C-band Dual-polarimetric Radar Signatures of Hail

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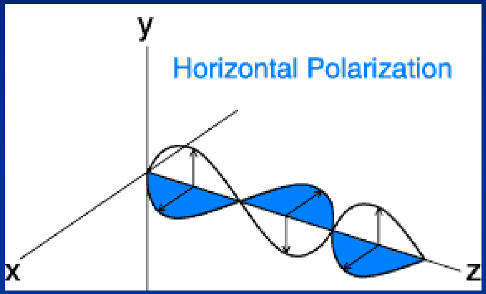
Introduction

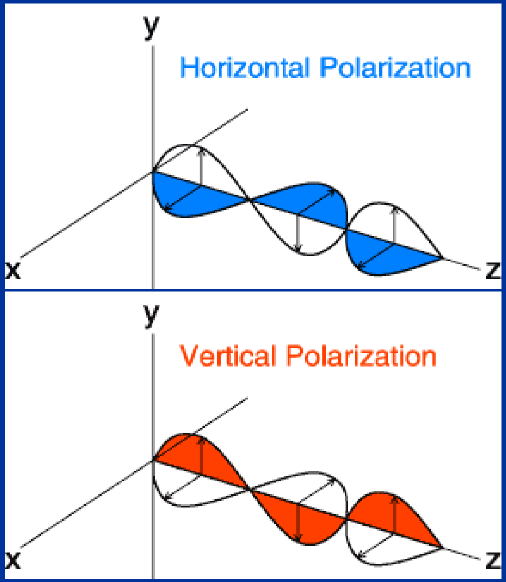
- Polarimetric Radar Overview
- Motivation
- April 10, 2009 case study
- General Conclusions

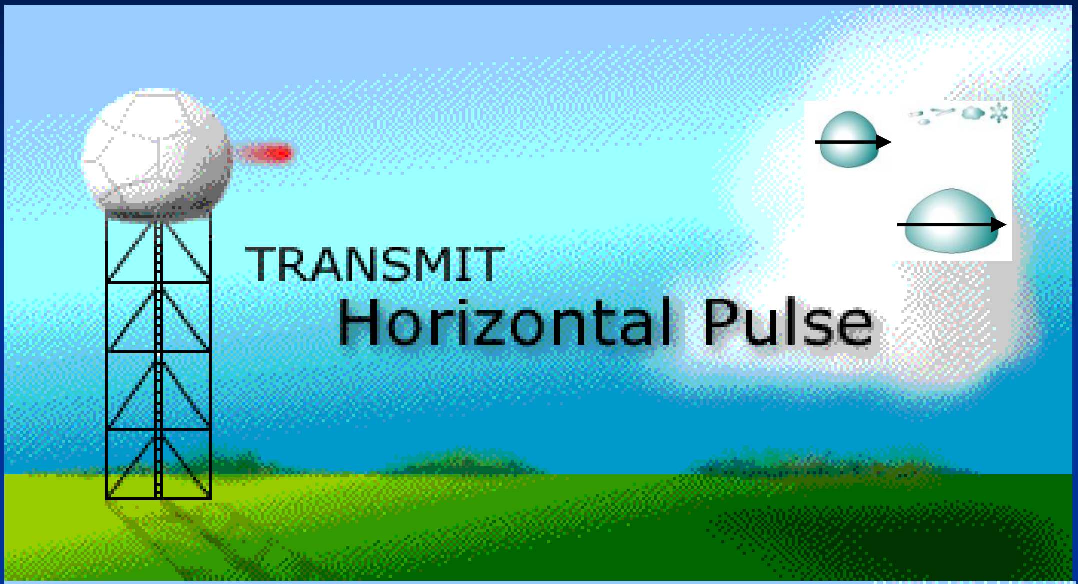
Background Information (Polarimetric Radar)

