Using Polarimetric Radar to Take Microphysical Fingerprints in Precipitation

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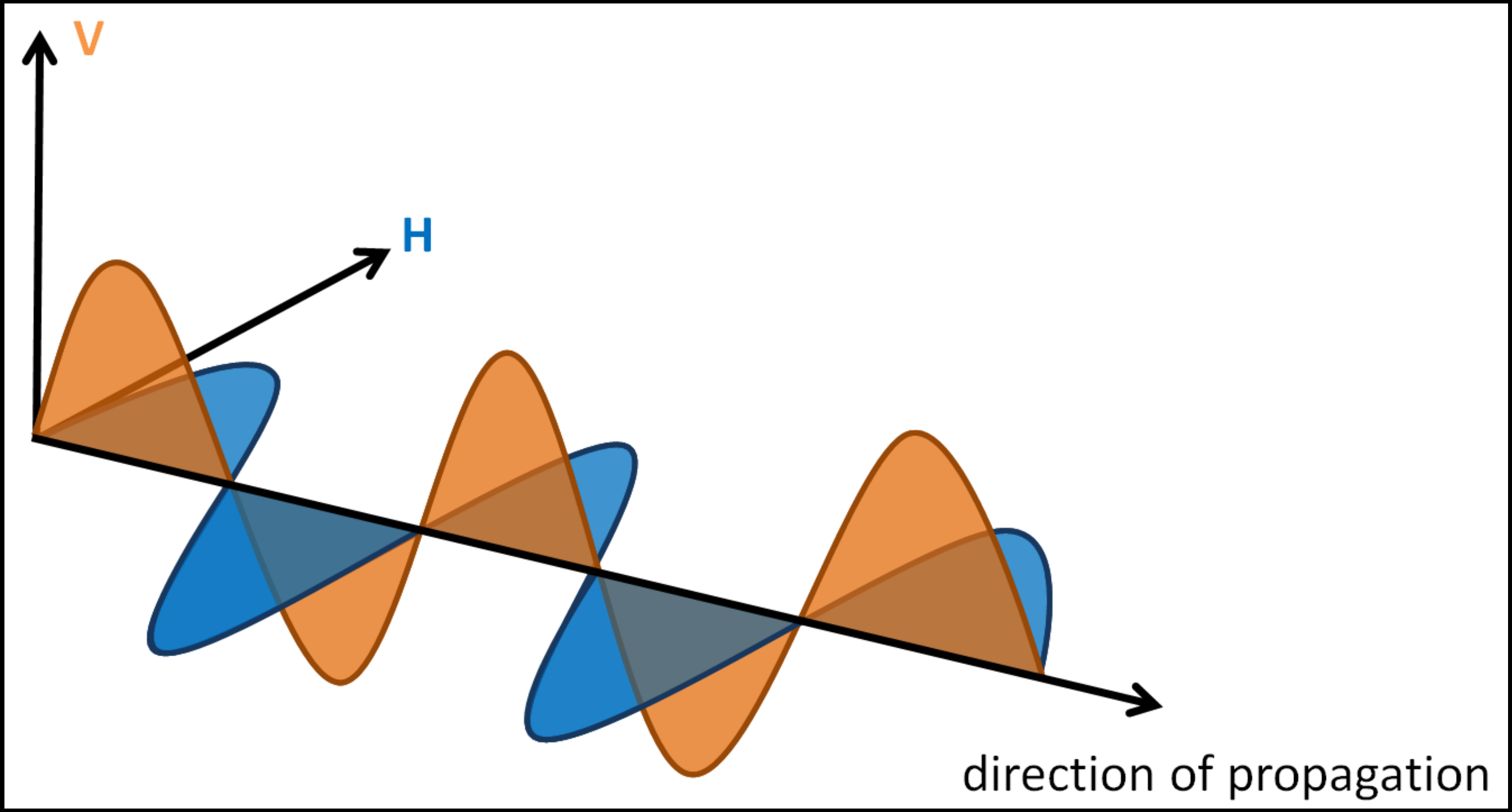
ARM Summer Workshop
20 July 2015
Norman, Oklahoma, USA

Motivation

- What can dual-polarization radar tell us about ongoing microphysical processes in clouds?

- If we can identify different processes, perhaps we can:
  - Distinguish them
  - Determine what conditions favor/disfavor them
  - Quantify them
  - Evaluate how well models treat them
  - Improve model representations of them

What is Polarimetric Radar?



Dual-Polarization Radar: Principles

Polarimetric radar variables:

Reflectivity factor at horizontal polarization: Z_H

Doppler velocity: V

Doppler spectrum width: SW

Differential reflectivity factor: Z_{DR}

Propagation differential phase shift: Φ_{DP}

- Specific differential phase: K_{DP}

Co-polar cross-correlation coefficient: ρ_{hv}

Available from the CSAPRs, XSAPRs

Backscatter differential phase shift: δ

Linear depolarization ratio: LDR

Differential Doppler velocity: V_{DV}

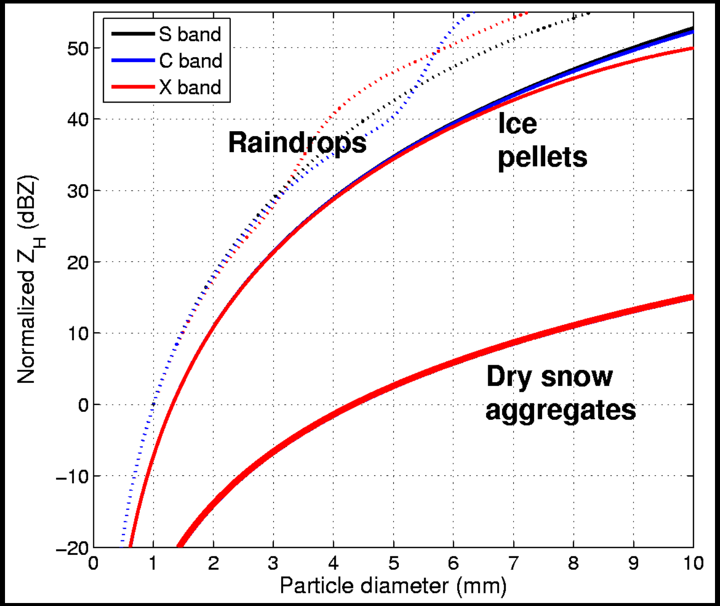
Co-cross-polar correlation coefficients: ρ_{xh}, ρ_{xv}

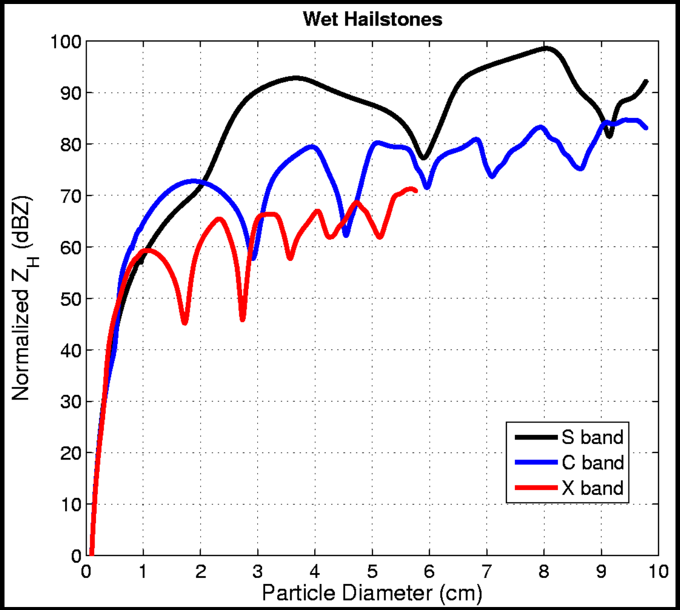
Cross-polar (depolarization) phase shifts: $\delta_{cr}^{(h)}$, $\delta_{cr}^{(v)}$

Dual-Polarization Radar: Principles

Reflectivity factor at horizontal polarization, Z_H

- Dependent on the size and concentration of hydrometeors, as well as their density and composition (which affect the particle's refractive index).
- Is a measure of the **amplitude** of the backscattered radiation from a collection of particles within the radar sampling volume.





Dual-Polarization Radar: Principles

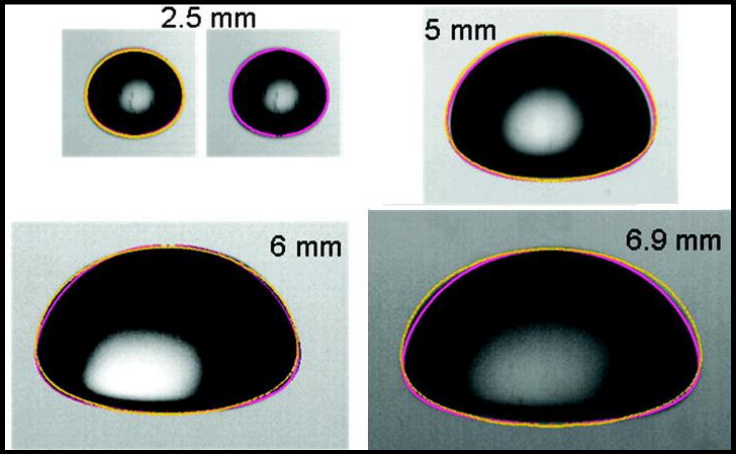
Differential reflectivity factor, Z_{DR}

- Is the difference between Z_H and Z_V (in logarithmic units)
- Dependent on the shape of hydrometeors, as well as their density and composition (which affect the refractive index).
- Is independent of hydrometeor concentration.
- Is a measure of the **reflectivity-weighted shape** of a collection of particles within the radar sampling volume.

Dual-Polarization Radar: Principles

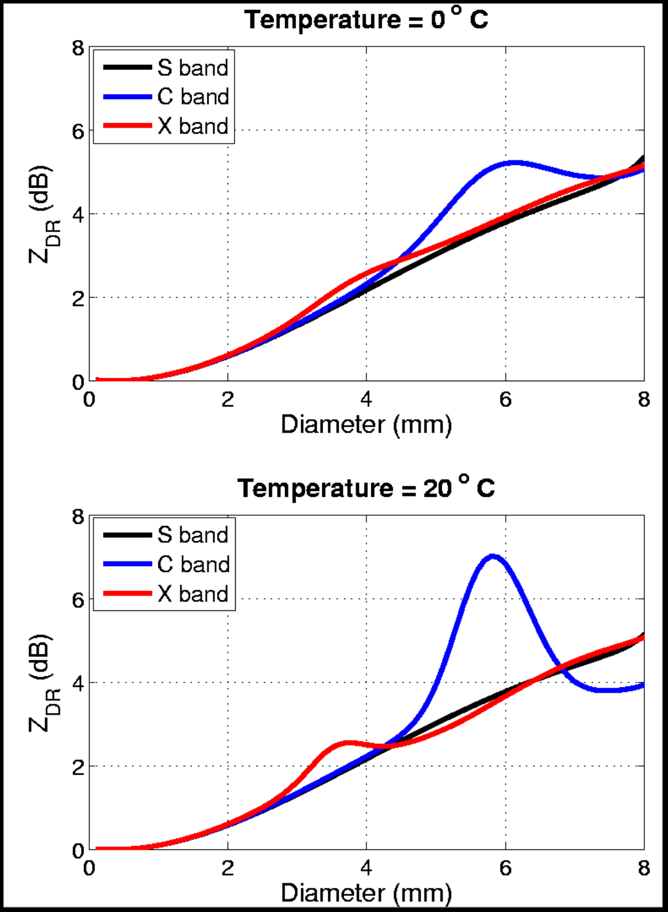
Differential reflectivity factor, Z_{DR}

- Raindrop oblateness increases with increasing size…



Adapted from Thurai et al. (2009)

…so Z_{DR} increases with increasing raindrop size.



