

Review of
“Observing Precipitation through Dual-
Polarization Radar Measurements”

by *Paul H. Herzegh and Arthur R. Jameson*

ATMO 689 Polarimetric Radar Meteorology

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Reference:

Herzegh, P. H., and A. R. Jameson, 1992: Observing precipitation through dual-polarization radar measurements. *Bull. Amer. Meteor. Soc.*, **73**, 1365-1374.

Overview

- Introduction and Motivation
- Polarization Radar Parameters
 - Differential Reflectivity (Z_{dr} , dB)
 - Rain
 - Relationship to drop shape, size, and orientation
 - Ice
 - Modulation of shape sensitivity by dielectric factor
 - Linear Depolarization Ratio (LDR, dB)
 - Propagation effects on Z_{dr} and LDR
- Dual-polarization radar observations and applications
 - Stratiform ice phase precipitation
 - Polarimetric bright band – melting processes
 - Rapidly developing convective precipitation
 - Warm rain
 - Z_{dr} column, LDR cap
 - Hailstorm
 - Hail hole, rain vs. hail, Z_{dr} column
- Summary

Motivation

- Meteorological radars use information conveyed by the *amplitude, phase, wavelength, and polarization* of backscattered electromagnetic waves.
 - Conventional Doppler radar use amplitude data at a single, fixed polarization to measure radar reflectivity and estimate precipitation intensity.
 - Typically horizontal (h) polarization (i.e., electric field vector oscillates in the horizontal plane)
 - By transmitting and/or receiving radar signals in two orthogonal polarization states, dual-polarization radars can obtain more detailed information related specifically to precipitation
 - Size
 - Shape
 - Orientation
 - Dielectric strength (i.e., thermodynamic phase [water or ice] and density of ice)
- Applications of dual-polarization radar measurements include: rainfall measurement, hail detection, and identification of hydrometeor types.

Introduction

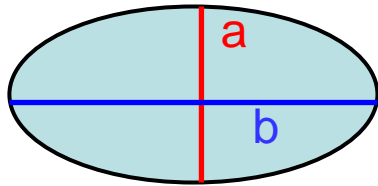
- Most common orthogonal polarization state used in meteorology is **linear polarization**, in which the transmitted wave is plane polarized in either the *horizontal (H)* or *vertical (V)* polarizations.
- For linear polarization, power measurements can be either *copolar* or *cross-polar*.
 - *Copolar*: backscattered radar returns are measured in the same polarization as that transmitted
 - Most backscattered power returns to radar in copolar channel
 - Transmit H; Receive H (e.g., $Z_{HH} \equiv Z_h$)
 - Transmit V; Receive V (e.g., $Z_{VV} \equiv Z_v$)
 - Parameters: Horizontal reflectivity (Z_h); differential reflectivity (Z_{dr})
 - *Cross-polar*: backscattered radar returns are measured in the orthogonal polarization channel
 - Shapes and spatial orientations of hydrometeors induce some of the transmitted wave at one polarization (e.g., H) to return to the radar with the orthogonal polarization (e.g., V).
 - Transmit H; Receive V (e.g., Z_{VH})
 - Transmit V; Receive H (e.g., Z_{HV})
 - Very small amount of backscattered power returns in cross-polar channel (i.e., typically 1-4 orders of magnitude lower than copolar channel).
 - Parameters: Linear depolarization ratio (LDR)

Differential Reflectivity

- Raindrops larger than 1 mm in diameter are deformed into oblate spheroids by aerodynamic forces
 - Drops fall with maximum dimension oriented in the horizontal
 - Slight disturbance in orientation may be induced by turbulence, drop collisions, and aerodynamic instability
 - Scattering and propagation will differ for horizontally and vertically polarized radar waves
 - In moderate to heavy rain, radar reflectivity at horizontal polarization (Z_h , dBZ) is slightly stronger than at vertical polarization (Z_v , dBZ).
- Differential reflectivity (Z_{dr}) is a measure of that difference in copolar backscattered power.
 - $Z_{dr} = Z_h(\text{dBZ}) - Z_v(\text{dBZ}) = 10 \cdot \text{LOG}_{10}(z_h/z_v)$ where units of z_h, z_v : $\text{mm}^6 \text{ m}^{-3}$
 - Typical values range from 0-5 dB
 - Can obtain copolar measurements through rapid switching between horizontal and vertical polarization.

Differential Reflectivity – Rain (shape and size effects)

- Magnitude of Z_{dr} in rain provides an indicator of mean drop shape.
 - Specifically, it is a measure of the *reflectivity-weighted mean axis ratio*.