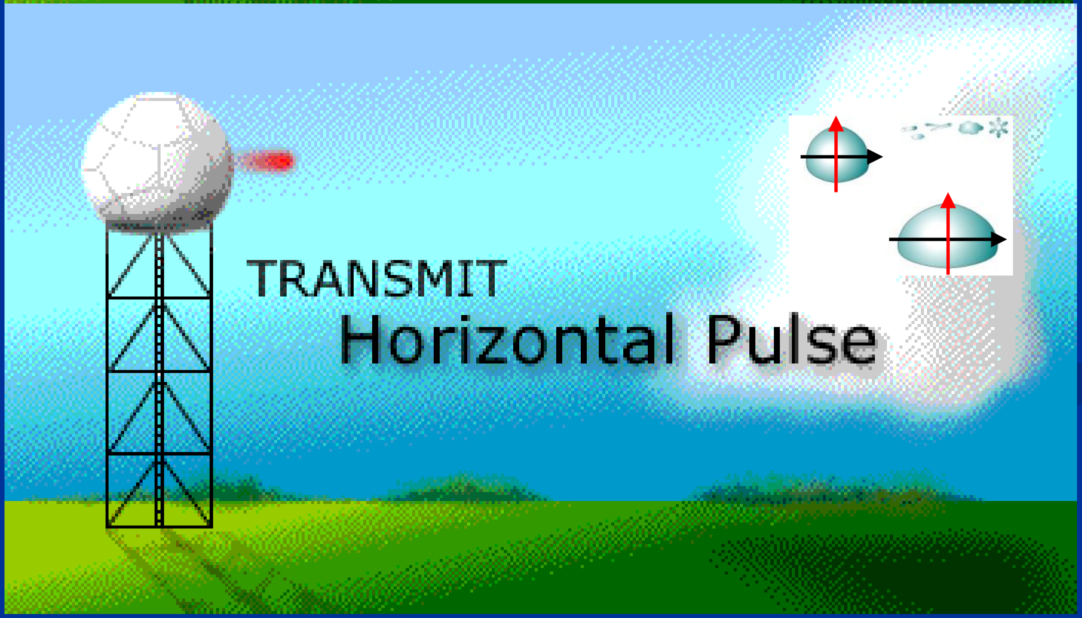
Conventional Radar
(NEXRAD)



Polarimetric Radar
(ARMOR)







Courtesy: NSSL CIMMS

Polarimetric Variable Review

- Reflectivity (Z_h) is defined as: $Z_h = 10\log_{10}(N(D)D^6)$ where N(D) is the number of particles in a radar volume and D is the average diameter of the particles.
- Differential Reflectivity (Z_{dr}) is a measure of the particles oblateness defined by the following equation $Z_{dr} = 10\log_{10}(Z_h/Z_v)$. Hail should have Z_{dr} near 0 dB (roughly spherical) rain should have a positive Z_{dr}.
- Specific Differential Phase (K_{dp}) range derivatives of differential phase between H and V polarizations. Discrimintates between isotropic (hail) and anisotropic (rain) hydrometeors.
- Correlation Coefficient (ρ_{hv}) pulse to pulse correlation returns between H and V within a given radar volume. A volume of mixed hydrometeor (a mixture of hail, melting hail, and rain) would have a low correlation coefficient.

Taken from Walt Petersen and Larry Carey Polarimetric Radar class notes.

Motivation

- Numerous S-Band studies have shown hail to be associated with areas of high Z_h (> 45 dBz) and Z_{dr} near 0 dB (e.g. Aydin et al. 1986, Bringi et al. 1986, Herzegh and Jameson 1992, Hubbert et al. 1998).
- However, studies at C-Band have not been as conclusive.
  - Studies at C-Band have shown hail to be associated with high Z_h (> 45 dBz) and high Z_{dr} (> 5 dB) (Meischner et al. 1991 and Ryzhkov et al. 2007).
  - C-band polarimetric radars are becoming more common among many different entities.