Notice the temperature dependence: warmer raindrops produce larger resonance scattering effects at C and X bands

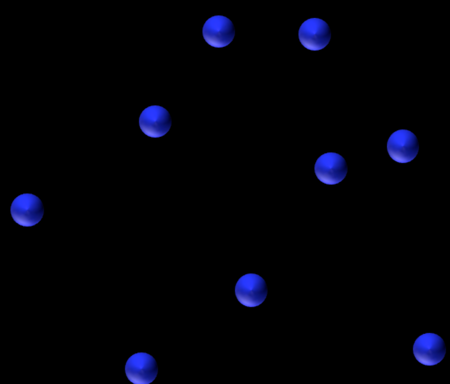
Dual-Polarization Radar: Principles

Differential reflectivity factor, Z_{DR}

For particles of the same size and nonspherical shape, Z_{DR} decreases for decreasing dielectric constant

	ε_{water}	ε_{ice}	ε_{snow}
C-band values:	$72.8 - j22.4$	$3.17 - j0.0023$	$\sim 2.0 - j0.0001$

Spherical particles have Z_{DR} = 0 dB, regardless of size or composition



[drizzle]

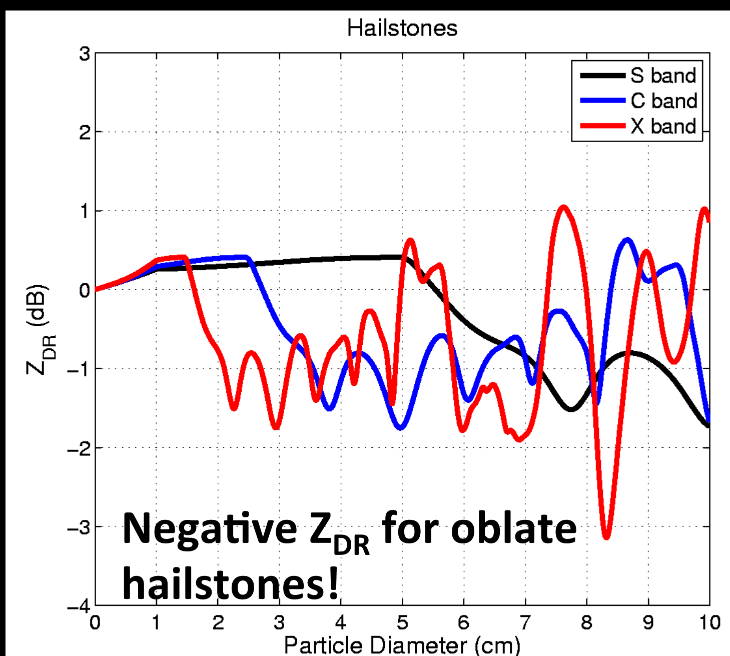
Dual-Polarization Radar: Principles

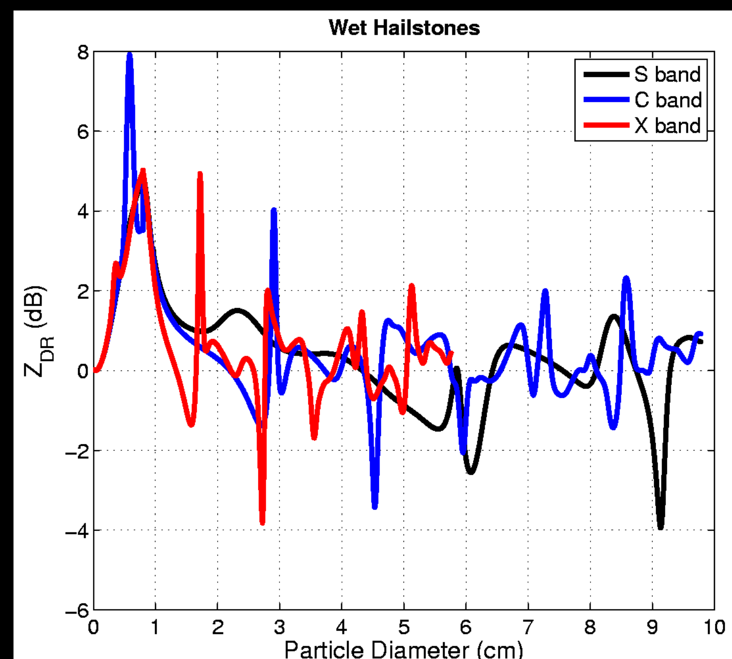
Differential reflectivity factor, Z_{DR}

Increased wobbling (i.e., increased distribution of canting angles within a radar sampling volume) leads to decreased Z_{DR}.

Totally chaotic orientation leads to Z_{DR} = 0 dB

Z_{DR} behavior becomes complicated for resonance (Mie regime) scatterers:



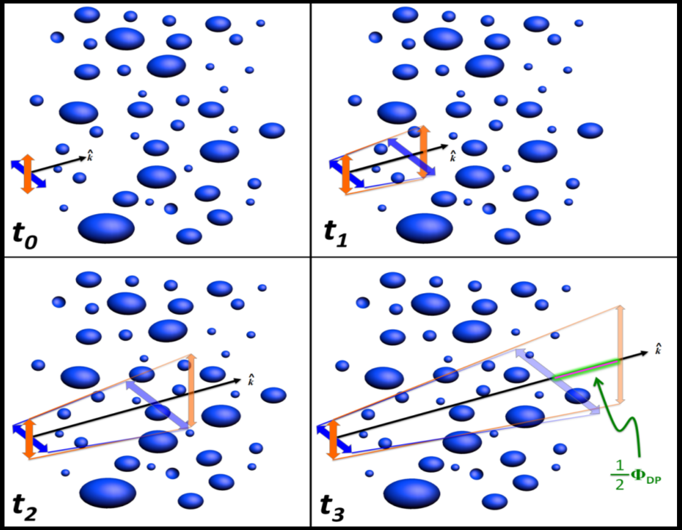


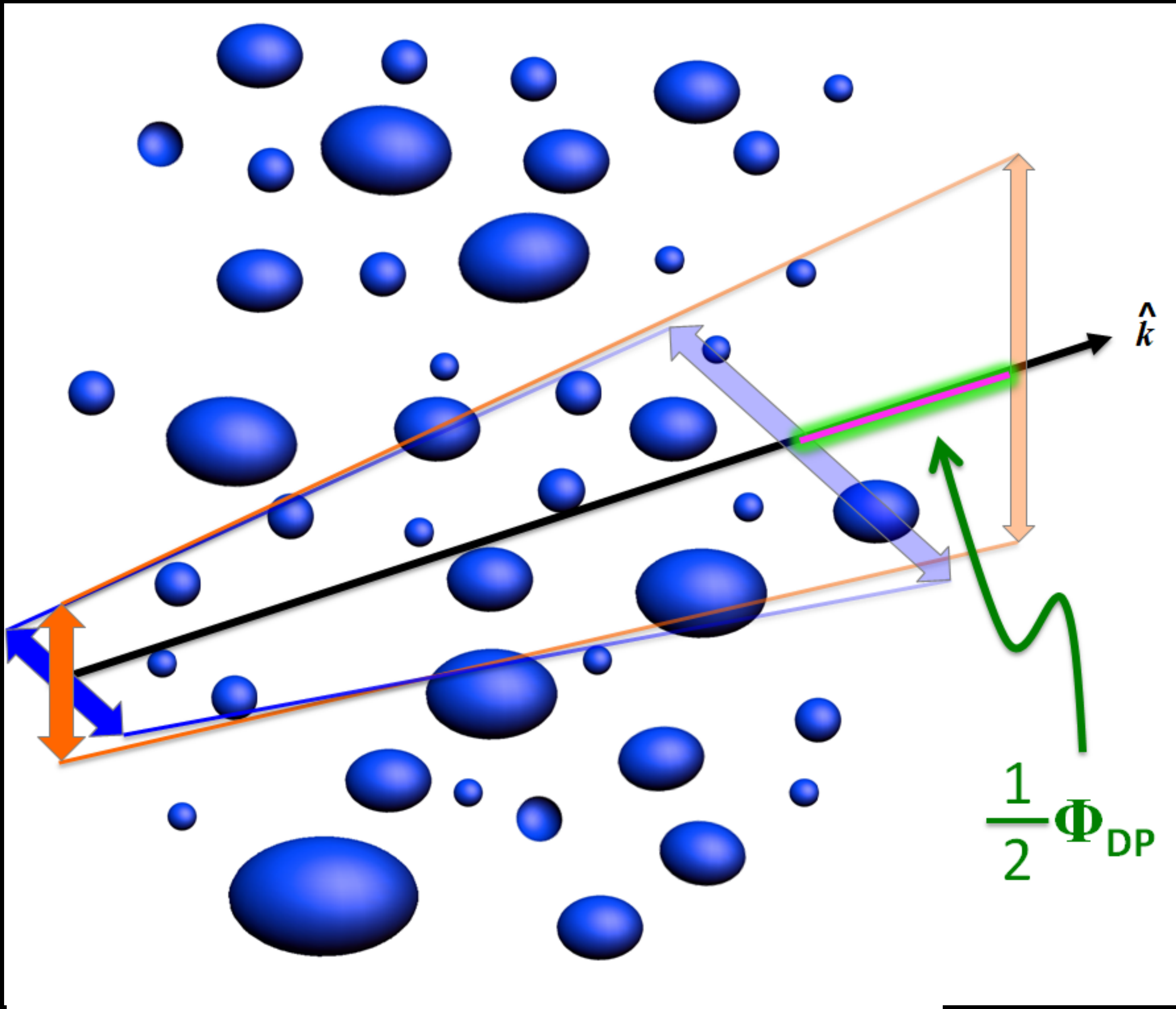
Dual-Polarization Radar: Principles

Specific Differential Phase Shift, K_{DP}

Electromagnetic radiation propagating through a dielectric medium acquires an additional phase shift compared to the same propagation distance through a vacuum. This can be thought of as the wave *traveling slower* through the medium.

Anisotropic particles will cause a *differential propagation phase shift* (Φ_{DP}) between the H- and V-polarization waves. One half of the range derivative of Φ_{DP} is the specific differential phase shift, K_{DP}. This tells us the amount of phase shift accumulated per unit distance (per km).





$\hat{k}$
$\frac{1}{2}\Phi_{DP}$

Dual-Polarization Radar: Principles

Specific Differential Phase Shift, K_{DP}

- Is dependent on particle concentration and size, as well as their composition.
  (Note: raindrop size dependence is weaker than Z_H. Thus, K_{DP} is more sensitive to changes in the small-drop end of the spectrum).

- Is not affected by spherical (or randomly-tumbling) particles.

- Because it is a *phase* measurement, it is immune to radar miscalibration, attenuation and differential attenuation, partial beam blockage, and is not biased by noise.

Dual-Polarization Radar: Principles

Co-polar cross-correlation coefficient, ρ_{hv}

$$|\rho_{hv}| = \frac{|\langle s_{hh}^{*} s_{vv} \rangle|}{\sqrt{\langle |s_{hh}|^2 \rangle}\sqrt{\langle |s_{vv}|^2 \rangle}}$$

- Is a measure of the variability of scattering properties within the radar sampling volume. In other words,

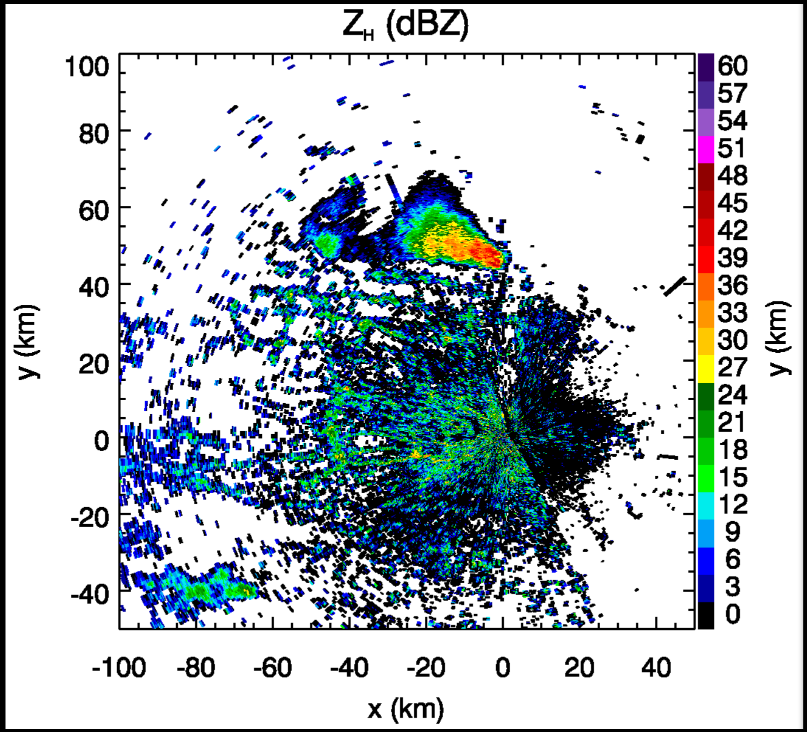
  variability of certain physical properties of hydrometeors (those that affect the backscattered amplitude and phase at H- and V-polarization) causes a reduction of ρ_{hv}.