- Since rain drop size is monotonically related to drop shape (axis ratio: a/b), Z_{dr} measurements can be used to estimate mean equivalent drop size (D_{eq}).
- Fig 1: Z_{dr} (dB) vs. Equivalent rain drop diameter (mm)

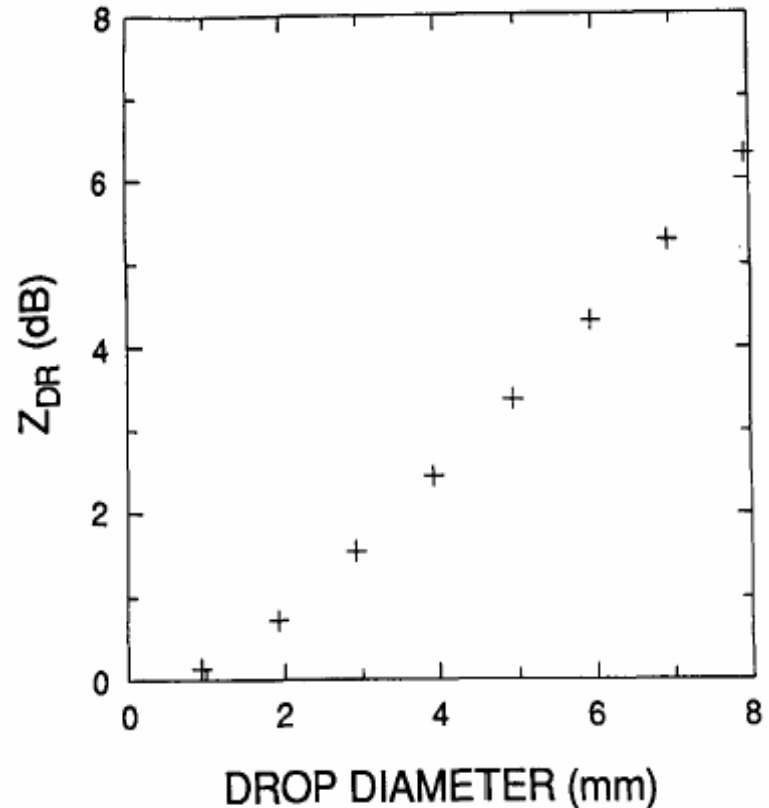


FIG. 1. Calculations of Z_{DR} in decibels as a function of drop diameter for the drop-size shape relationship of Beard and Chuang (1987). Calculations use the scattering theory of Gans (1912).

Differential Reflectivity – Ice (dielectric effects)

- Response of Z_{dr} to hydrometeor shape for ice is very different than for water drops.
 - Shapes of ice particles and water drops are different
 - Also, Z_{dr} sensitivity to hydrometeor shape varies with dielectric constant of the scattering hydrometeors.
 - Since dielectric constant of ice is about 20% that of water, particle shape has a much smaller effect on Z_{dr} measurement in ice than in liquid water hydrometeors.
 - Inclusion of air in ice particles of low bulk density (e.g., snow) lowers effective dielectric constant further.
- Fig. 2: Z_{dr} (dB) vs. axis ratio (a/b) for oblate spheroids of varying dielectric.
 - Rain
 - Solid ice (hail, ice crystals; 0.9 g cm^{-3})
 - Graupel (bulk density: $0.3\text{-}0.6 \text{ g cm}^{-3}$)
 - Snow (bulk density: $0.03\text{-}0.12 \text{ g cm}^{-3}$)
- Canting can also decrease Z_{dr}
 - Mean canting angle in rain is zero
 - Hail wobbles and spins in descent