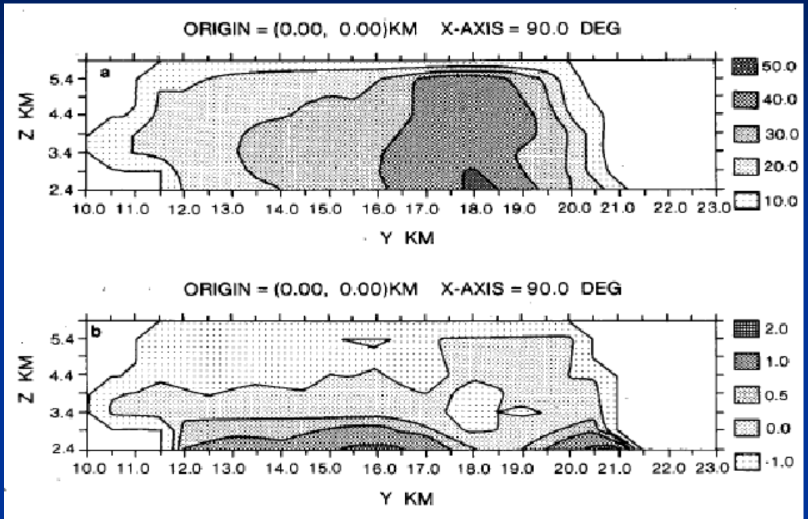


FIG. 5. (a) RHI of reflectivity and (b) Z_{DR} in contours/halftones through the core of a convective cell on 28 May 1983. Contours for reflectivity start at 10 dBZ in steps of 10 dB. Note the Z_{DR} hail signal in the region $18 \leq Y \leq 19$ km.

Bringi et al. 1986 Figure 5

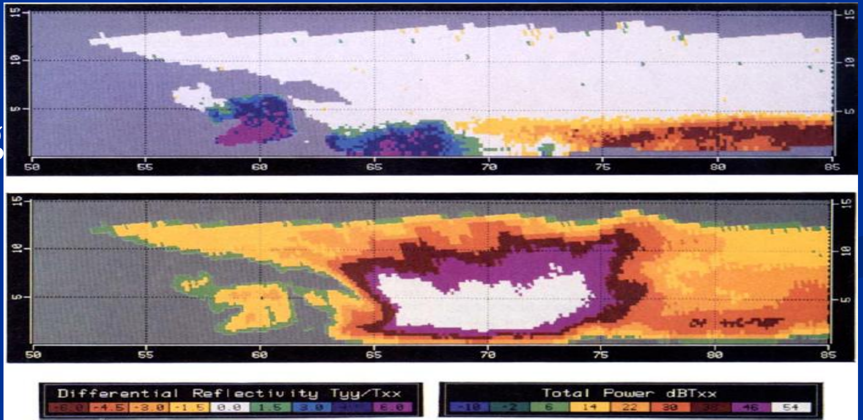
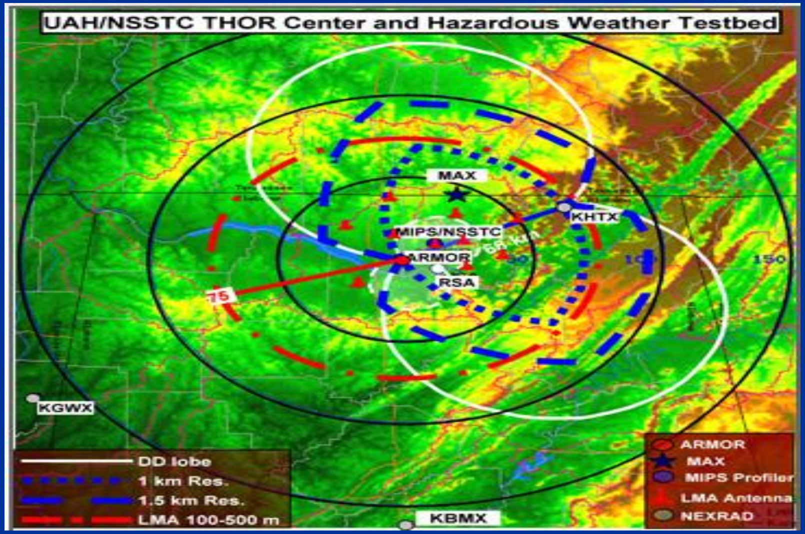


FIG. 12. Vertical cross section (RHI) of T_{VV} the reflectivity or total backscattered power (bottom panel) and Z_{DR} (top panel) taken at 1250:52 UTC along the 274° azimuth (towards the west).