This includes particle shape, orientation angle, and composition (i.e., complex dielectric constant).

Dual-Polarization Radar: Principles

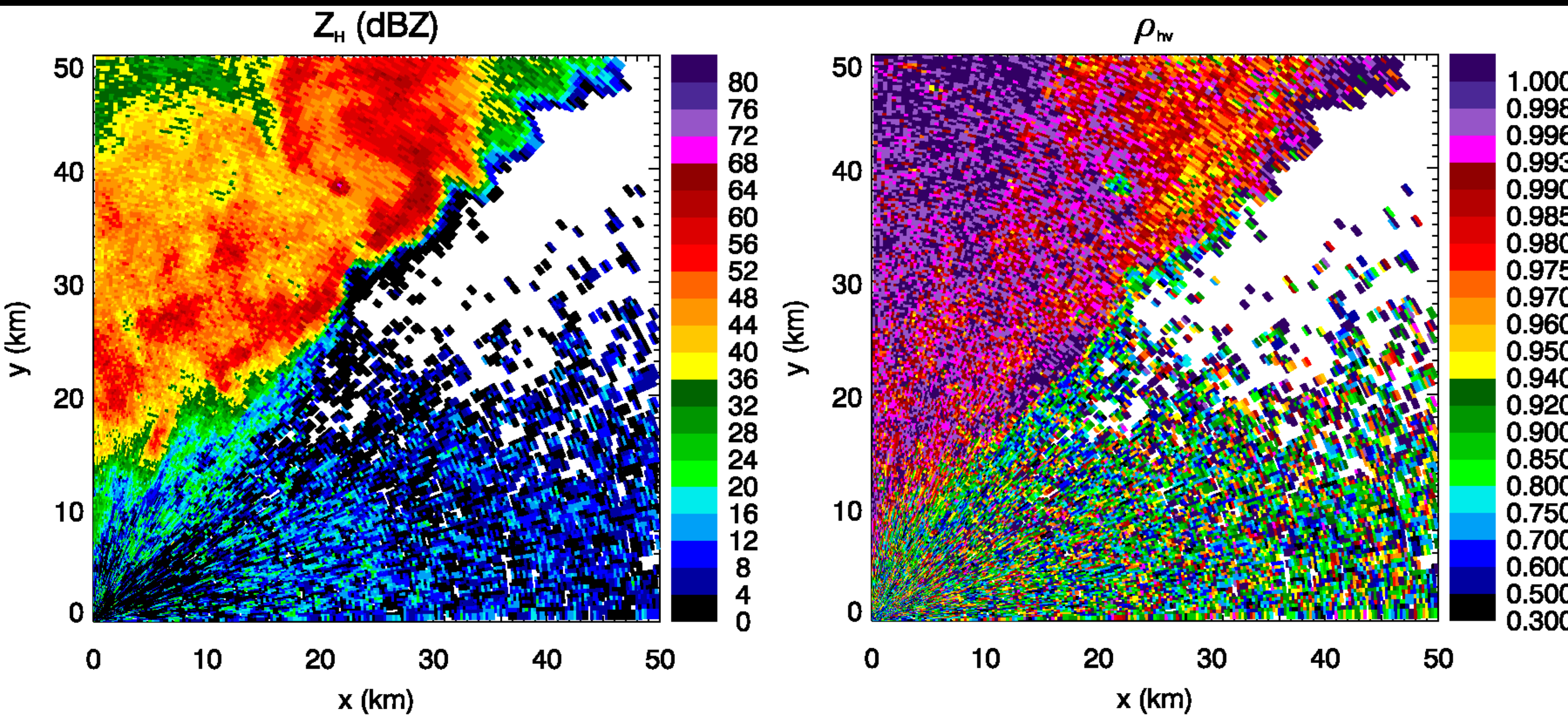
Co-polar cross-correlation coefficient, ρ_{hv}

- Is close to 1.0 in pure rain, pure aggregated snow, pure graupel, etc.
- Is lowered in a mixture of rain and snow, rain and hail, and in the presence of Mie scatterers (e.g., large wet hail).
- Is anomalously low in nonmeteorological targets



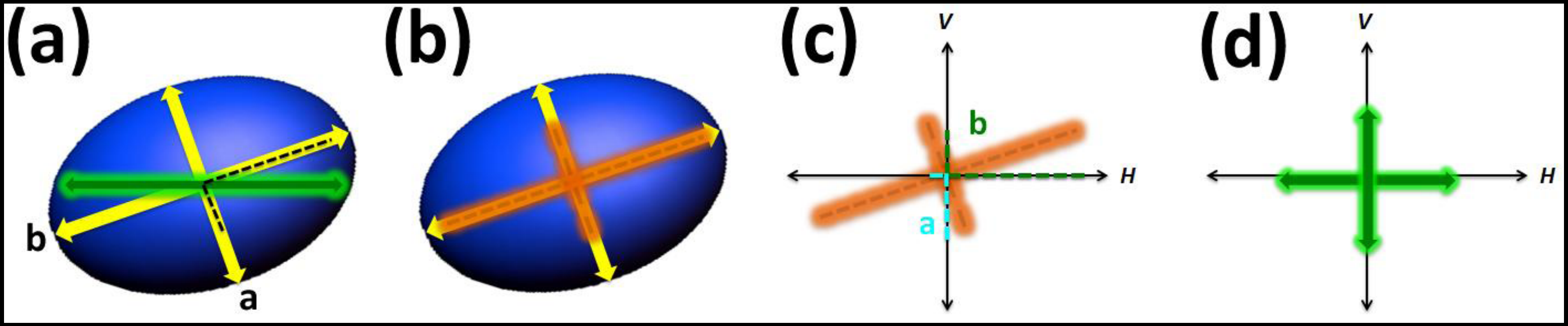
Dual-Polarization Radar: Principles

Co-polar cross-correlation coefficient, ρ_{hv}



Dual-Polarization Radar: Principles

Linear depolarization ratio, LDR



- Is the ratio of the magnitude of the depolarized component of the backscattered signal to the co-polar component.

- Is independent of hydrometeor concentration

Dual-Polarization Radar: Principles

Linear depolarization ratio, LDR

- Increases for irregularly shaped particles that are canted with respect to incident wave polarization

- Affected by the dispersion of hydrometeor canting angles

- For a given particle shape and canting, increases with increasing ϵ

Precipitation Processes

What could happen to raindrops after they form?

- Sedimentation
- Collision
- Coalescence
- Breakup
- Evaporation
- Collection by ice
- Freezing

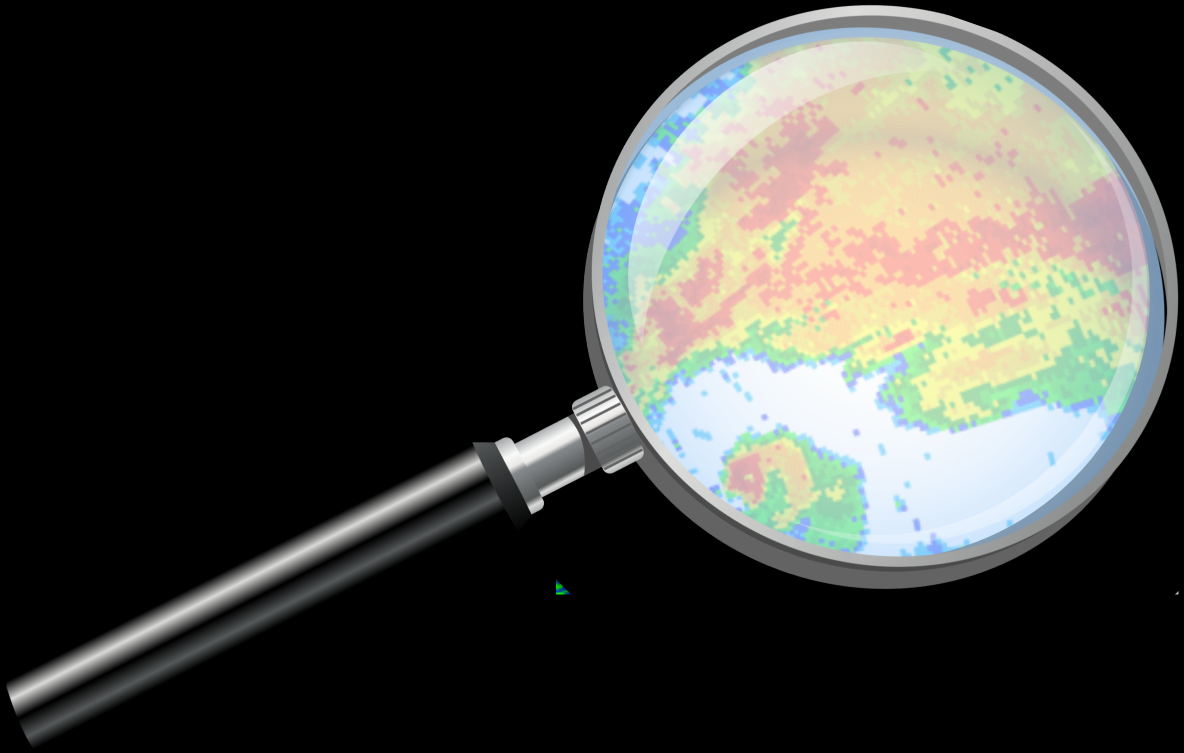
Precipitation Processes

If a collection of drops in the radar sampling volume undergoes changes (in size, concentration, phase, etc.), they could produce predictable changes in the observed radar variables!

Precipitation Processes

These changes can be thought of as "**microphysical fingerprints**"

Let's investigate what types of fingerprints may arise from different physical processes.