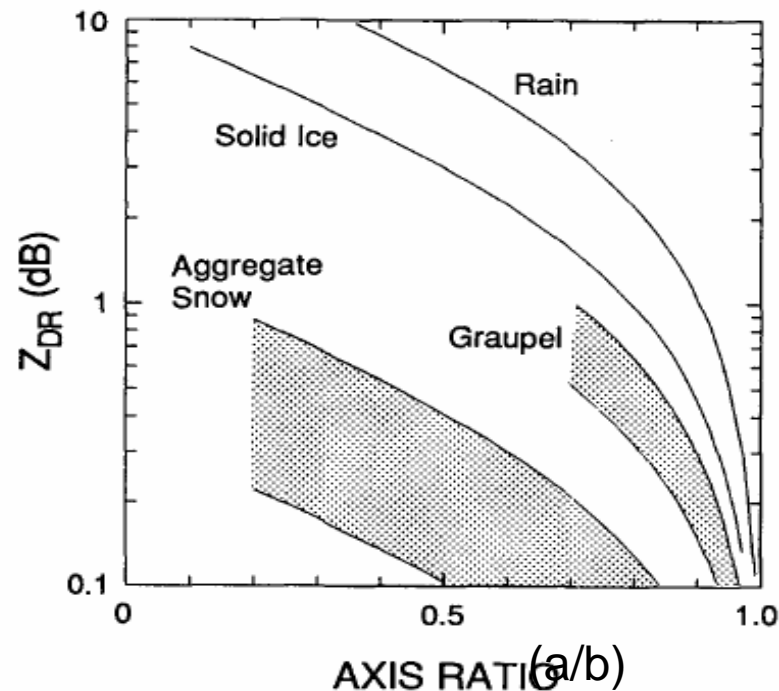


FIG. 2. Calculations of Z_{DR} in decibels as a function of particle axis ratio for spheroids having the effective dielectric properties of raindrops, solid ice, graupel, and aggregate snow. As axis ratio decreases from 1 toward 0, particle (spheroid) shape becomes more oblate. Curves shown for graupel cover bulk densities of 0.3 g cm^{-3} (lower boundary of shaded region) to 0.6 g cm^{-3} (upper boundary). Values shown for aggregate snow cover bulk densities of 0.03 g cm^{-3} (lower boundary of shaded region) to 0.12 g cm^{-3} (upper boundary). Calculations use the scattering theory of Gans (1912).

Linear Depolarization Ratio

- Non-spherical hydrometeors, which are canted with respect to the axis of polarization (say H), will cause a small fraction (0.1% to 1%) of the incident radar energy to be depolarized, or scattered at the orthogonal polarization (V).
 - Amount of depolarized energy depends on size, effective aspect ratio or shape, dielectric constant, degree of canting, and radar viewing angle.
- Linear depolarization ratio (LDR) is given by the ratio of the depolarized or cross-polar return (which reaches the radar as a vertically polarized wave) over the copolar return (which retains the horizontal polarization of the original transmitted wave).
 - $LDR(dB) = Z_{VH}(dBZ) - Z_{HH}(dBZ) = 10 * LOG_{10}(z_{VH}/z_{HH})$ where units of z_{VH}, z_{HH} : $mm^6 m^{-3}$
- Response to hydrometeor shape and canting angle effects is strongly tied to the effective dielectric constant of the hydrometeors.
 - Larger dielectric yields more sensitivity to drop shape and canting
 - Oblate hydrometeors in mixed phase or wetted conditions yield high-LDR signatures (i.e., have some shape, are canting, and have high dielectric)

Propagation Effects

- Interaction of radar wave and hydrometeors it encounters can significantly modify the wave as it travels to target.
 - Absorption and scattering of wave energy
 - Can affect interpretation of dual polarization measurements, especially for shorter wavelengths (i.e., $\lambda \leq 5$ cm)
- Oblate shapes of raindrops can induce *differential attenuation*, in which attenuation at horizontal polarization is greater than at vertical polarization.
- Raindrops and oriented ice crystals can also induce *differential phase shift*, in which return of the horizontal signal slightly lags that of the vertical signal
 - Due to a slight difference in propagation speeds at the two polarizations
- Differential attenuation and phase shift are range cumulative effects
 - Progressively influence radar measurement as path length through precipitation increases.
- Differential attenuation has significant effect on Z_{dr} , particularly for $\lambda \leq 5$ cm
 - Reduces radar estimate of Z_h more than Z_v , leading to a decrease in Z_{dr} that increases with range through rainfall.
 - Not *usually* a significant effect at S-band (10 cm) (but can be in right situation!)
- Differential attenuation and phase shift affect LDR, particularly for $\lambda \leq 5$ cm
 - X-band (3.2 cm) in this paper
 - Differential attenuation leads to over-estimation of LDR for path lengths of 5-10 km through $R \geq 5-10$ mm h⁻¹.
 - Differential phase shift progressively alters the polarization of the radar signal, thus influencing estimate of LDR
 - Some of forward scattered radiation has vertical polarization, thus the propagating wave acquires a significant cross-polarized (vertical) component.
 - Causes radar wave to gradually become elliptically polarized – increases LDR with increasing range.

