Full Polarization Observations of Oriented Ice Crystals and Rain by the NCAR GV High Spectral Resolution Lidar

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Polarization Lidar Parameters

Total Backscatter
\[ N = N_\perp + N_\parallel \]

Depolarization Ratio
\[ \delta = \frac{N_\perp}{N_\parallel} \]
Backscattering by randomly oriented particles

Two degrees of freedom

\[ \mathbf{F}(\pi) = \beta \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1-d & 0 & 0 \\ 0 & 0 & d-1 & 0 \\ 0 & 0 & 0 & 2d-1 \end{bmatrix} \]

Linear Depolarization Ratio

\[ \delta_L = \frac{N_\perp}{N_\parallel} = \frac{d}{2-d} \]

Circular Depolarization Ratio

\[ \delta_C = \frac{N_\perp}{N_\parallel} = \frac{d}{1-d} \]
Backscattering by oriented particles

Six degrees of freedom

\[ \mathbf{F}(\vec{k}_i, -\vec{k}_i) = \beta \begin{bmatrix} 1 & f_{12} & 0 & 0 \\ f_{12} & f_{22} & 0 & 0 \\ 0 & 0 & f_{33} & f_{34} \\ 0 & 0 & -f_{34} & f_{44} \end{bmatrix} \]

Linear Depolarization Ratio

\[ \delta_L = \frac{1 - f_{22} \cos^2 2\psi_L + f_{33} \sin^2 2\psi_L}{1 + 2f_{12} \cos 2\psi_L + f_{22} \cos^2 2\psi_L - f_{33} \sin^2 2\psi_L} \]

Circular Depolarization Ratio

\[ \delta_C = \frac{1 + f_{44}}{1 - f_{44}} \]
Implicit assumption of random orientation

“Assuming the volume consists of randomly oriented, axially symmetric particles...”

Unless stated otherwise, analysis of polarization lidar data **ALWAYS** assumes that the particles are randomly oriented.

No diagnostic for influence of oriented particles

Oriented ice particles make a great “gotcha”

Don’t like someone’s polarization lidar data?
Suggest oriented particles are corrupting the data
HSRL started measuring the full scattering matrix in Spring 2012
Operated it three tilt angles:

\[
\alpha = 4^\circ \text{ (minimum angle)} \quad \text{Summer 2013}
\]
\[
\alpha = 22^\circ \quad \text{Summer 2012, Fall 2012}
\]
\[
\alpha = 32^\circ \quad \text{Summer 2012, Winter 2012}
\]

HSRL Specifications:
Wavelength: 532 nm
Max Range Resolution: 7.5 m (30 m typical)
Time Resolution: 0.5 s (20 s for full matrix)
RX Aperture: 40 cm
TX Power: 400 mW @ 4kHz
Coaxial TX/RX

What does an atmospheric oriented scattering matrix look like?

What observations can safely assume randomly oriented particles?

One paper published on the subject: *Kaul et. al, Appl. Opt. 2004*
Total Cloud Observations Histogram

June-July 2012 with 30° Tilt

\[ f_{44} = 1 + 2f_{33} \]

See Hayman et. al, Opt. Express In Review.
Filtered for Oriented Ice Crystals

\[ f_{44} = 1 + 2f_{33} \]

\[
\begin{bmatrix}
1 & f_{12} & 0 & 0 \\
f_{12} & f_{22} & 0 & 0 \\
0 & 0 & f_{33} & f_{34} \\
0 & 0 & -f_{34} & f_{44}
\end{bmatrix}
\]

\[
\begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1-d & 0 & 0 \\
0 & 0 & d-1 & 0 \\
0 & 0 & 0 & 2d-1
\end{bmatrix}
\]
How often do oriented signatures appear in polarization lidar data?

Oriented rain is frequently observed at all tilt angles
Oriented ice crystals are most frequently observed at 32° tilt

See Hayman et. al, Opt. Express In Review.
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• What polarization lidar observations can safely assume randomly oriented particles?
  • Most ice cloud observations, particularly at near zenith pointing angles
  • Never rain regardless of pointing angle

• What does an atmospheric oriented scattering matrix look like?
  • Ice crystals
    • Significant diattenuation ($f_{12}$)
    • Little or no retardance ($f_{34}$)
    • Dependent diagonal terms
  • Rain
    • Large diattenuation ($f_{12}$)
    • Large retardance ($f_{34}$)
    • Independent diagonal terms

\[
\begin{bmatrix}
1 & f_{12} & 0 & 0 \\
 f_{12} & f_{22} & 0 & 0 \\
0 & 0 & f_{33} & f_{34} \\
0 & 0 & -f_{34} & f_{44}
\end{bmatrix}
\]