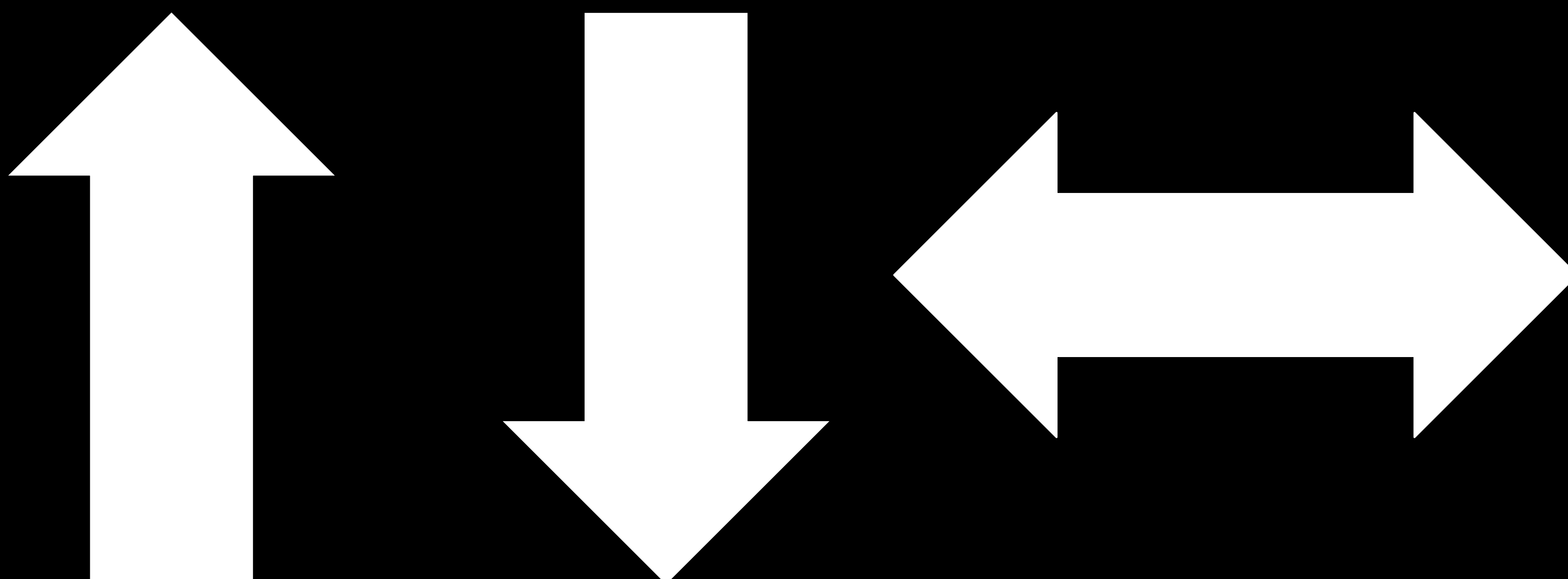
Raindrop Coalescence

- Two or more raindrops collide and merge, forming a single, larger raindrop

How might this affect the different polarimetric radar variables?