Meischner et al. 1991 Figure 12

Data and Methodology

Location (GPS): 34º 38' 45.5 N 86º 46' 16.7 W
Huntsville International Airport
Transmit frequency: 5625 MHz
Peak Power: 350 kW
Antenna diameter: 3.7 m
Beam width: 1.0º
Rain1 scanning mode: Scans the 3 lowest elevation angles every 5 minutes
Volume scanning mode: Provides multiple elevation angles.
Typical PRF: 250 - 2000 Hz
Pulse length: 0.4 - 2.0 - 2.5 μs
Transmit polarization: Simultaneous H, V (STAR) or H
Receive polarization: H and V
Signal Processor and Controller: SIGMET RVP/8, RCP/8
Variables: STAR mode- P, Z, V,W, ZDR,
H-transmit H,V receive: P, Z, V, W, LDR



- The domain for this study is locations in the Tennessee Valley within 100 km of the ARMOR radar located at the Huntsville International Airport.

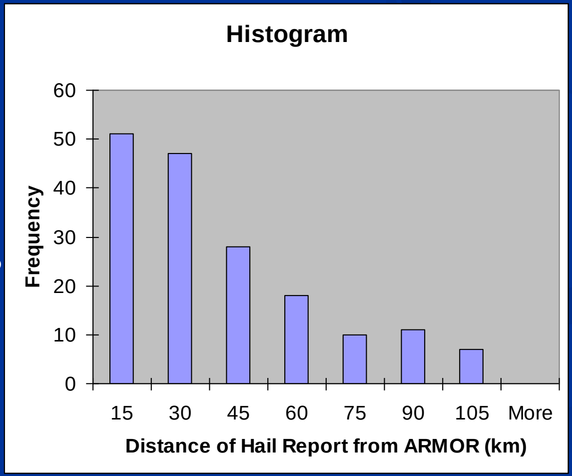
Data and Methodology (Case Selection)

-The events ranged from warm to cool season events from 2005 to 2010.

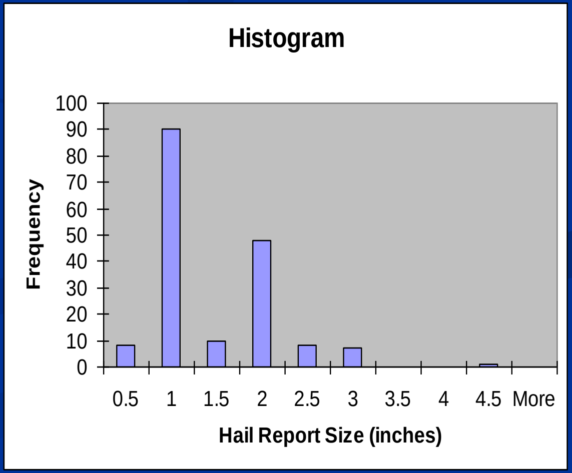
- The data sources for the reports are the National Climate and Data Center's *Storm Data*, the Storm Predication Center's (SPC's) archived Local Storm Reports (LSRs), the National Weather Service (NWS) Chat that contains non-severe hail LSR's, and an internet survey conducted for the April 10, 2009 hail event.

- Storm report must correspond to a 50 dBZ echo plus or minus 15 minutes and within 1 km of the report to be considered for this study. If these criteria were not meet the report was thrown out.