Dual-polarization application: stratiform ice phase precipitation

- Widespread stratiform precipitation
- Radar bright band associated with hydrometeor (snow) melting appears at 2 km AGL
- Z_{dr} bright band at 1.5 to 2 km
 - Melting of snow into raindrops results in Z_{dr} maximum
- LDR bright band ~ 2 km
 - Wobbling, wet snow that is melting

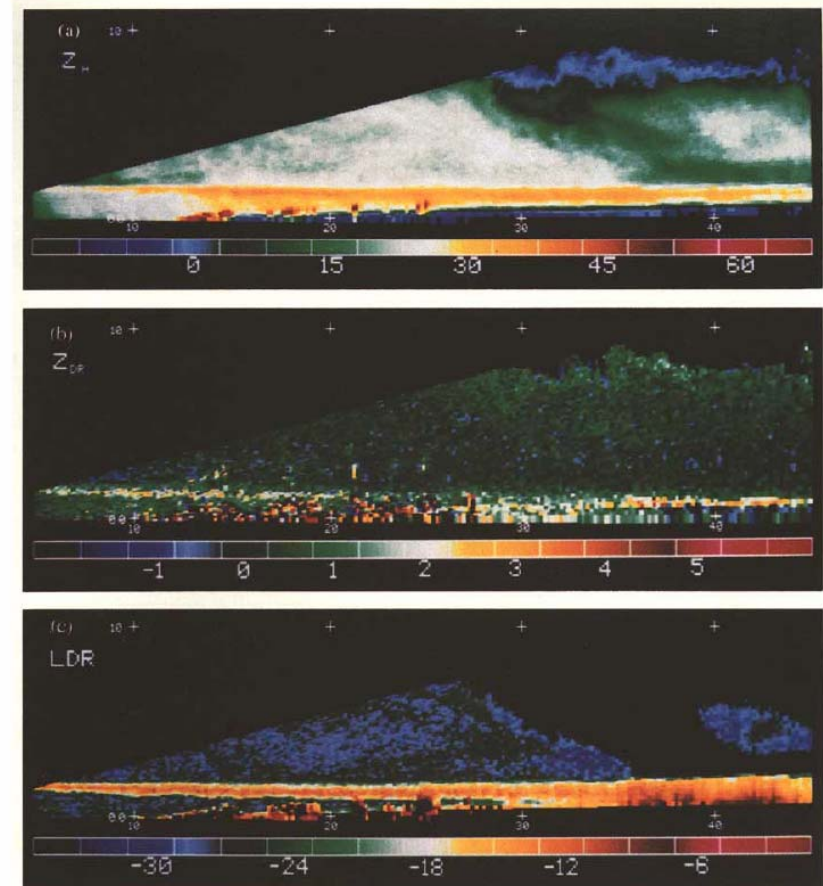


FIG. 3. CP-2 radar data for a vertical section through stratiform upslope precipitation observed on 24 May 1984 near Boulder, Colorado. Color scales at bottom of (a), (b), and (c) indicate values of Z_r , Z_{dr} , and LDR, respectively. (a) Z_r (dBZ) showing a well-defined melting-level bright band at 2 km AGL. (b) Z_{dr} (dB) showing a Z_{dr} bright band near 2 km AGL. (c) LDR (dB) showing a LDR bright band near 2 km AGL. Regions in which LDR signals are below the detectable level are shown in black.