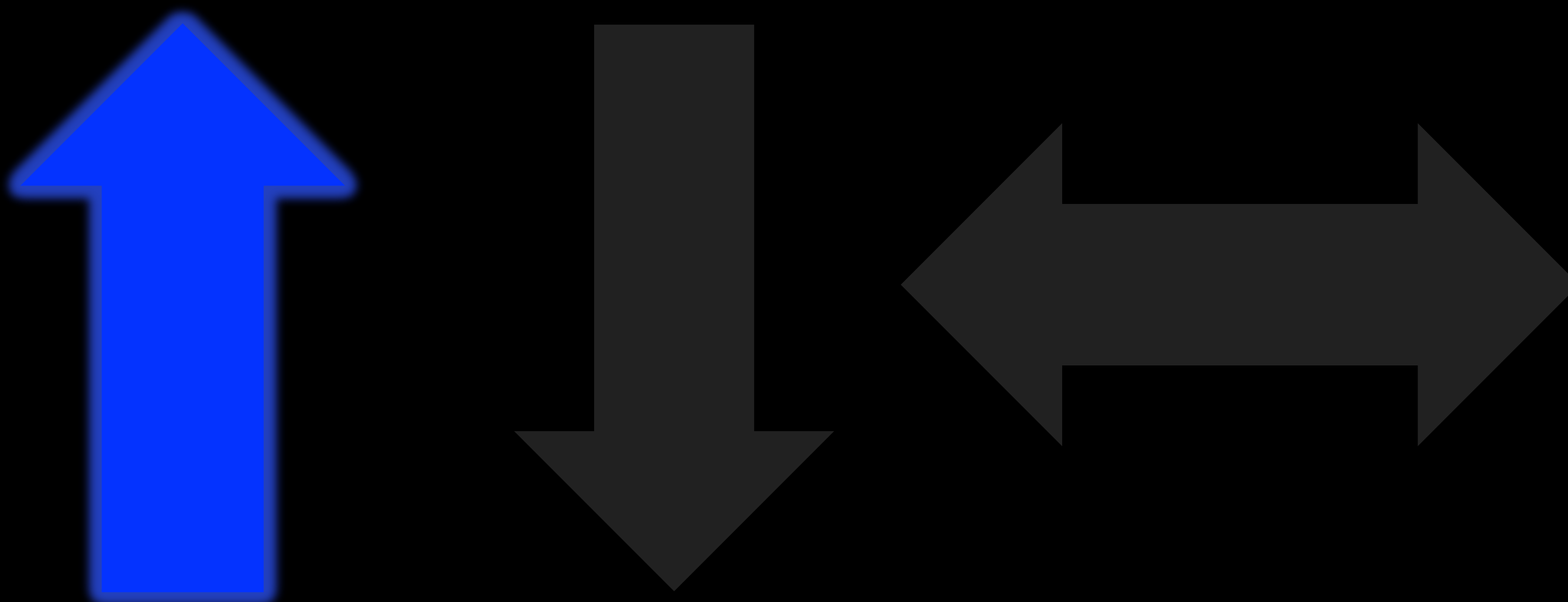
Raindrop Coalescence

Reflectivity factor at horizontal polarization, Z_H



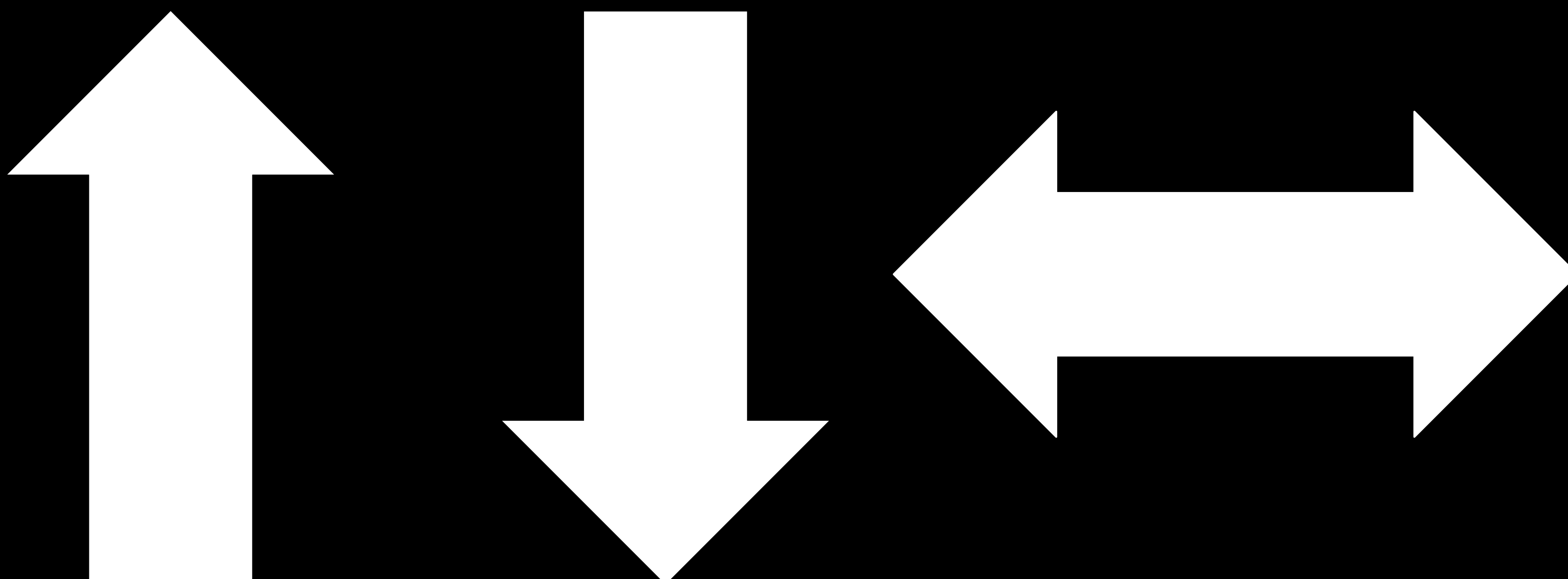
Raindrop Coalescence

Reflectivity factor at horizontal polarization, Z_H



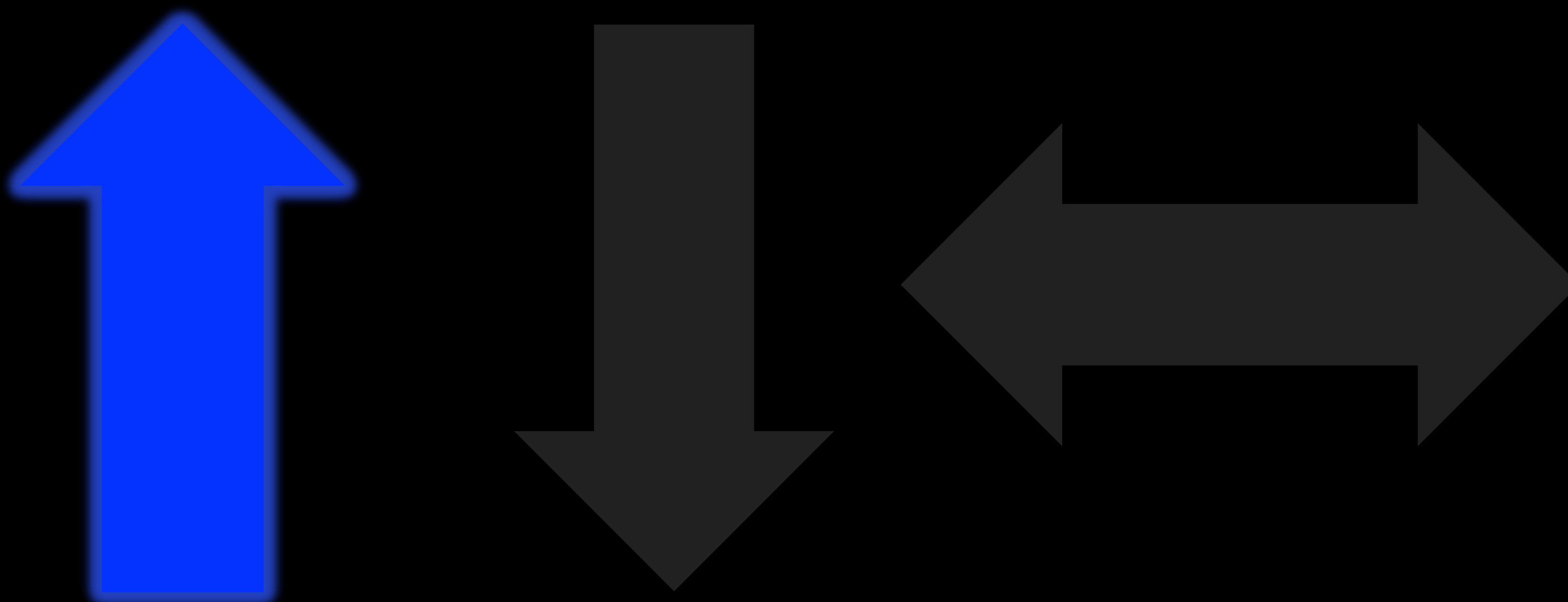
Raindrop Coalescence

Differential reflectivity, Z_{DR}



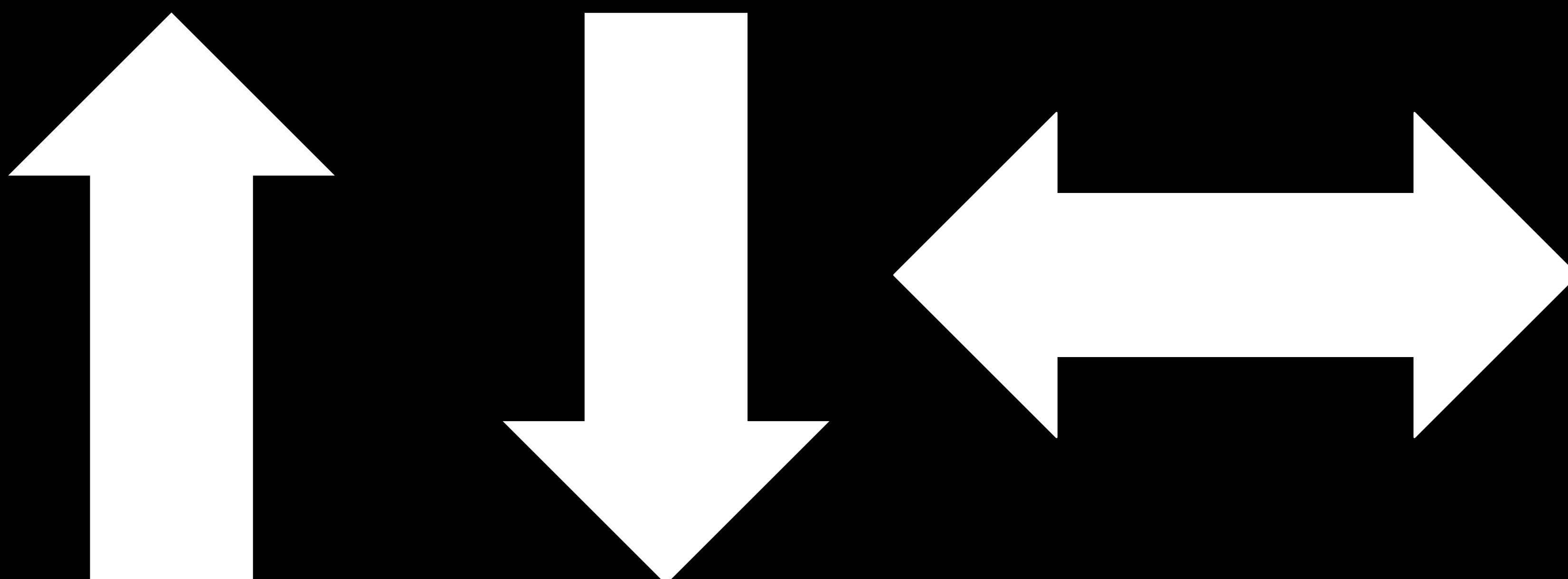
Raindrop Coalescence

Differential reflectivity, Z_{DR}



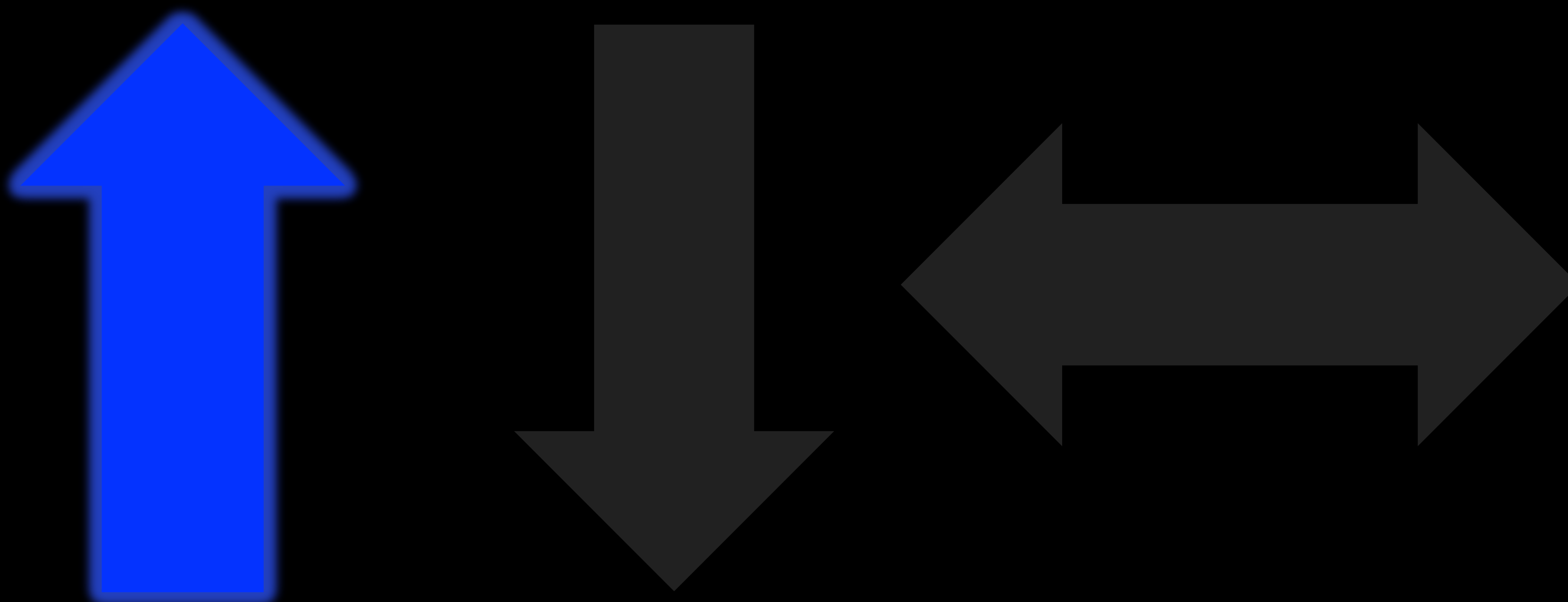
Raindrop Coalescence

Specific differential phase, K_{DP}

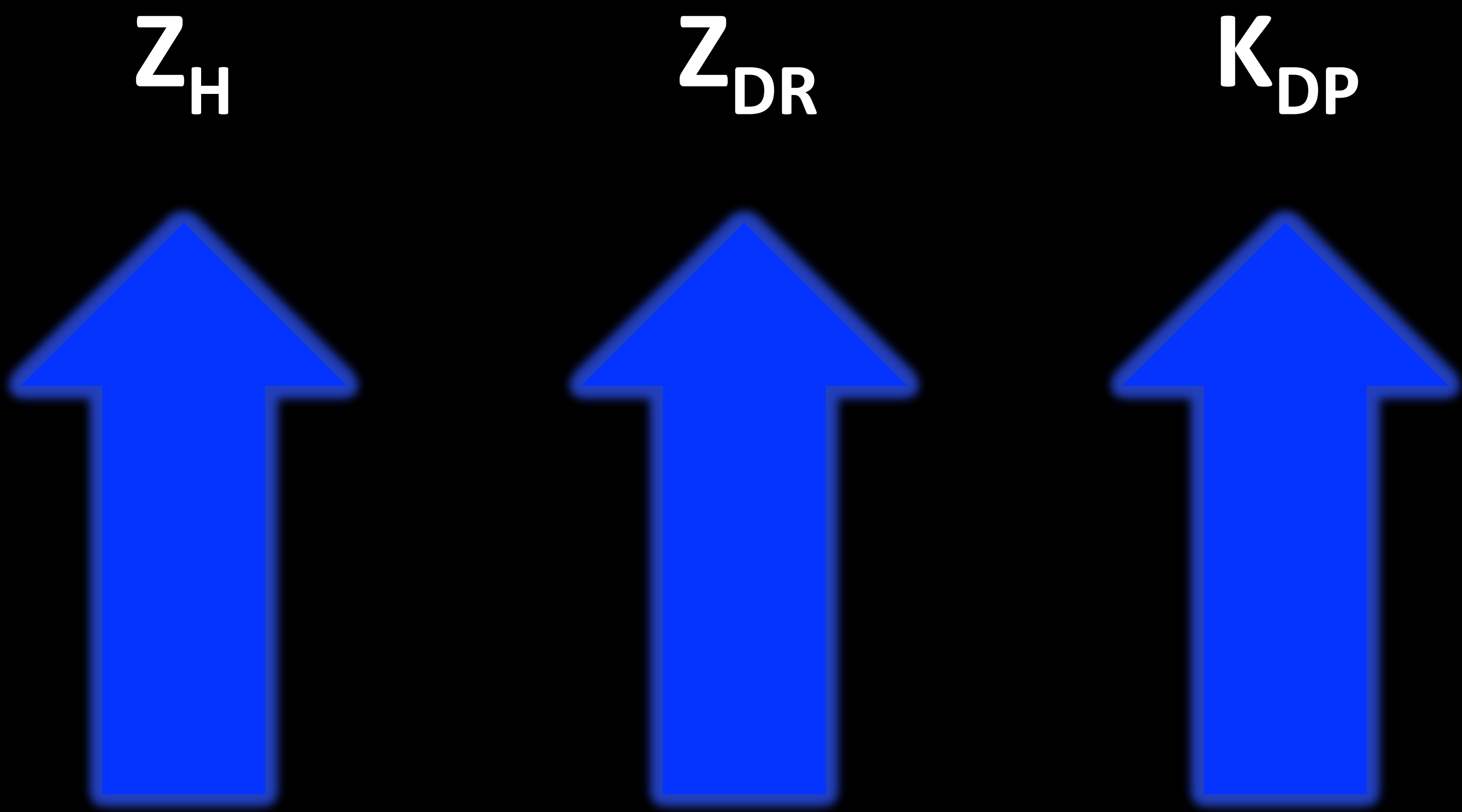


Raindrop Coalescence

Specific differential phase, K_{DP}



Raindrop Coalescence



Raindrop Breakup

A raindrop breaks up into multiple smaller fragments

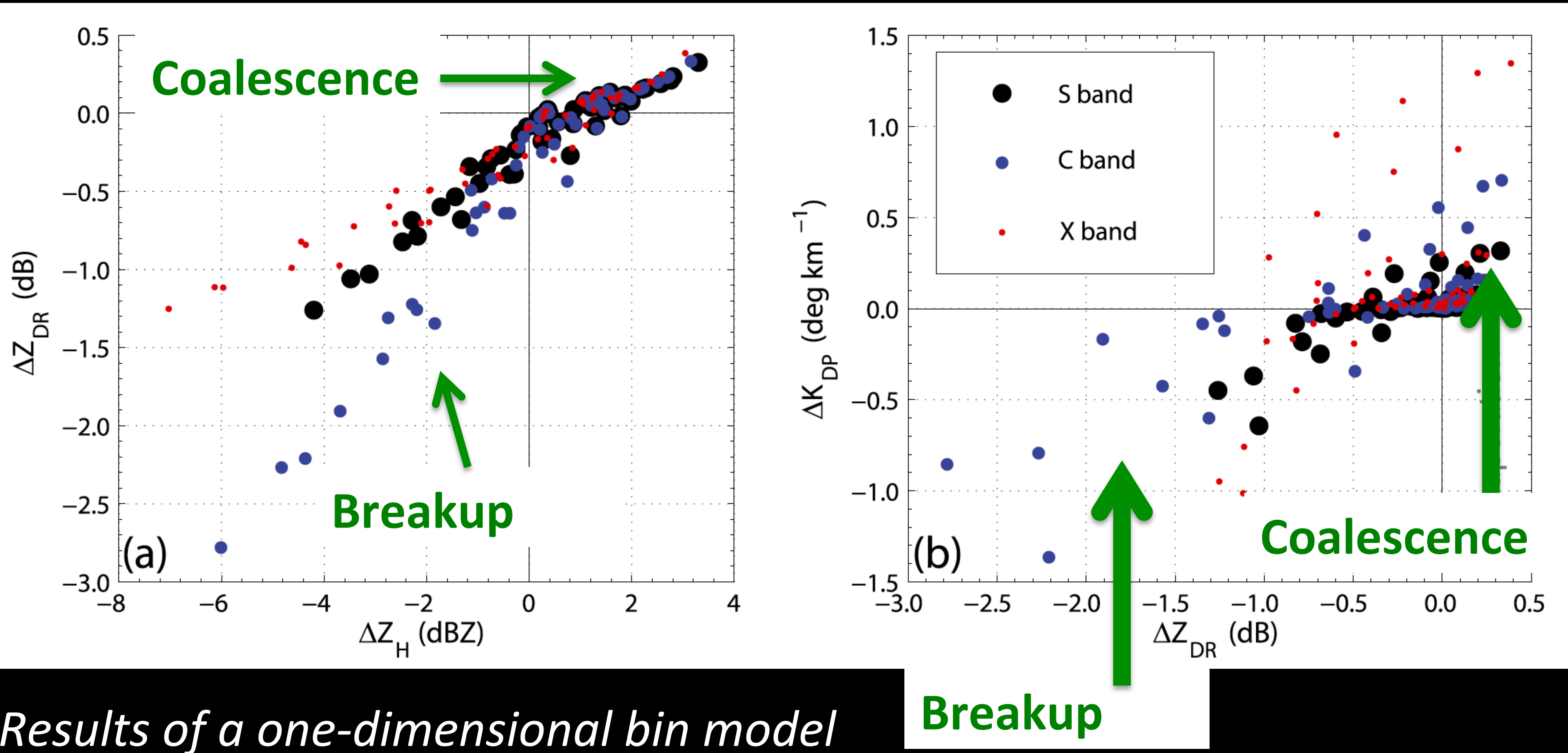
Z_H Z_{DR} K_{DP}

Raindrop Collisional Processes

Of course, in our atmosphere, these processes may both occur. *Which one dominates*?

