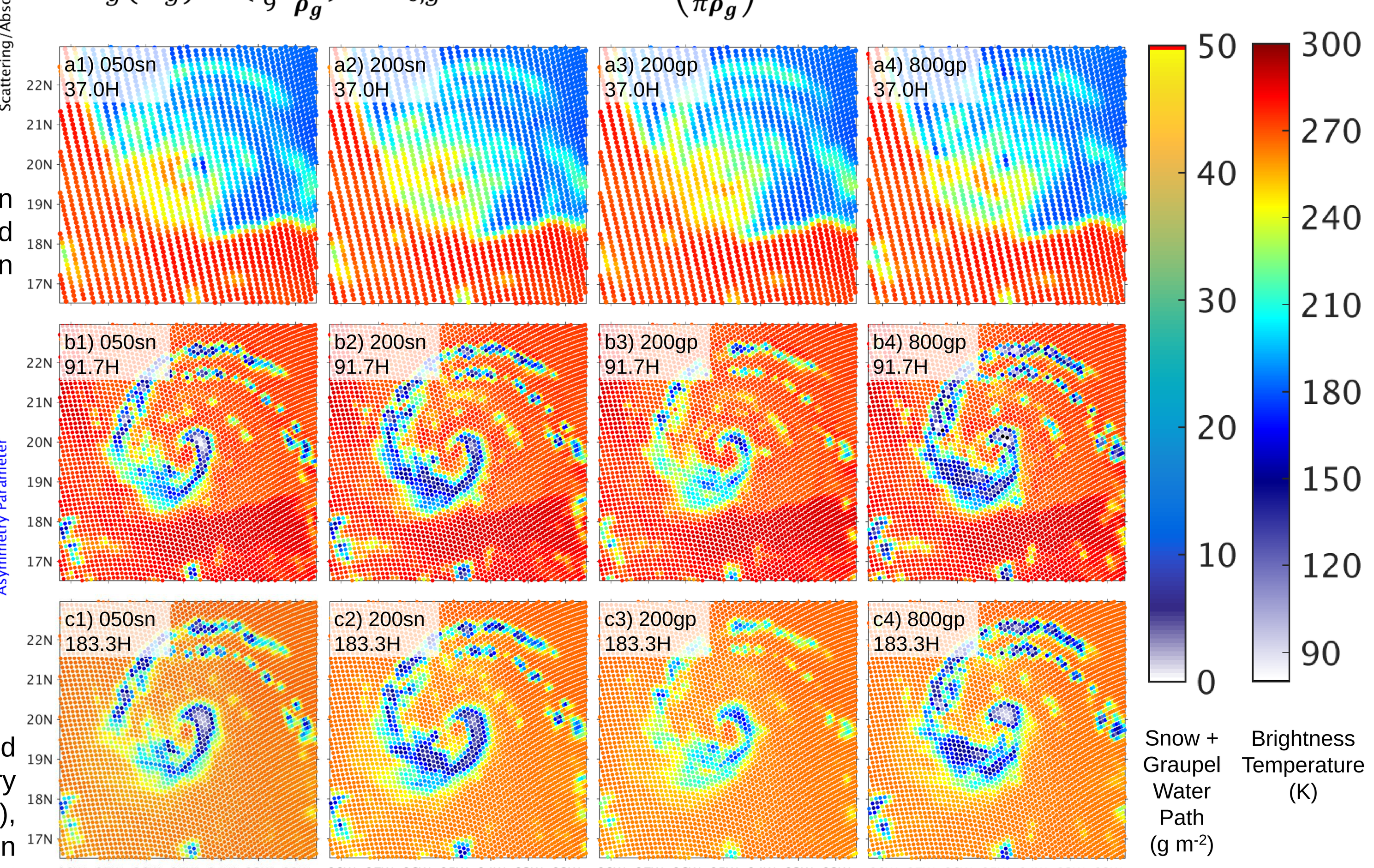

Figure 7. Similar to brightness temperatures in Figure 4 (2 through 5), but using a CRTM-DS lookup table that is fully consistent with the respective modification made to the WSM6 microphysics scheme.

