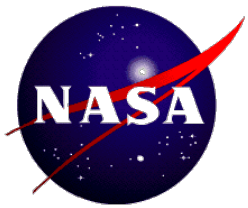


The fluid dynamics of falling hydrometeors often results in preferential orientations that can affect both the intensity and polarization of electromagnetic radiation. In order to properly interpret remote sensing observations of ice and snow, such alignments should be considered when constructing databases of scattering particles; however, the inclusion of aligned particles increases the complexity of the scattering data. To demonstrate the use of scattering properties of preferentially-aligned particles, millimeter-wave brightness temperatures and radar observables, including reflectivity and linear depolarization ratio, are modeled using the Atmospheric Radiative Transfer Simulator (ARTS). The necessary scattering parameters for vector radiative transfer, particularly with respect to ARTS, are reviewed, and the exploitation of particle symmetries, as well as scattering reciprocity relationships, are detailed.



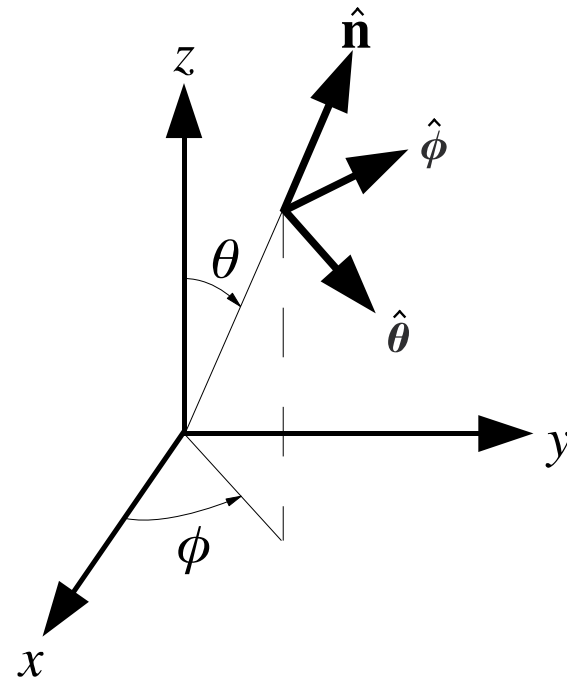
Active and Passive Radiative Transfer Modeling with Preferentially-Aligned Particles

Ian Stuart Adams

NASA Goddard Space Flight Center

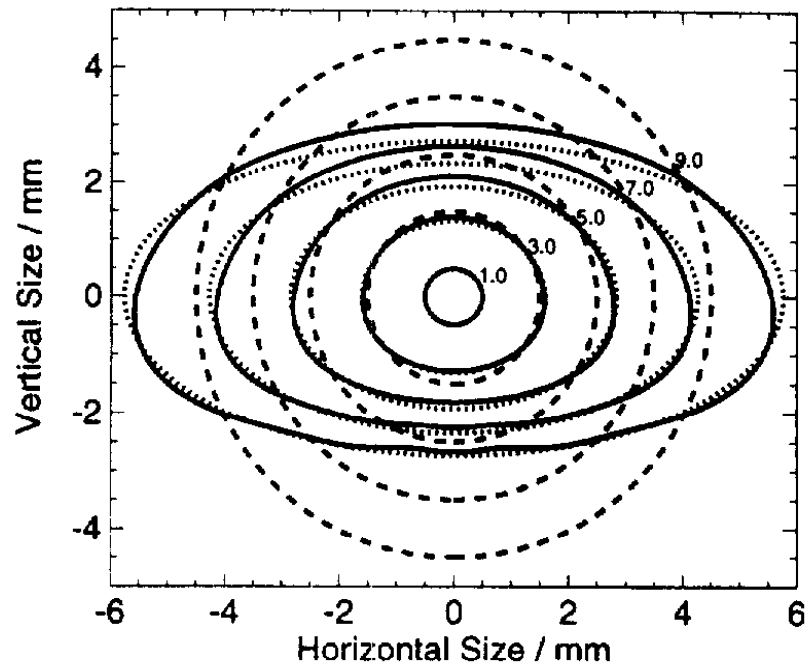
Polarization

- Break in symmetry
 - Spatial inhomogeneities
 - Particle shape
- Rotation of polarized electric field
 - $Q \leftrightarrow U$
- Differential phase between orthogonal polarizations
 - Elliptical polarization