Date	Number of Cells	Number of Hail Reports
February 21, 2005	9	25
April 3, 2007	2	9
March 15, 2008	4	7
August 2, 2008	4	19
March 28, 2009	4	4
April 10, 2009	5	77
April 13, 2009	3	4
January 21, 2010	2	6
March 12, 2010	10	21
Total:	46	172



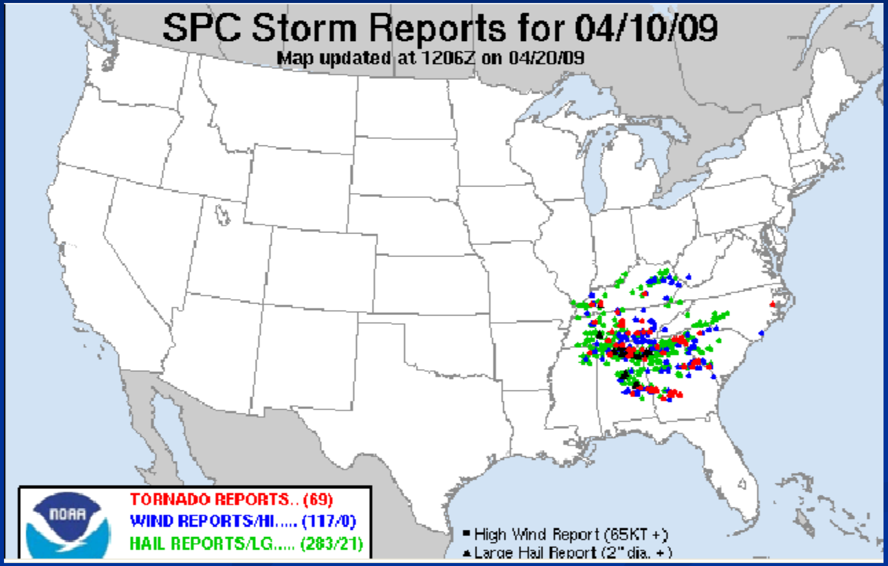
Histogram of locations of reports relative to ARMOR.



Histogram of hail report sizes (inches).

The April 10, 2009 Outbreak – Northern Alabama

- On 10 April 2009, there were at least 289 reports of severe hail across the southeast and Ohio River Valley.
- The NWS WFO HUN received 87 reports of severe hail within a 14 county warning area in under 4 hours.