Non-Spherical Particles

(Sieron et al. 2017, submitted)

- A soft sphere poorly represents the physical nature of a snow particle (less so for graupel)
- The symmetry and homogeneity of a soft sphere cause unique scattering properties

Goal: Replace microphysics-consistent soft spheres with non-spherical particle constructions, while otherwise maintaining consistency with the microphysics scheme
- Utilize database by Gousheng Liu (2008; MWR), which contains 11 particle constructions and thousands of particle sizes for each
- Allow a non-spherical particle to replace spherical particle of equal size
- Maintain microphysics-specified total mass of particles of a given size by scaling the microphysics-specified number of particles by the ratio of the mass of the soft sphere to the mass of the non-spherical particle that it replaces

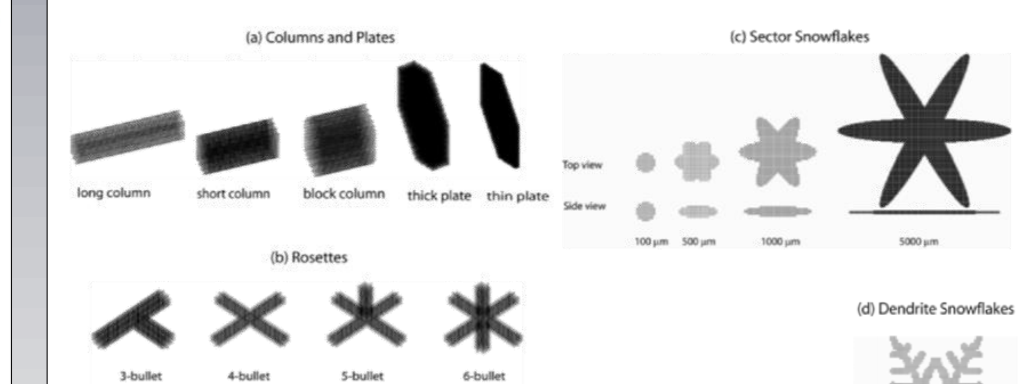

Figure 8. Shapes of (a) columns and plates, (b) rosettes, (c) sector snowflakes, and (d) dendrite snowflakes. The drawings are made of small dots that are the dipoles used in DDA model simulations. (Adapted from Liu 2008.)

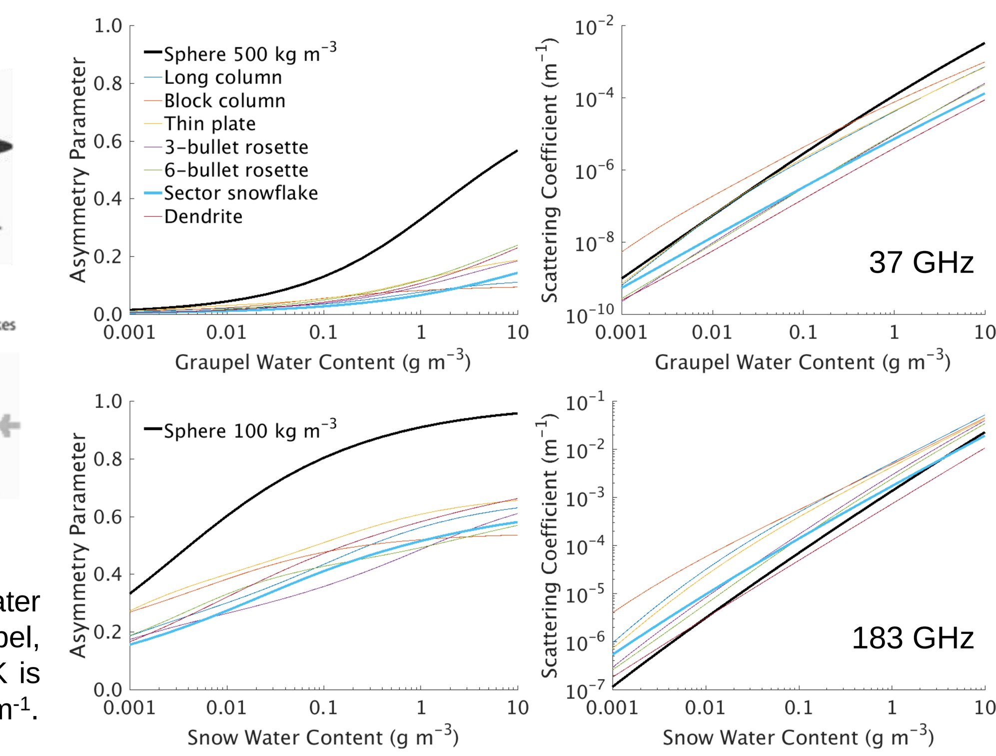

Figure 9 (right). Scattering property values as a function of ice water content for a variety of particle types. The top row uses WSM6 graupel, and the bottom row uses WSM6 snow. A snow temperature of 256 K is assumed, resulting in an intercept parameter value of 1.56 × 10^7 m^{-3} m^{-1}.