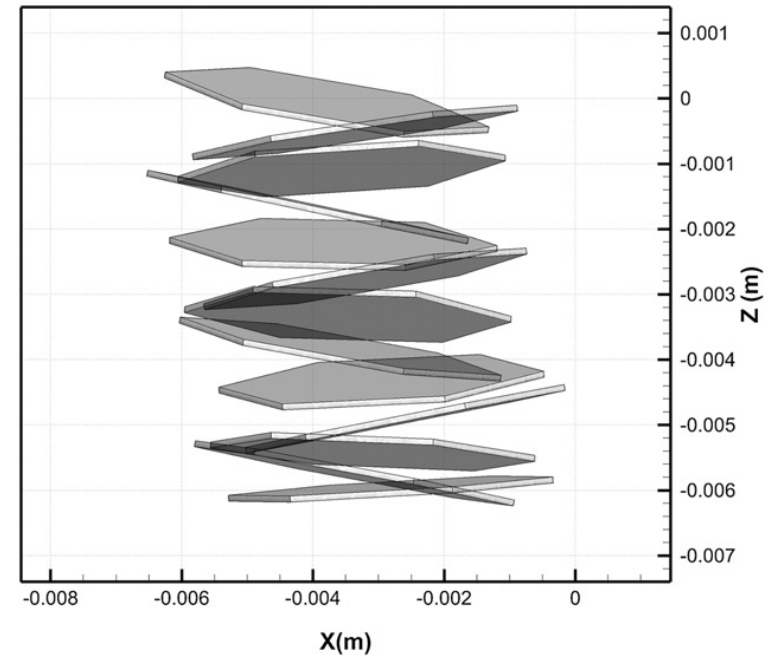


$$\begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} \propto \begin{bmatrix} E_{0\theta} E_{0\theta}^* + E_{0\phi} E_{0\phi}^* \\ E_{0\theta} E_{0\theta}^* - E_{0\phi} E_{0\phi}^* \\ -E_{0\theta} E_{0\phi}^* - E_{0\phi} E_{0\theta}^* \\ i(E_{0\phi} E_{0\theta}^* - E_{0\theta} E_{0\phi}^*) \end{bmatrix}$$

Particle Orientation



Czekela and Simmer 1998

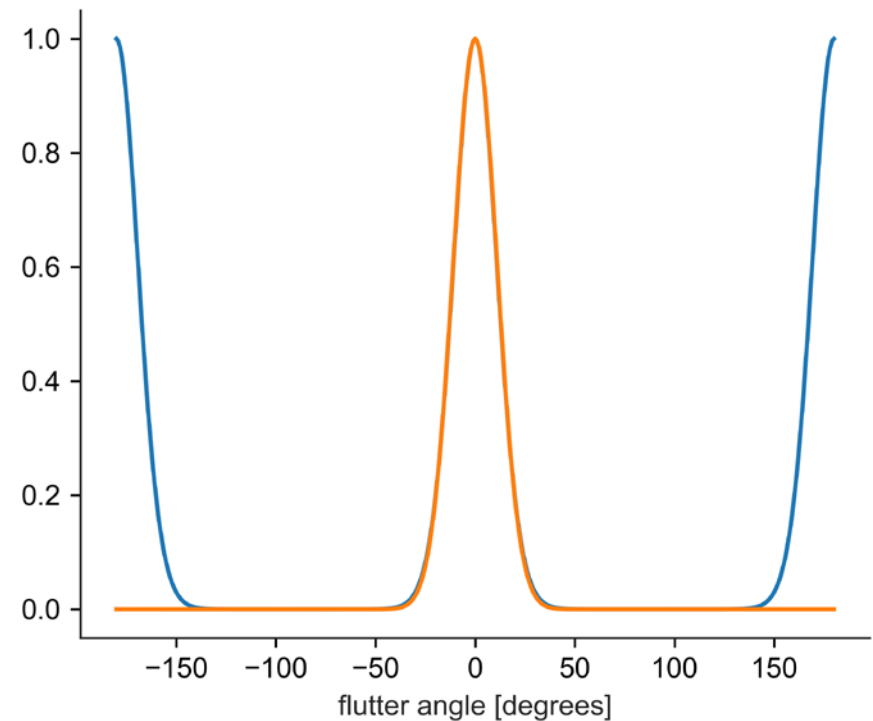
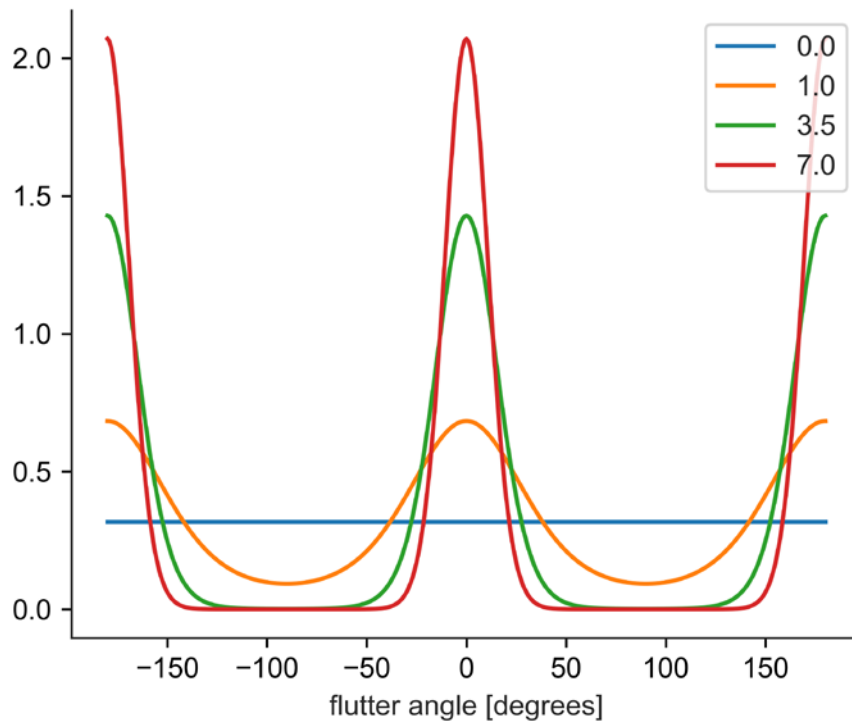