It depends!

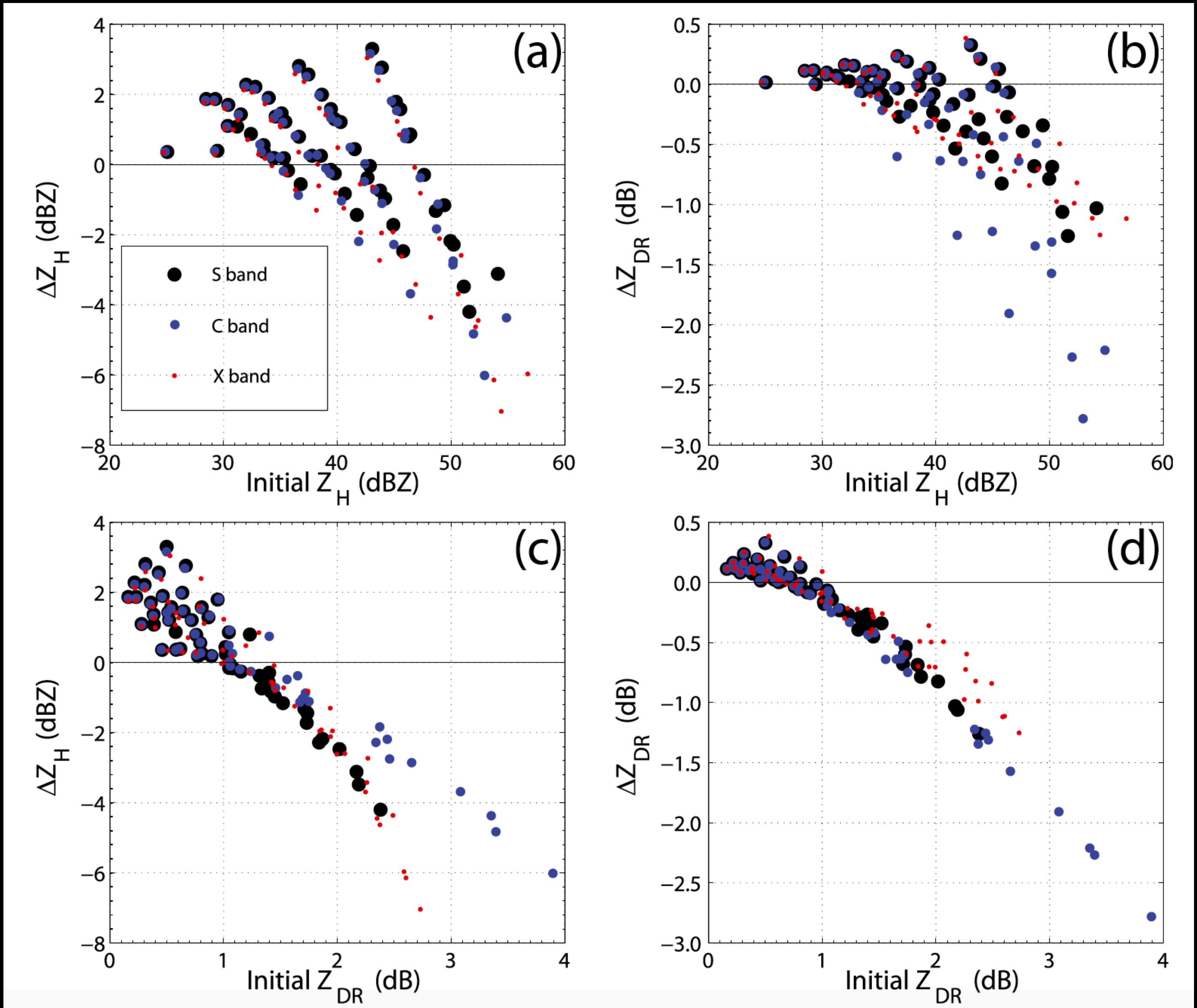
Raindrop Collisional Processes



Results of a one-dimensional bin model

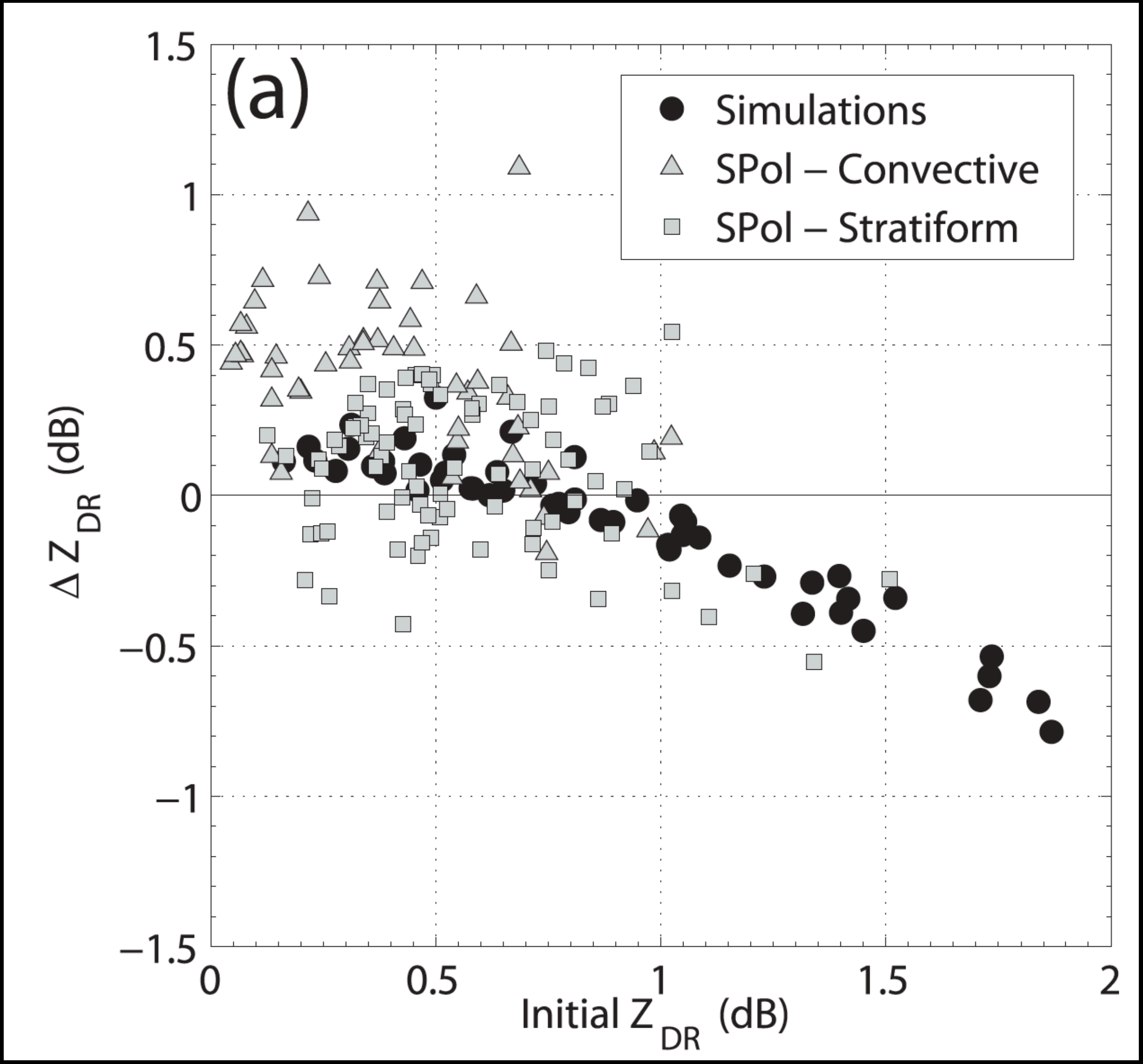
Raindrop Collisional Processes

Simple 1D bin model



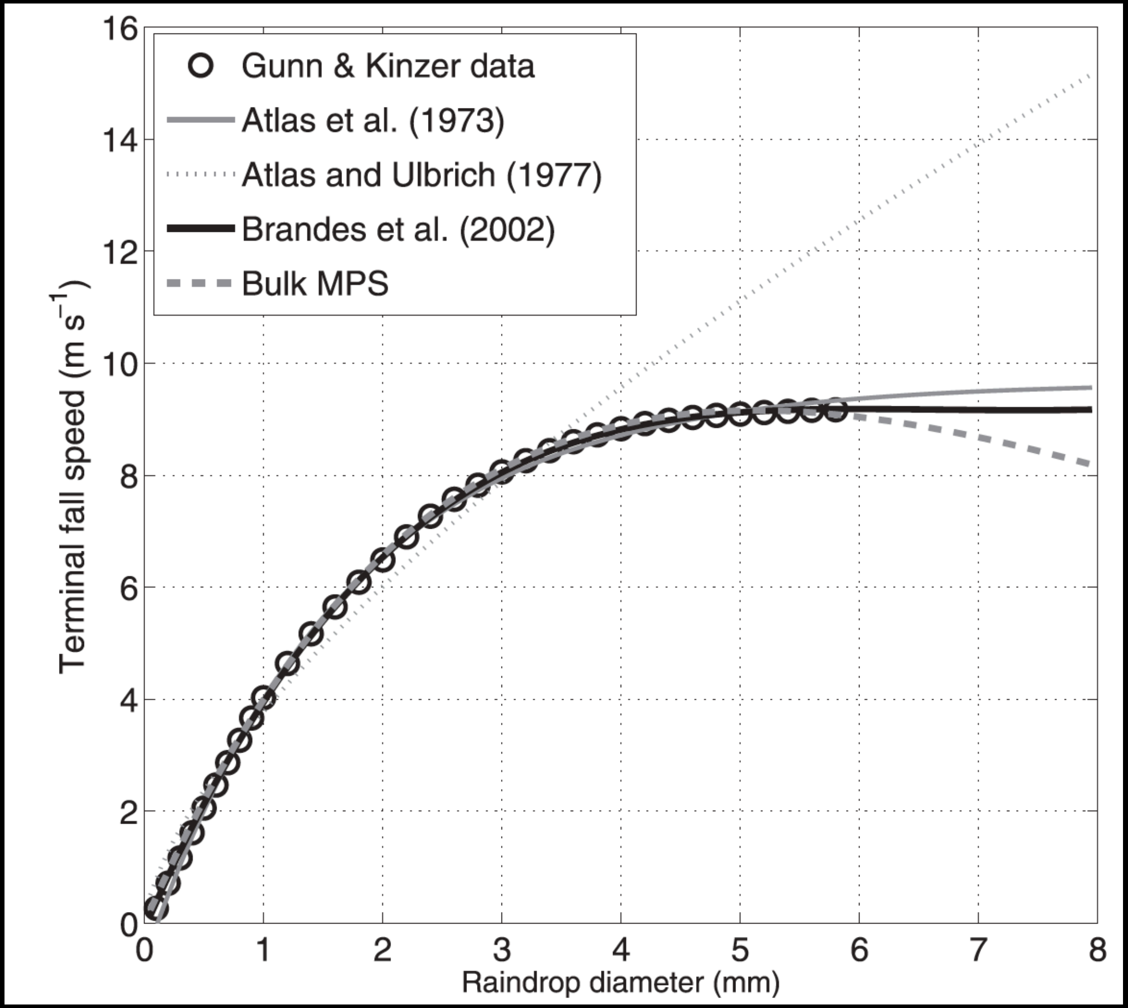
Raindrop Collisional Processes

Observations?