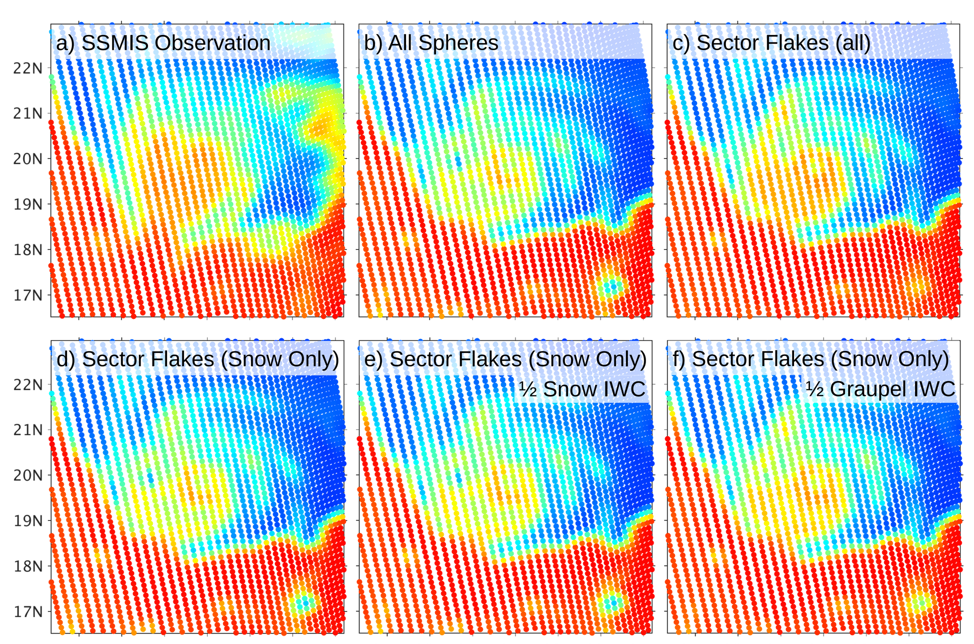

Figure 10. CRTM-simulated and (a) F16 SSMIS observed brightness temperatures (K) at 37 GHz (SSMIS channel 12). Panel (b) is for cloud scattering properties using microphysics-consistent spheres for all ice species, while panel (c) shows results when sector snowflakes replace spheres for all ice precipitation (snow and graupel) and (d) for only snow. Snow and graupel water contents are halved in panels (e) and (f), respectively, with sector snowflakes used only for representing snow.

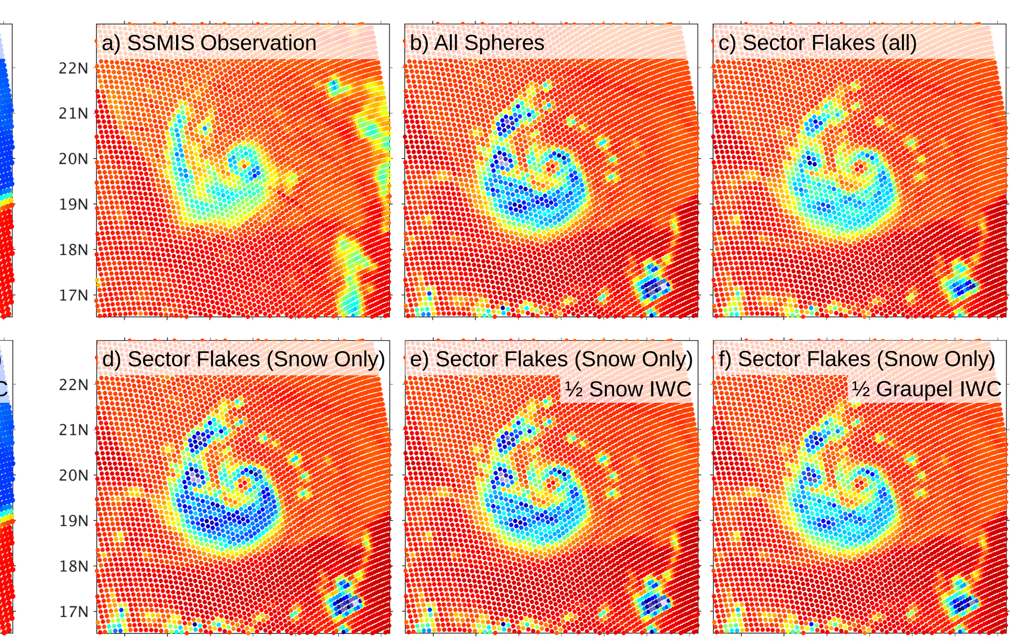

Figure 11. Same as Figure 10 but for 91.7 GHz (SSMIS channel 18).