Cheng et al. 2015

Particle Flutter: von Mises Distribution

$$P(\theta) = \frac{e^{\kappa \cos(\theta - \mu)}}{\pi I_0(\kappa)}$$

$$\kappa = 7$$
$$\sigma \approx 11$$



ARTS Implementation

Phase Matrix (**Z**)

- 16 elements
- $\theta_i \in [0^\circ, 90^\circ]$
 - Poses problem for preferential melting
- $\theta_s \in [0^\circ, 180^\circ]$
- $\Delta\phi \in [0^\circ, 180^\circ]$
 - $S_{12}(-\Delta\phi) = -S_{12}(\Delta\phi)$
 - $S_{21}(-\Delta\phi) = -S_{21}(\Delta\phi)$

ARTS Implementation

Extinction matrix (**K**)

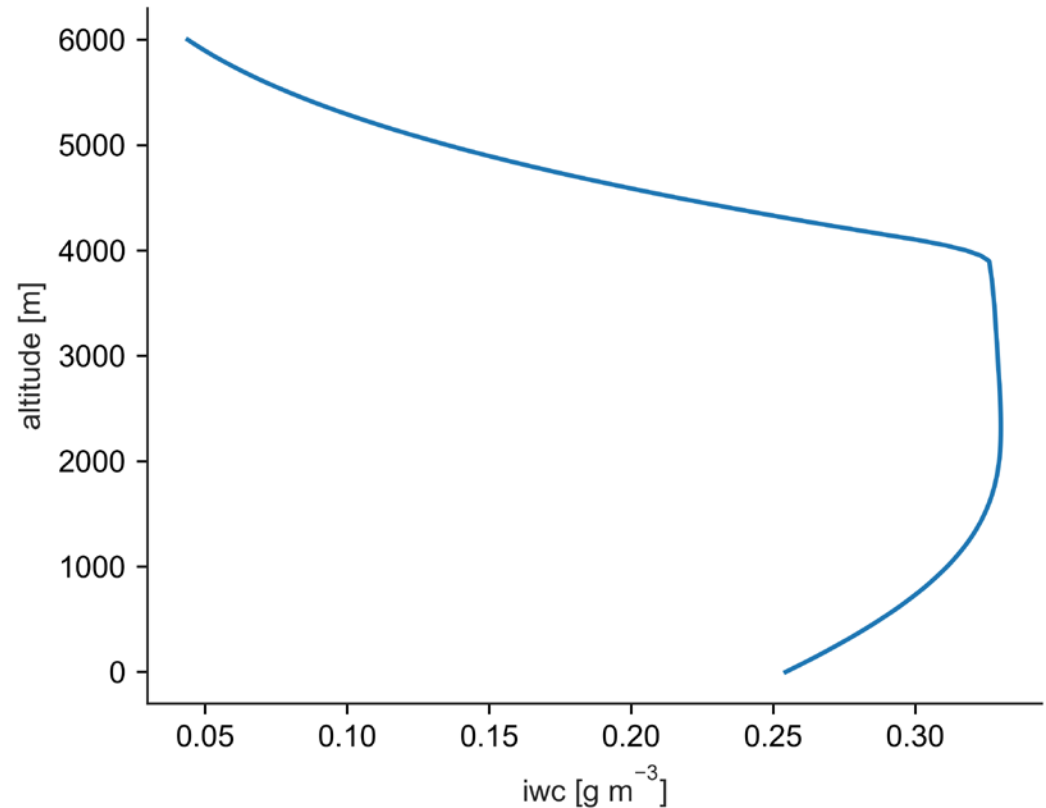
- 3 independent elements
- Block diagonal 4 x 4 matrix
- $\theta_i \in [0^\circ, 90^\circ]$
 - Poses problem for preferential melting