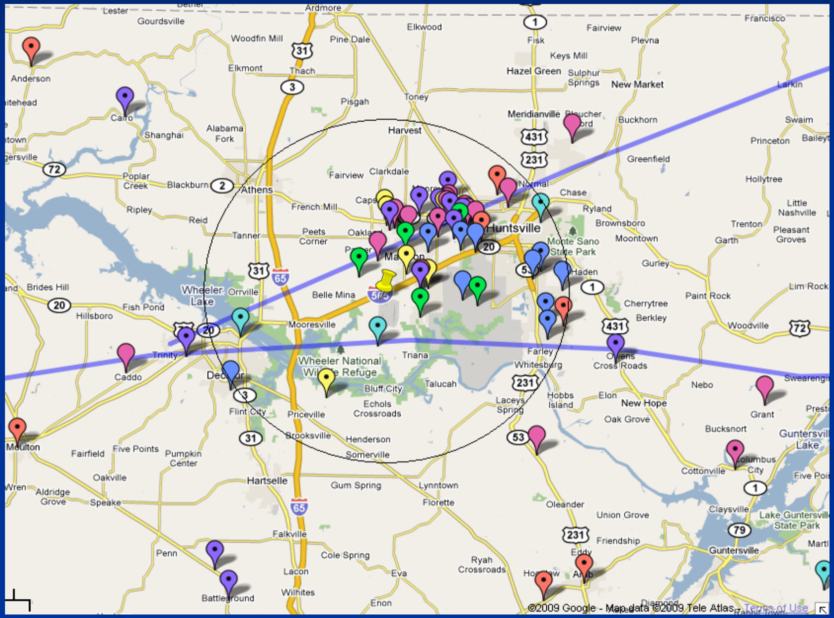
Courtesy: NOAA SPC




Courtesy: NWS WFO Huntsville, AL and WHNT Huntsville, AL

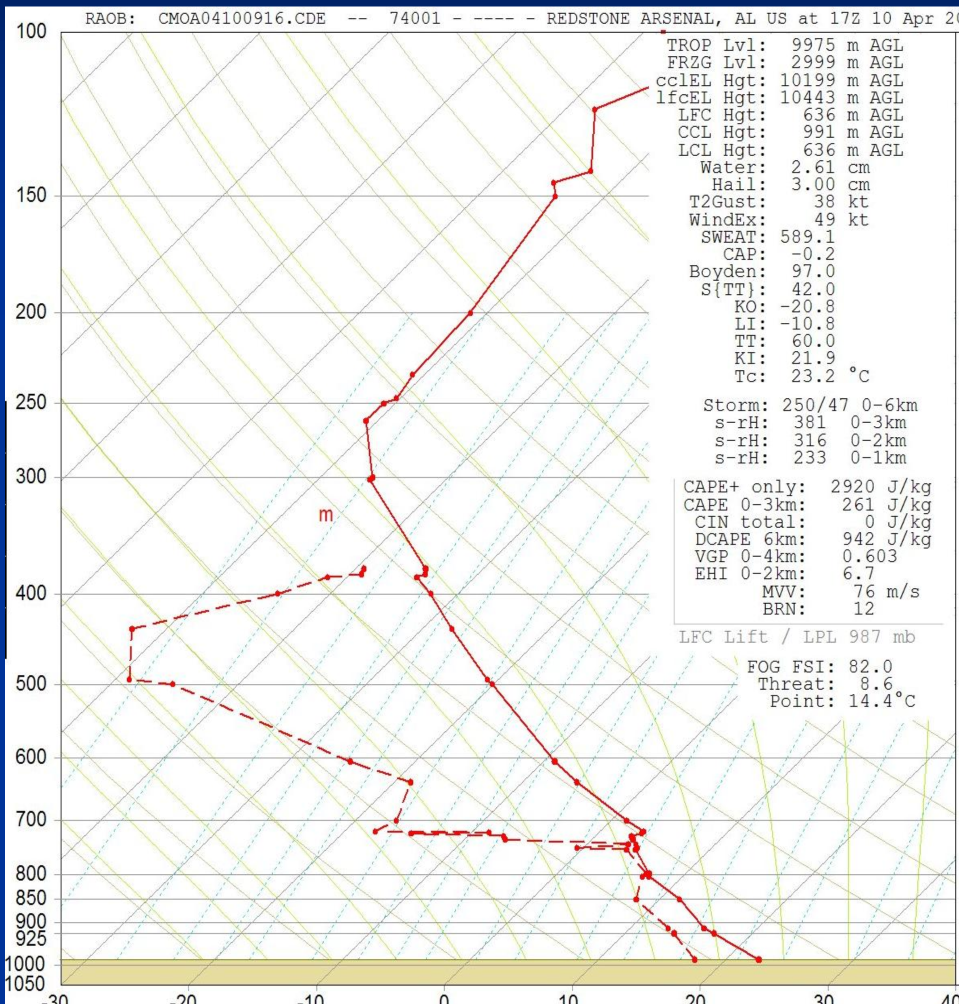
Hail Survey

- In addition to the NWS reports an internet survey was conducted to add to the number of reports. Sent to other scientist within the NSSTC.
- The survey produced an additional 56 reports.
- Hail sizes ranged from pea to baseball.
- Total hail reports used for this study 77.



Produced in Google Maps. Black lines 25 km interval range ring. Blue lines are storm tracks.