Raindrop Size Sorting

- Big raindrops fall faster than small raindrops.



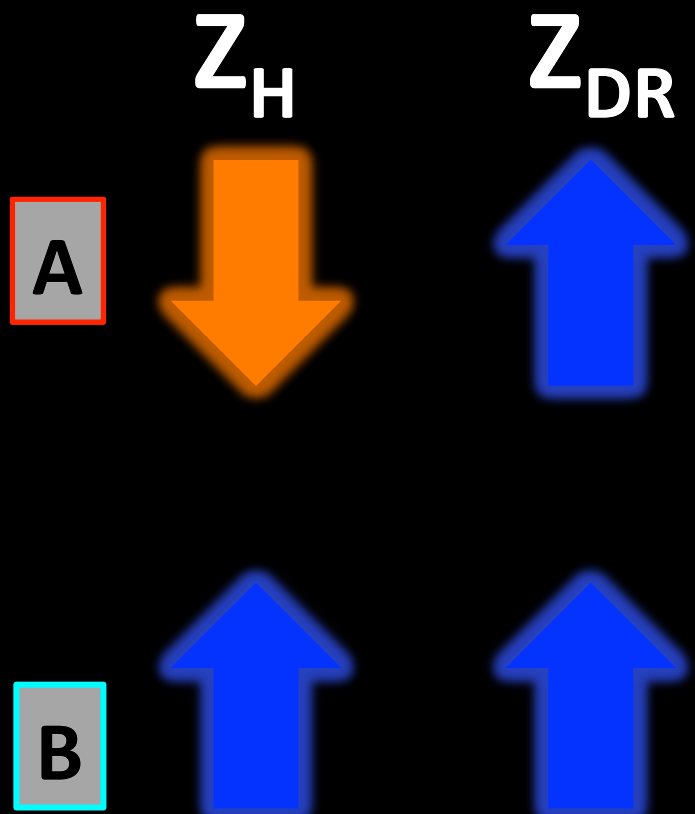
Raindrop Size Sorting

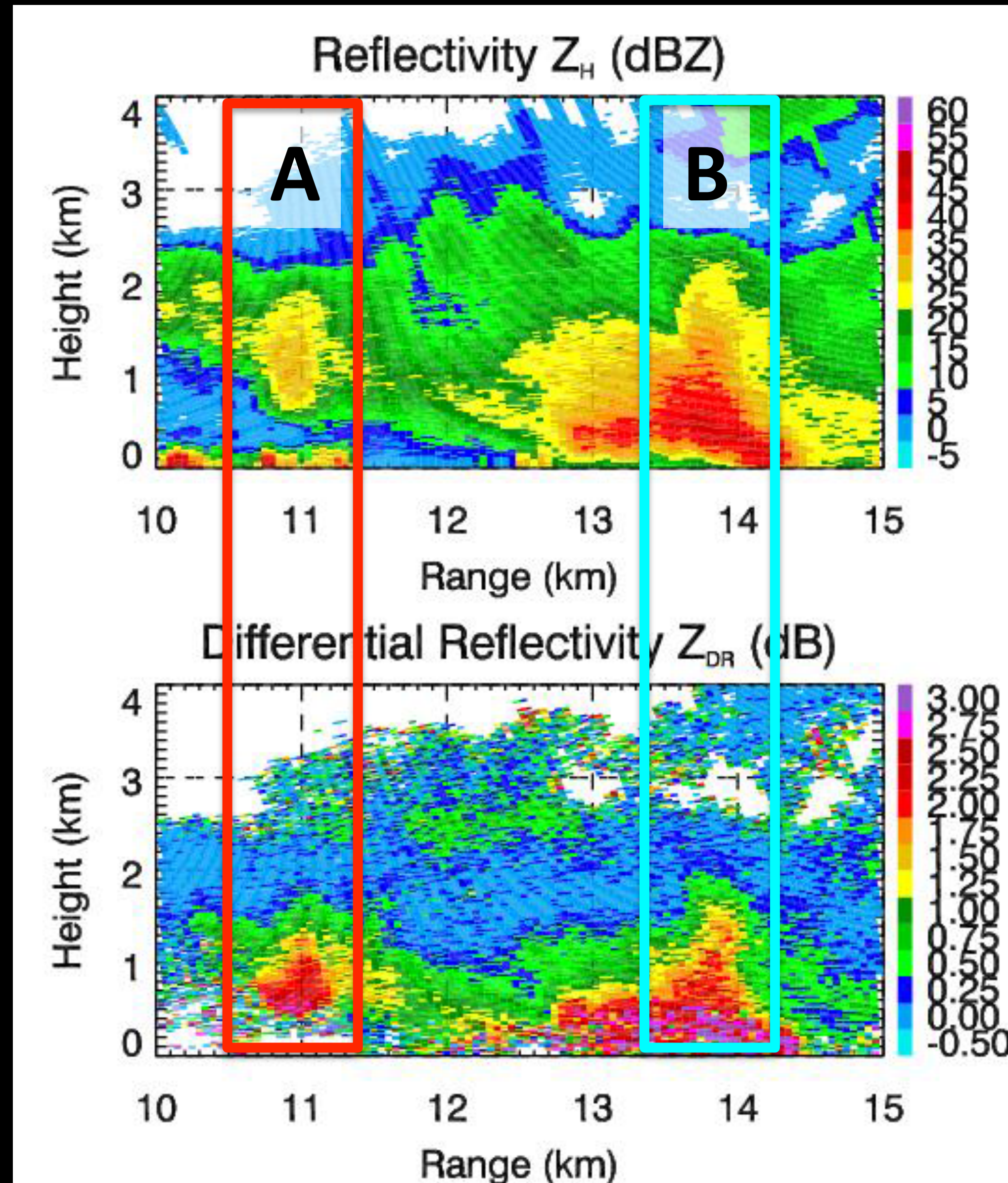
Suppose a fresh population of drops begins to descend. What will the fingerprint look like?