Absorption (Emission) vector (K_e)

- 2 nonzero elements
- Requires removing scattering contribution from **K**
- $\theta_i \in [0^\circ, 180^\circ]$

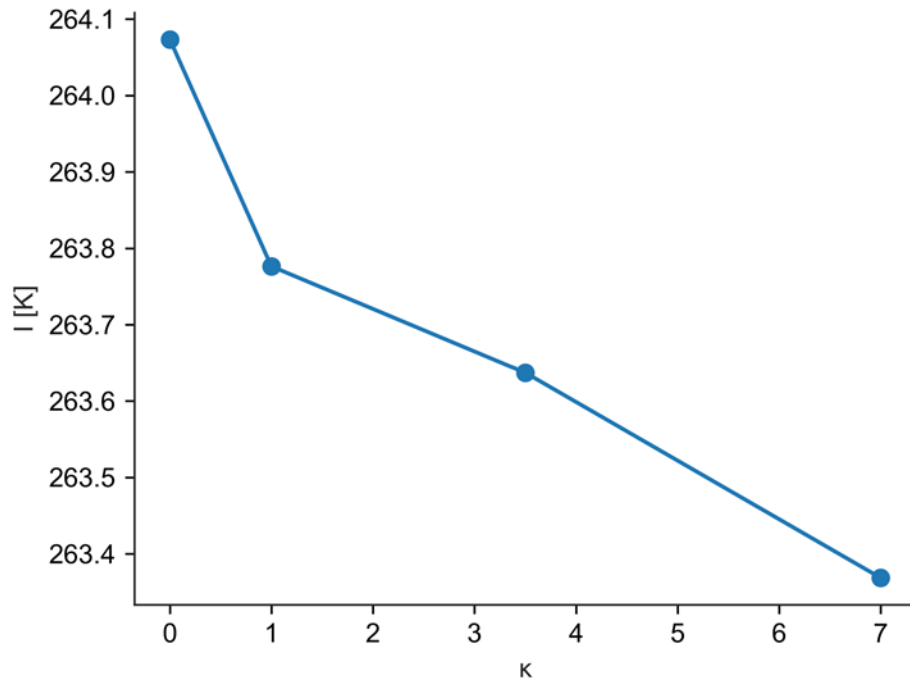
Application to Idealized Profile

- Cylindrical plates
- Gamma distribution
- $r_e = 100 \mu\text{m}$
- $ar = 6.5$
- Vary κ
- W-band
 - T_b : I, Q
 - Z, LDR, MS effects