Severe Weather Environment



Redstone Arsenal 17z Sounding April, 10th

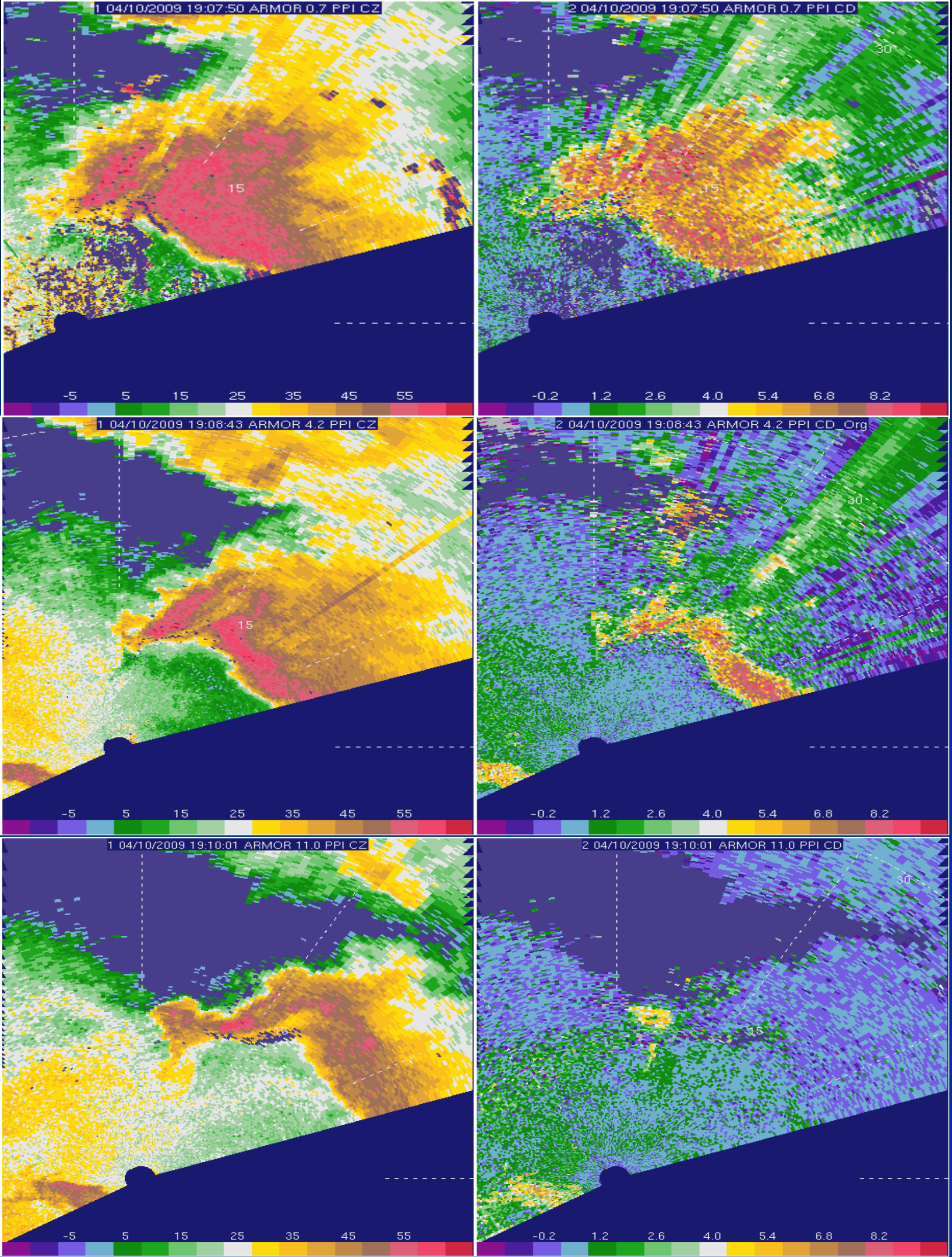
- Freezing level height near 3 km with wet bulb height closer to 2.5 km.

- Steep low and mid-level lapse rates of 7-8°C/km.

- Surface based CAPE of 2920 J/kg.

- Producing a maximum updraft speed of 76 m/s (170 mph).

- A more reasonable assumption would be half this value 38 m/s (85 mph).