Raindrop Size Sorting

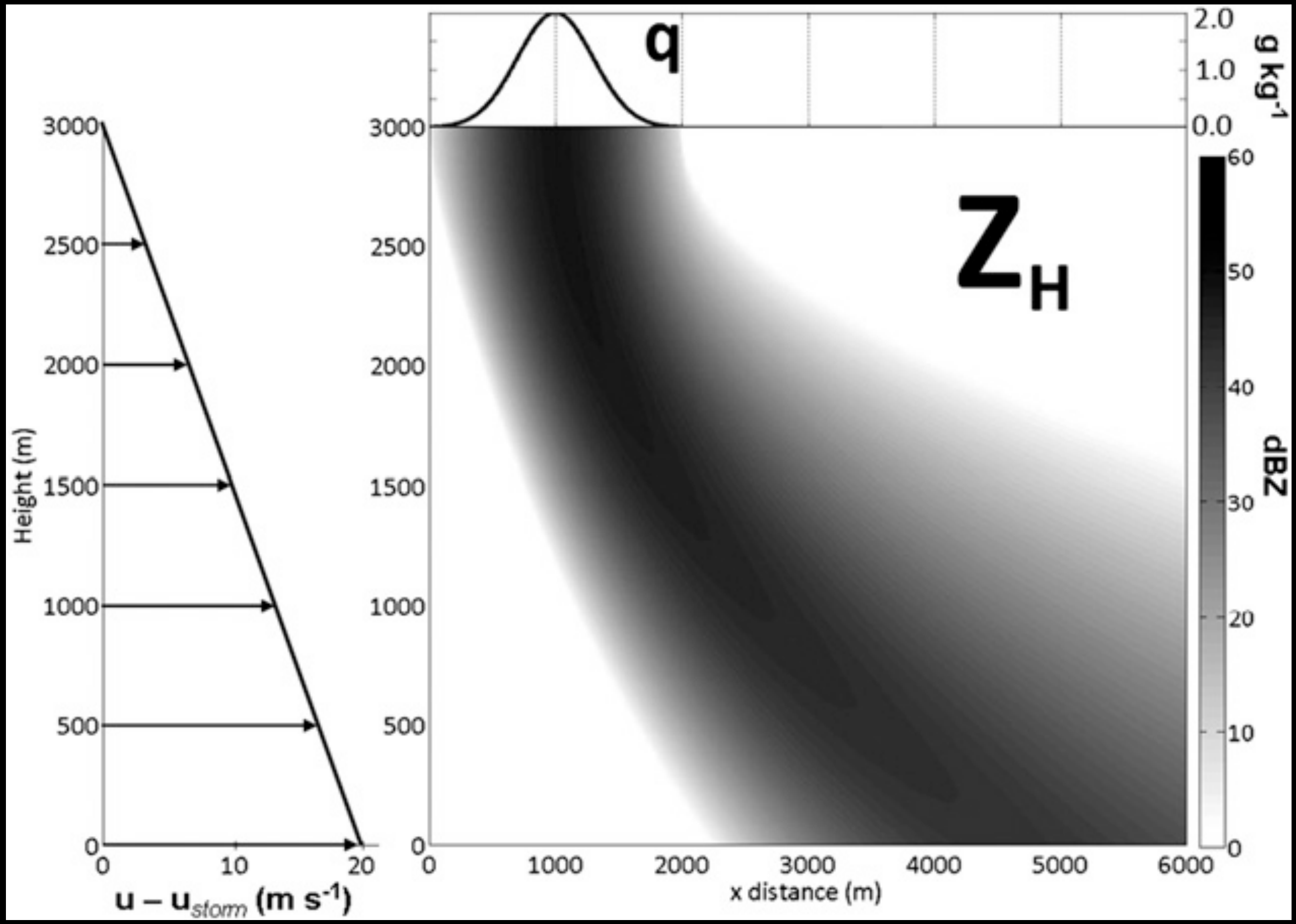
Z_H Z_{DR} K_{DP}

Raindrop Size Sorting



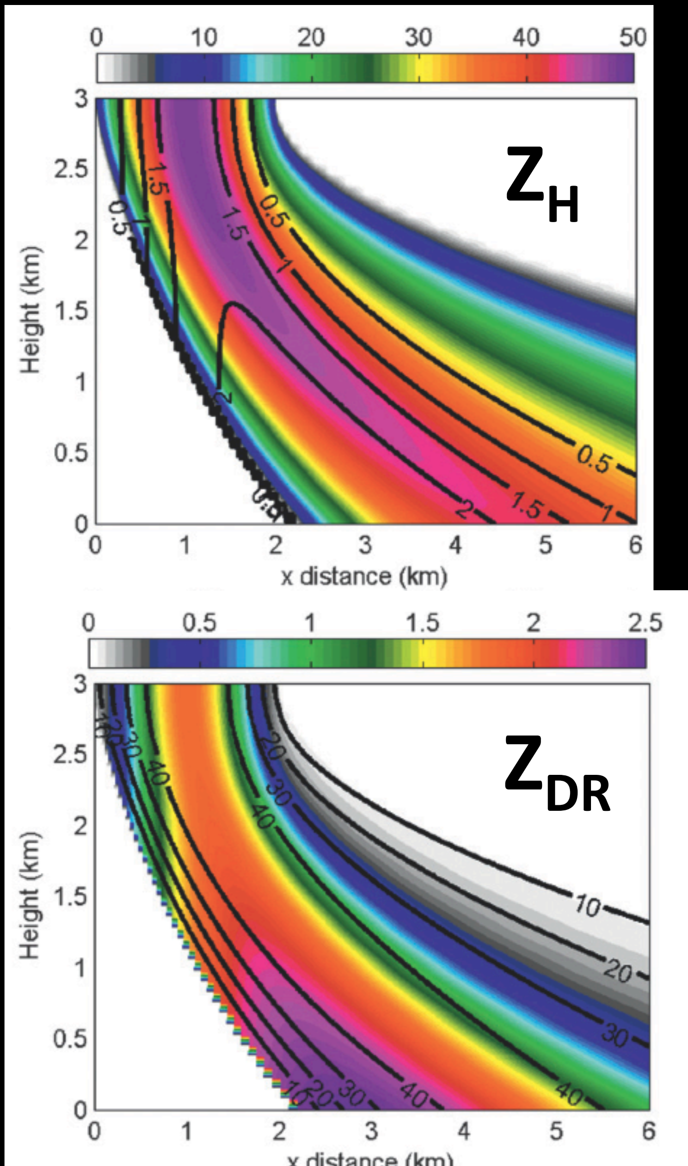


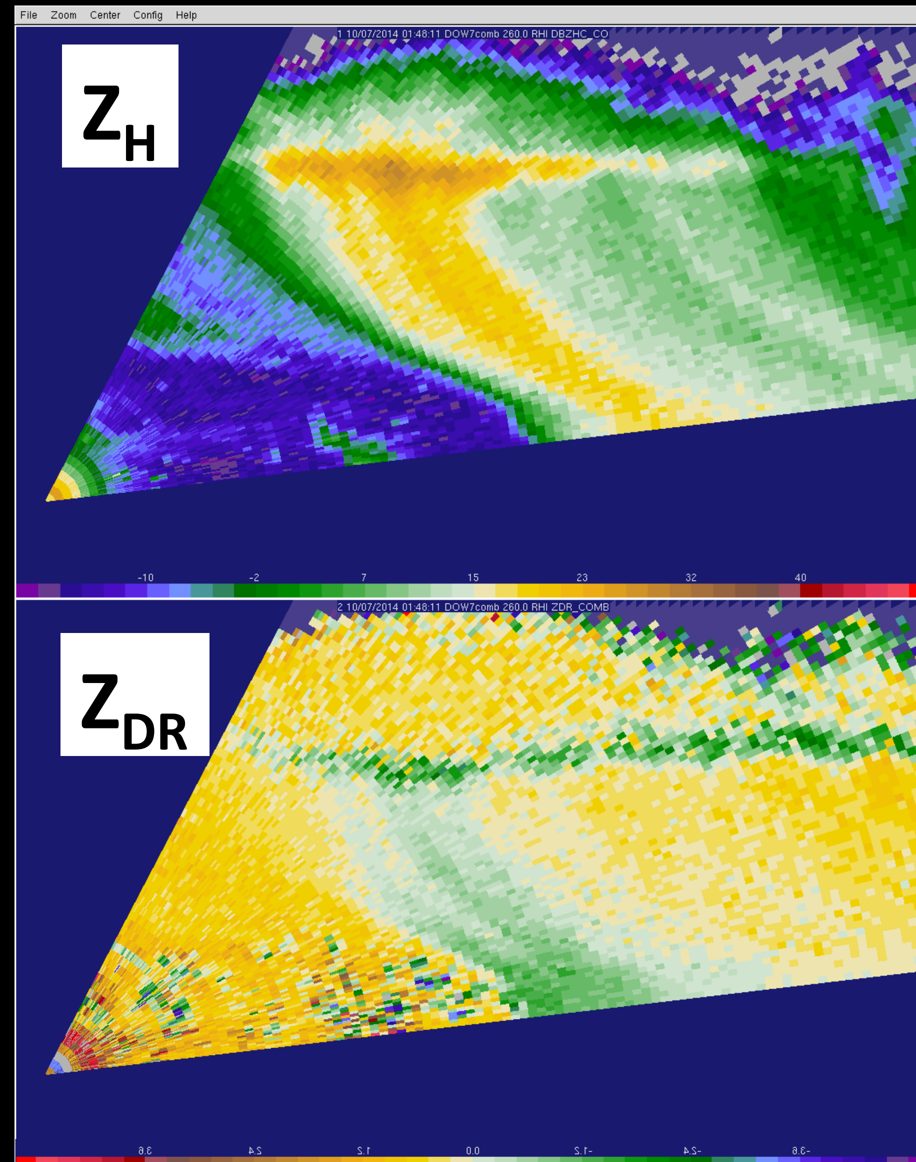
Raindrop Size Sorting



What might happen in this example?

Raindrop Size Sorting





Raindrop Evaporation

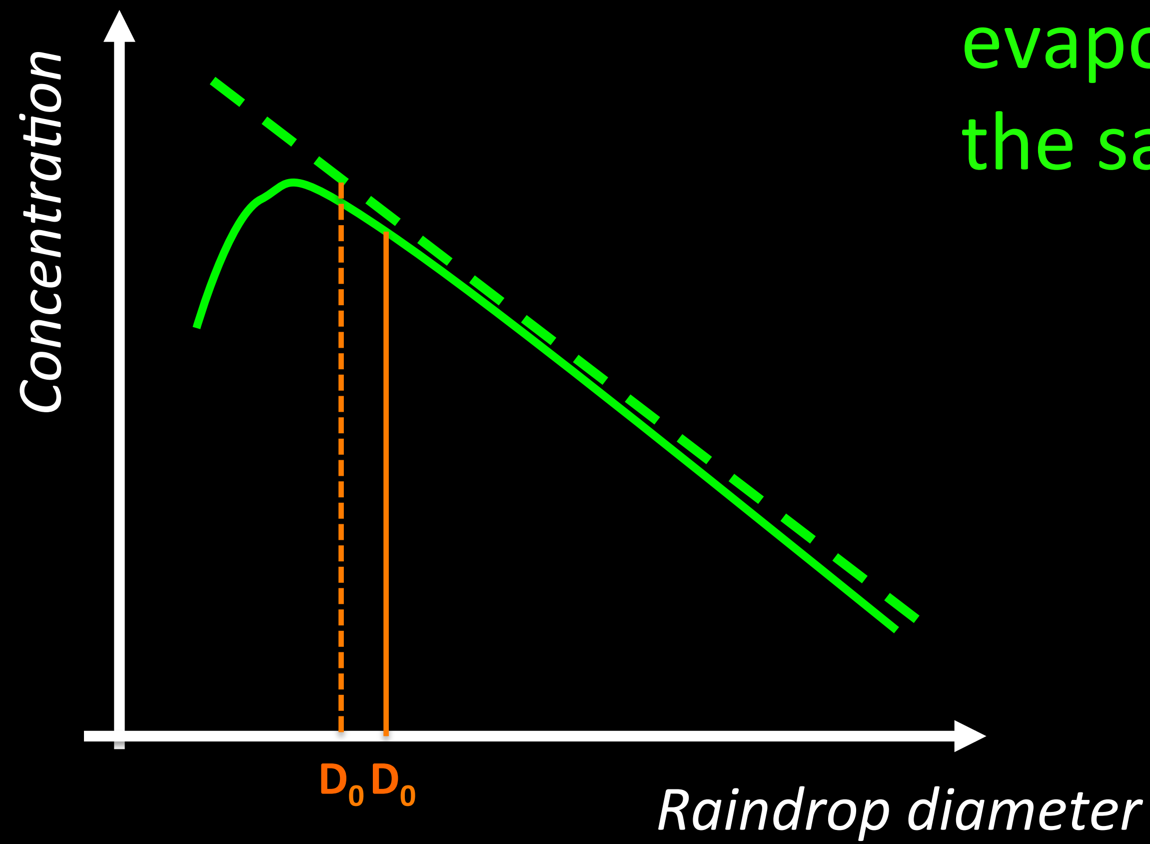
Consider raindrops falling into subsaturated air.

Raindrop Evaporation

Z_H **Z_{DR}** **K_{DP}**

Raindrop Evaporation

What's going on?



Not all drops evaporate at the same rate!

Fingerprints of Warm Processes

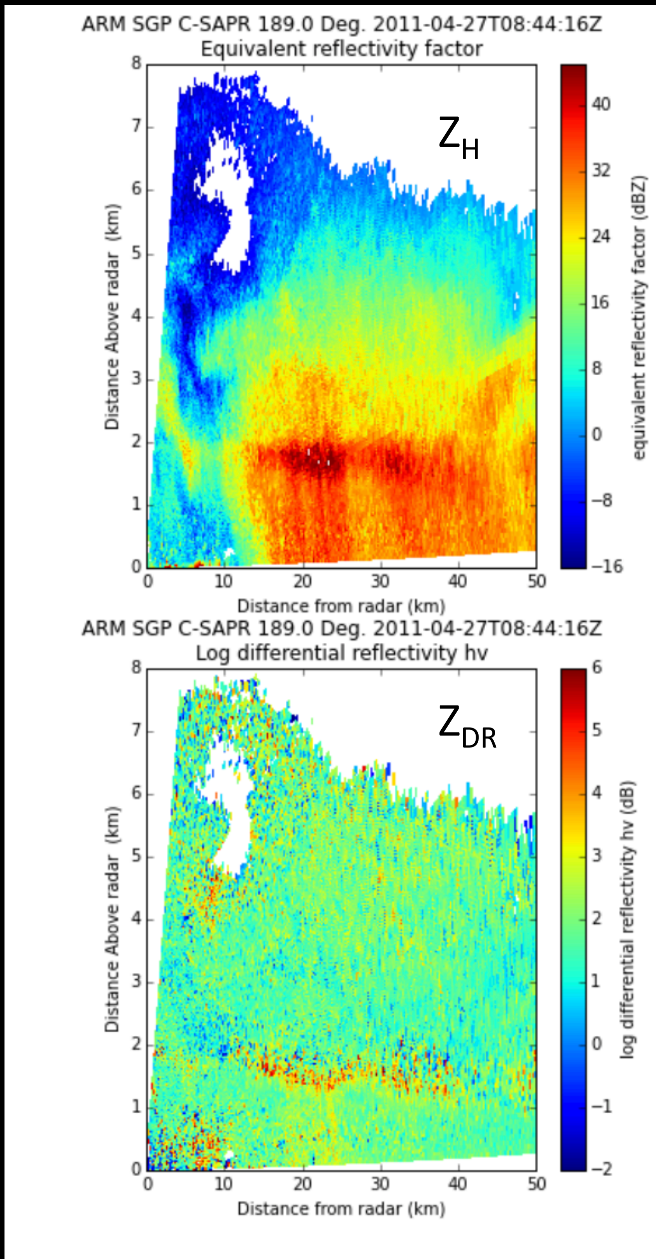
	Z_H	Z_{DR}	K_{DP}
Coalescence dominates	↑	↑	↑
Breakup dominates	↓	↓	↓
Coalescence+Breakup	↑	↓	↑
Size sorting	↓	↑	↓
Evaporation	↓	↑	↓

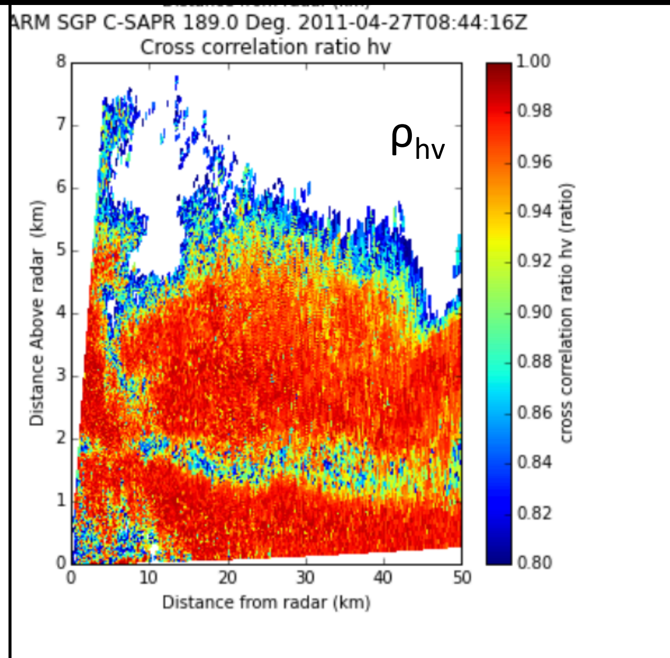
Bonus!

Aggregation

Melting

Riming





Precipitation Properties Group