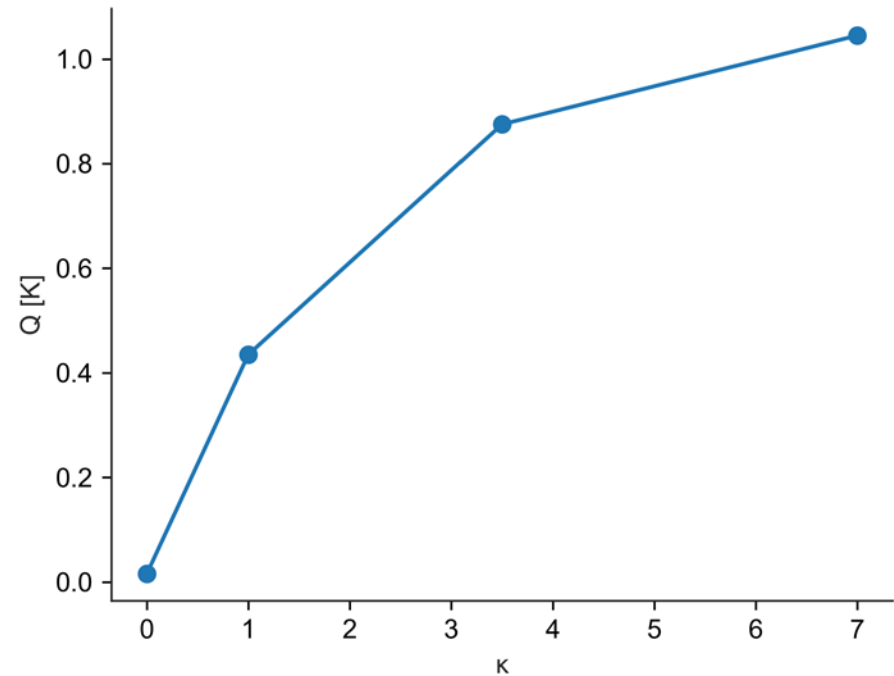


Brightness Temperatures

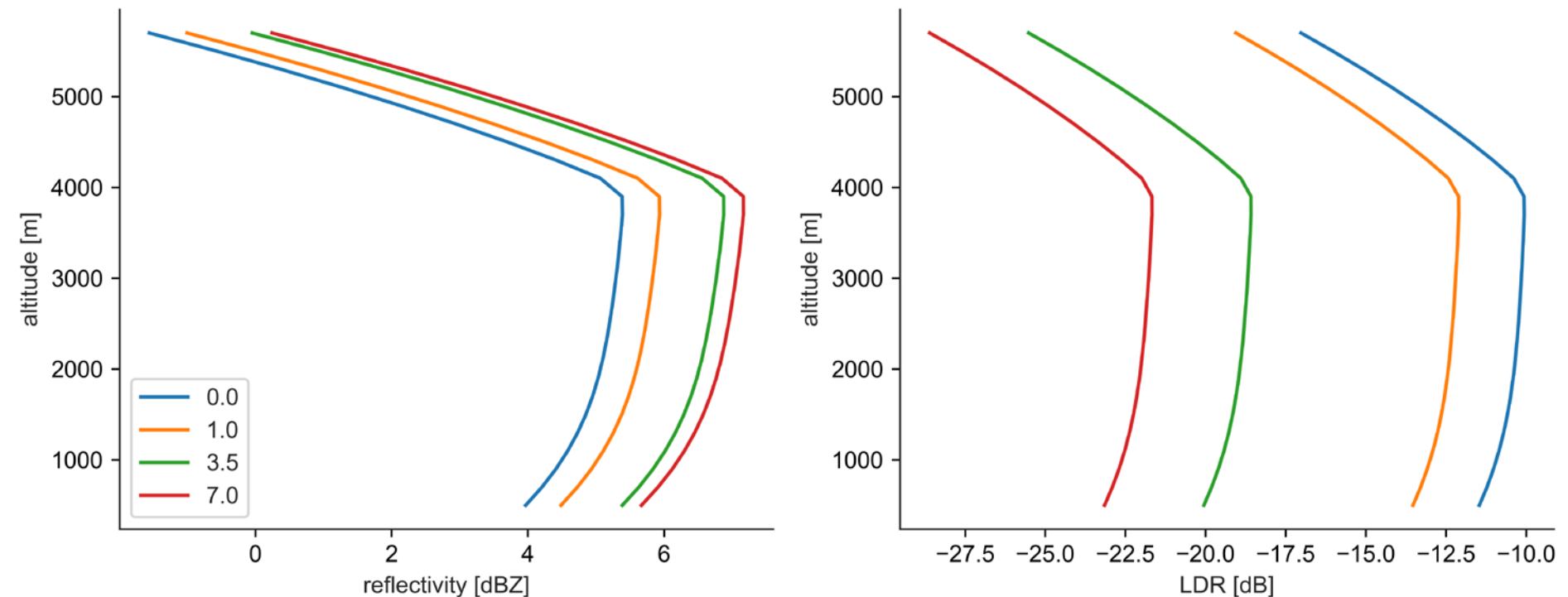
Intensity



Polarization Difference

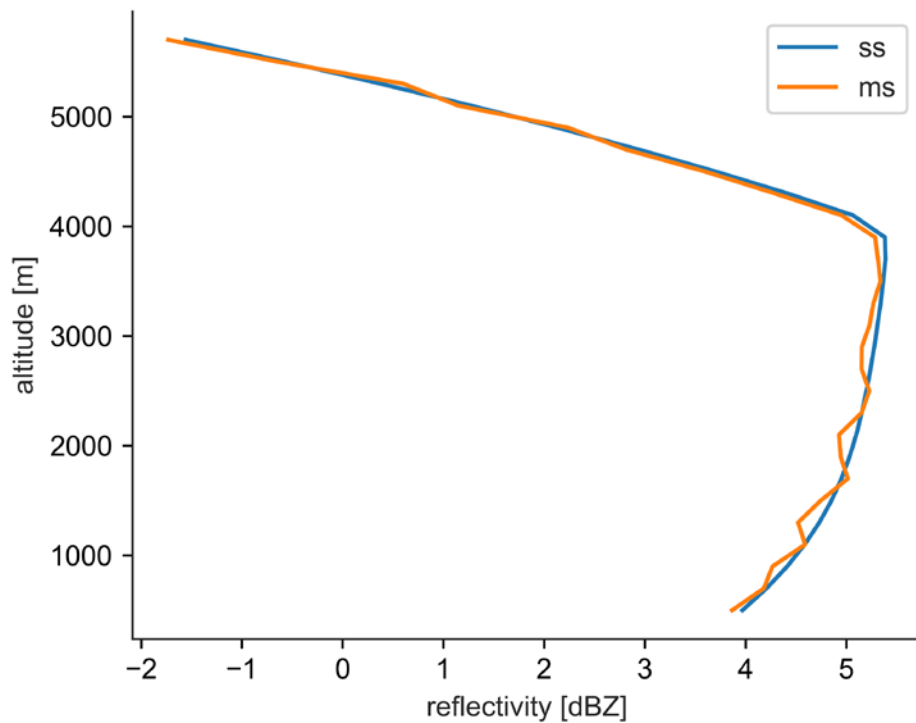


Reflectivity and Linear Depolarization Ratio