Dual-polarization application: developing warm rain convection

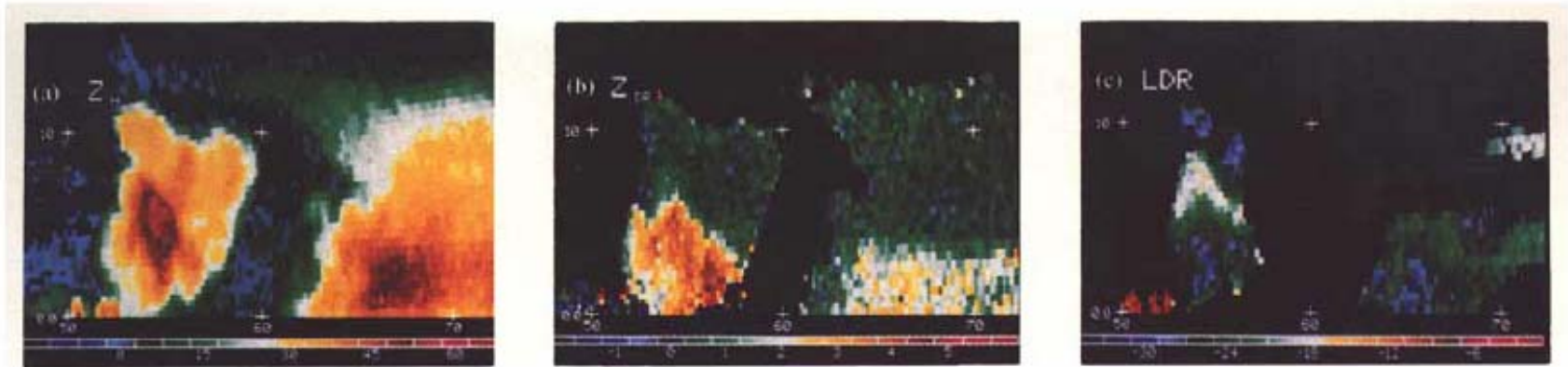


FIG. 4. As in Fig. 3, but for a rapidly developing convective cell (at 54-km range) observed near Huntsville, Alabama, on 25 July 1986. Color scales at bottom of (a), (b), and (c) indicate values of Z_h , Z_{DR} , and LDR, respectively. Evidence of supercooled water drops above the 5-km freezing level is given in (b). LDR signature associated with mixed-phase precipitation growth is given in (c).

- Notice “ Z_{dr} column” – supercooled water drops that extend above environmental freezing level
- Notice “LDR cap” – maximum of LDR at top of Z_{dr} column indicates freezing of drops – mixed phase and wetted particles that cant.
- Importance of coalescence-freezing microphysics
 - Warm rain to frozen drops

Dual polarization applications – mature hailstorm

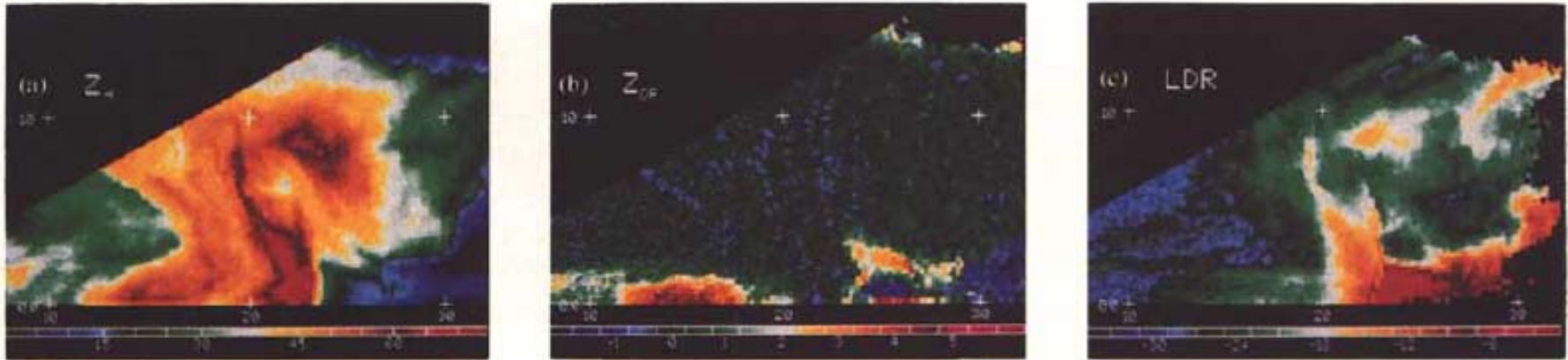


FIG. 5. As in Fig. 3, except for a severe hailstorm observed over Denver, Colorado, on 13 June 1984. Color scales at bottom of (a), (b), and (c) indicate values of Z_h , Z_{DR} , and LDR, respectively. (a) Z_h (dBZ,) showing the precipitation core at 22-km range. (b) Z_{DR} (dB), showing a hail signature at the surface at 22-km range and a region of supercooled water drops in the storm inflow aloft from 23- to 29-km range. (c) LDR (dB), showing significant propagation effects through the rain near the surface and beyond the precipitation core aloft.

- Notice high Z_h and low Z_{dr} signature – “hail hole”
 - Indicative of hail near surface
- Notice elevated Z_h and LDR aloft – hail signature aloft
- Notice Z_{dr} column feeding updraft in weak echo region
 - Some hail embryos may be frozen drops

Summary

- Dual polarization radar measurements of precipitation are sensitive to size, shape, orientation, and dielectric strength (phase and density).
 - Therefore, can serve as tool for remote hydrometeor ID and microphysical studies.
 - Using Z_h , Z_{dr} , LDR
 - Z_{dr}
 - Differentiate solid and liquid water precipitation – hail ID
 - Rain drop size
 - Identification of supercooled drops
 - LDR
 - Hail regions
 - Mixed phase and drop freezing environments
 - melting