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

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Polarization

• Break in symmetry
  o Spatial inhomogeneities
  o Particle shape

• Rotation of polarized electric field
  o $Q \leftrightarrow U$

• Differential phase between orthogonal polarizations
  o Elliptical polarization

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

- 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 ($\mathbf{K}$)
• 3 independent elements
• Block diagonal 4 x 4 matrix
• $\theta_i \in [0^\circ, 90^\circ]$
  - Poses problem for preferential melting

Absorption (Emission) vector ($\mathbf{K}_e$)
• 2 nonzero elements
• Requires removing scattering contribution from $\mathbf{K}$
• $\theta_i \in [0^\circ, 180^\circ]$
Application to Idealized Profile

- Cylindrical plates
- Gamma distribution
- $r_e = 100 \, \mu m$
- $a_r = 6.5$
- Vary $\kappa$
- 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

DDSCAT

AR 4, Dens 0.4

Observed
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