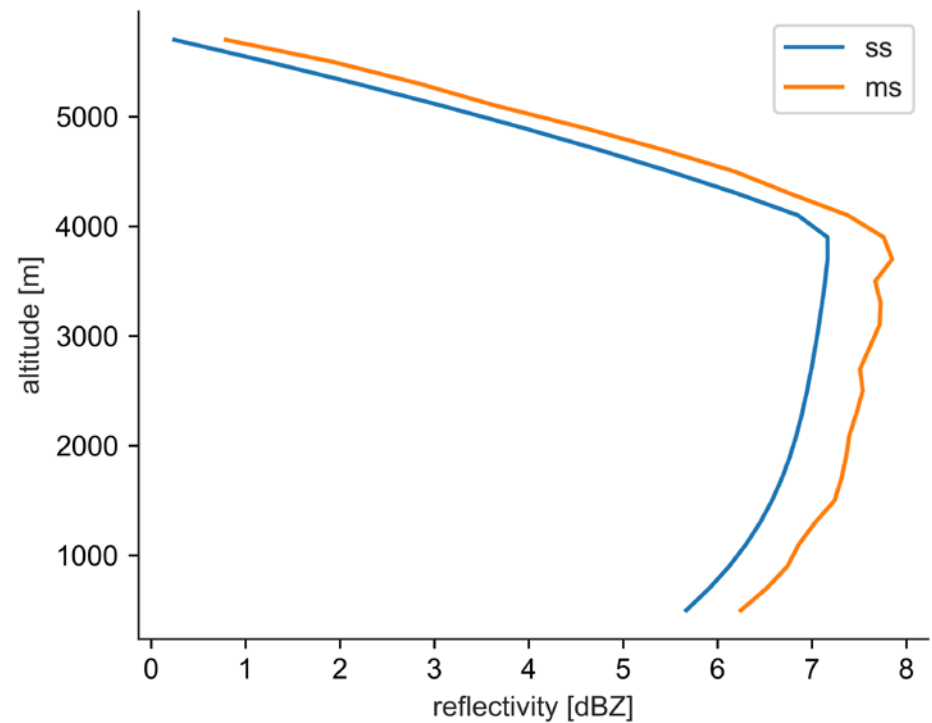


Multiple Scattering Effects: Z

$\kappa = 0$

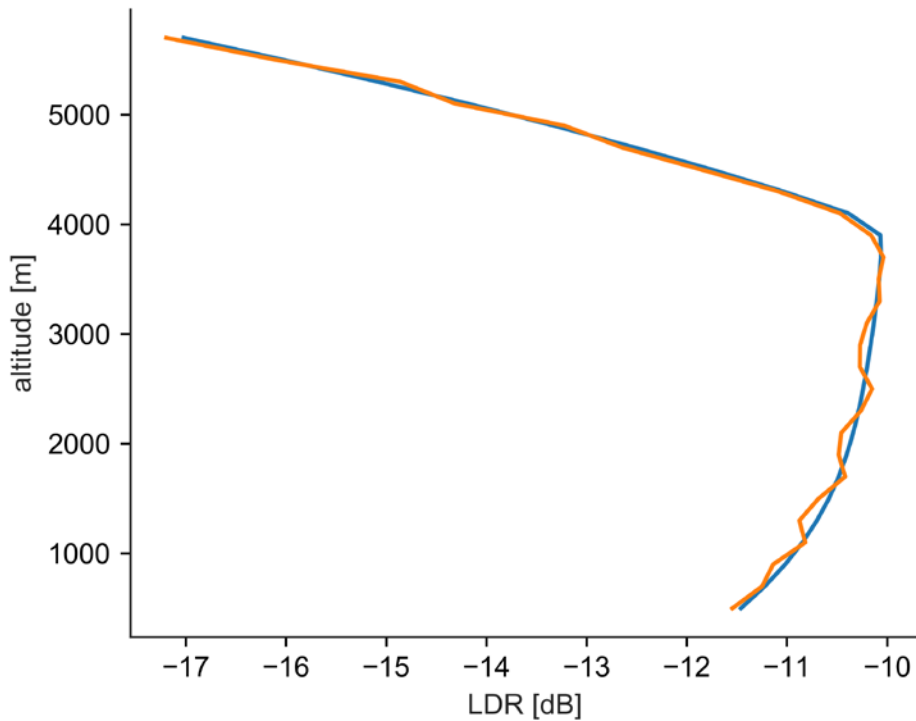


$\kappa = 7$

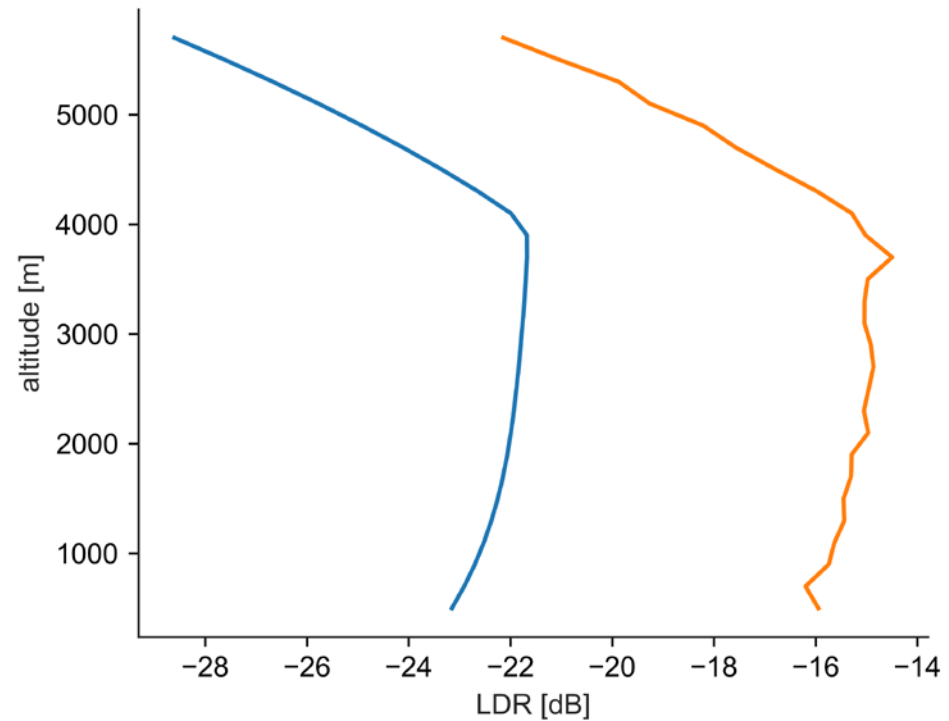


Multiple Scattering Effects: LDR

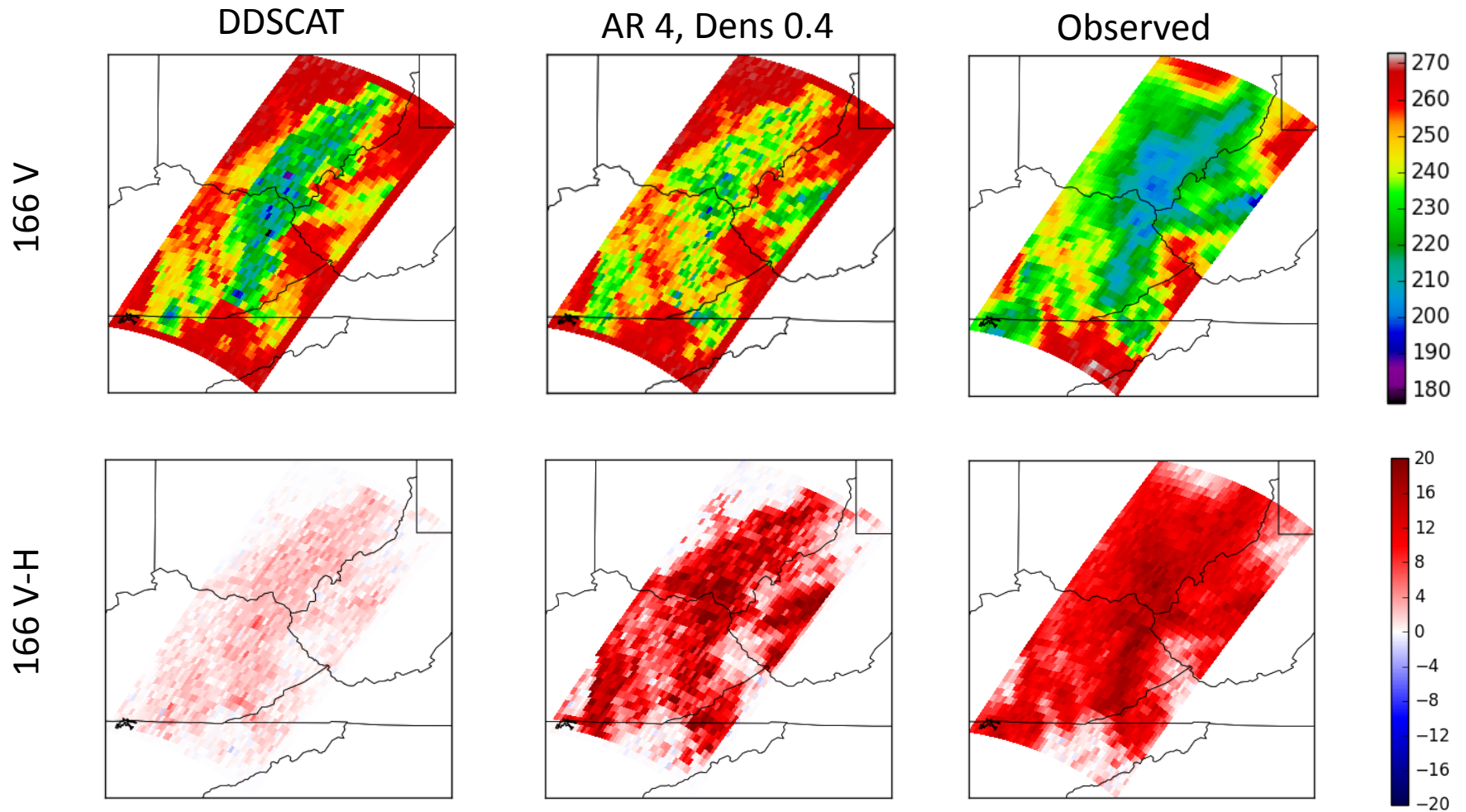