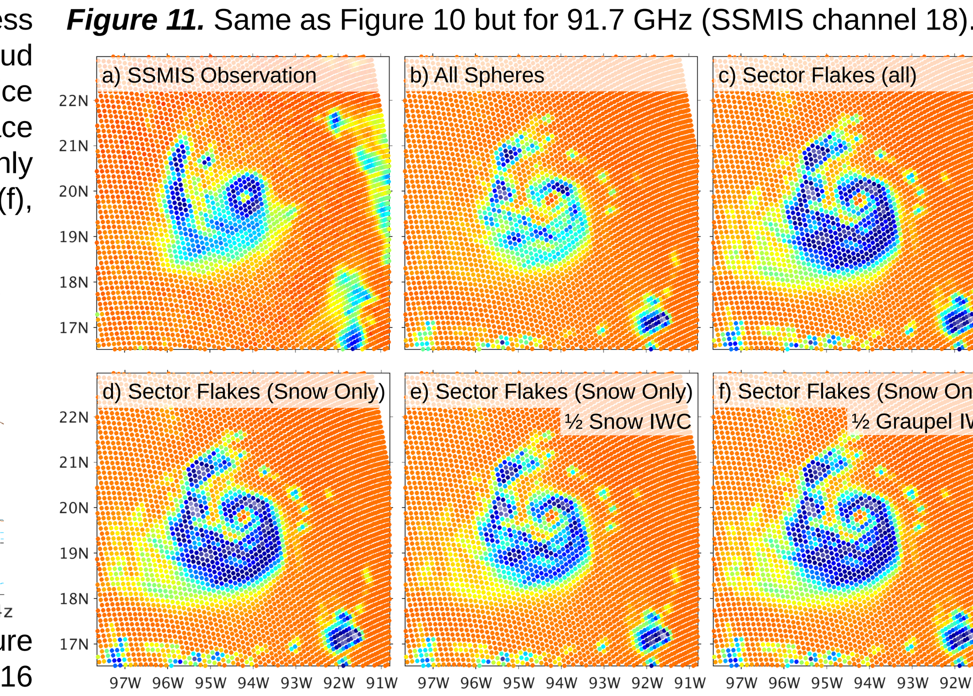

Figure 12. Same as Figure 10 but for 183.3 GHz (SSMIS channel 12.)

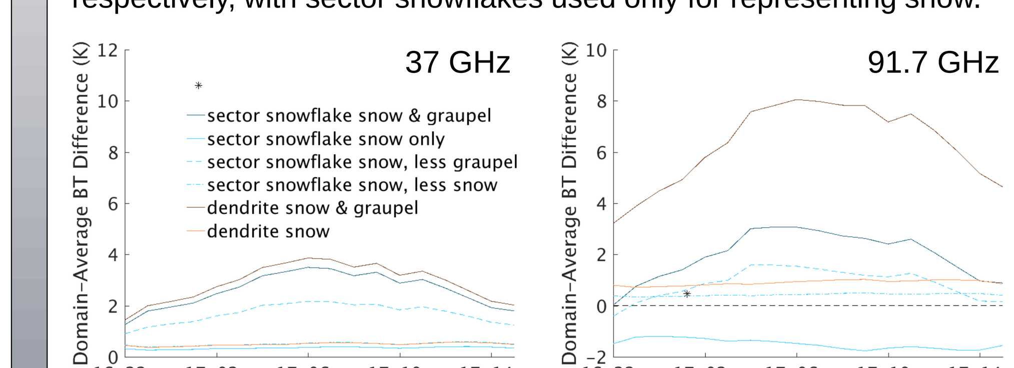

Figure 13. Time series of domain-average brightness temperature difference to using spheres for all precipitation ice. Difference to F16 SSMIS observed brightness temperatures at 0117 UTC is indicated by the star in each panel.

Conclusions

- Changing bulk density in microphysics scheme produces some change in snow and graupel water contents, but not significant 1) in resolving biases of simulated brightness temperatures and 2) compared to differences between microphysics schemes.
- Changing the bulk density in the particle size distribution is insignificant relative to how particle optical properties of spheres differ with bulk density.
- With all three bulk density influences combined, there are substantial changes to simulated BTs. But the 183/91 GHz bias is ever-present.
- Replacing soft spheres with non-spheres for snow is necessary to resolve the 183/91.7 GHz bias. Sector snowflakes do this better than any other particle type. With this substitution, both high frequencies have low simulated brightness temperatures, suggesting that snow is being overproduced in this simulation using WSM6.
- Cold biases at lower frequencies are caused by graupel and can be reduced either by reducing graupel water contents or replacing soft spheres with sector snowflakes. Spheres better represent graupel particle constructions.

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