$\kappa = 0$



$\kappa = 7$



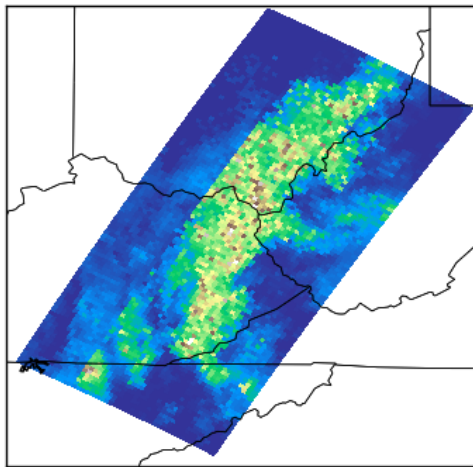
GPM Case Study: Observations



GPM Case Study: Retrievals

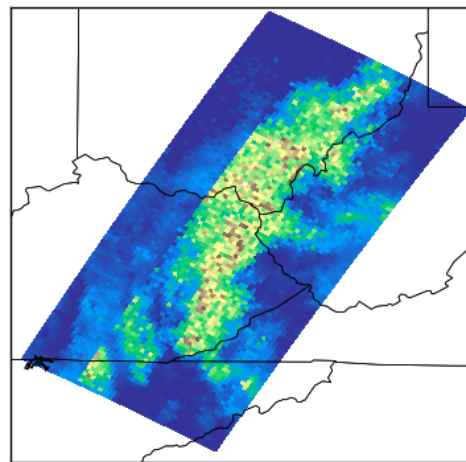
DDSCAT

Randomly Oriented

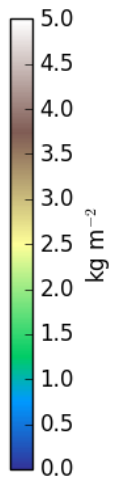
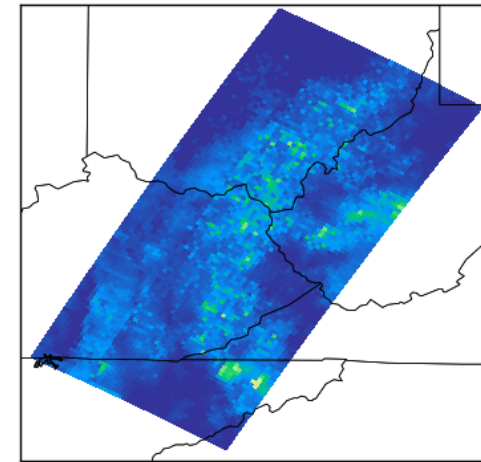


Oblate Spheroids

AR 4, Dens 0.1



AR 4, Dens 0.4



Summary

Preferentially-aligned particles

- Random in azimuth
- Flutter modeled using von Mises distribution
- Orientation affects intensity and polarization