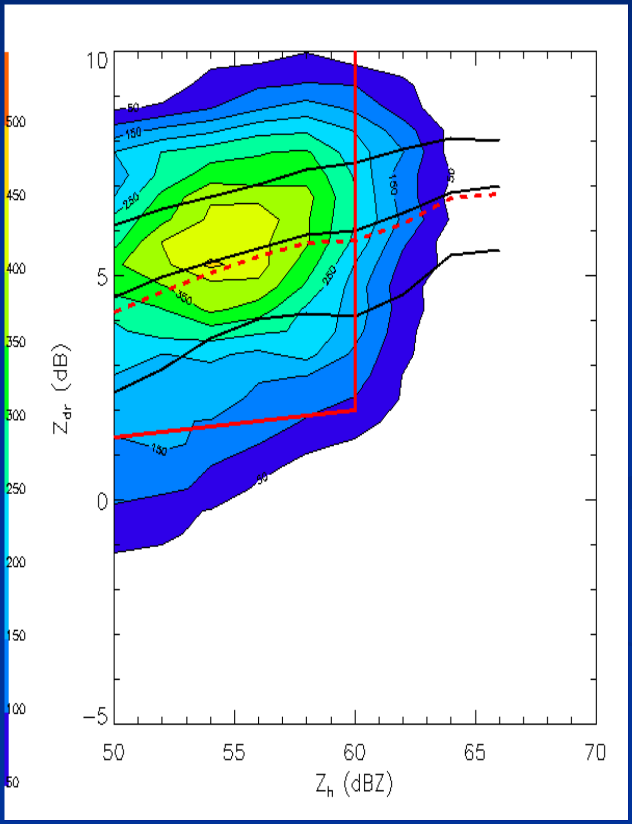
- PPI 0.7° elevation angle. High Z_h and Z_{dr} no signs of a lowering in the Z_{dr} data.

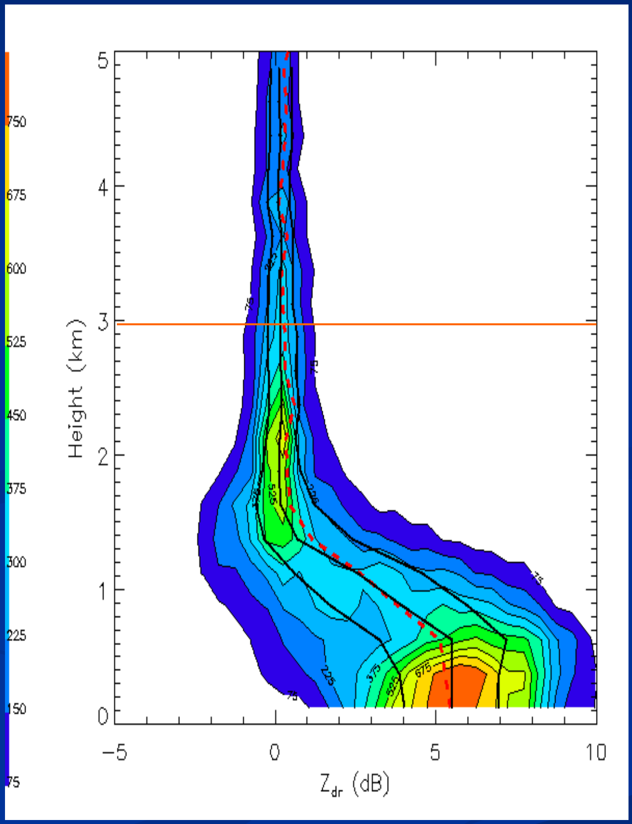
- PPI 4.2° elevation angle. High Z_h and still high Z_{dr} some signs of lowering.

- PPI 11.0° elevation angle. High Z_h and finally some signs of near 0 dB Z_{dr}.

April 10, 2009 Comparisons of Polarimetric Variables of Hail – Z_h and Z_{dr} and Height

- The Z_{dr} mode is near 5.5 dB at a Z_h of 54 dBZ with a maximum occurring as high as 10 dB at high Z_h (> 50 dBZ).
  - Results similar to those found by Meischner et al. (1991) and Ryzhkov et al. (2007).
  - Anomalously high Z_{dr} most likely due to melting hail and resonance at C-Band for particles over 5 mm.
- Melting can act to stabilize the hailstone if a sufficient water torus can develop (Aydin and Zhao 1991).

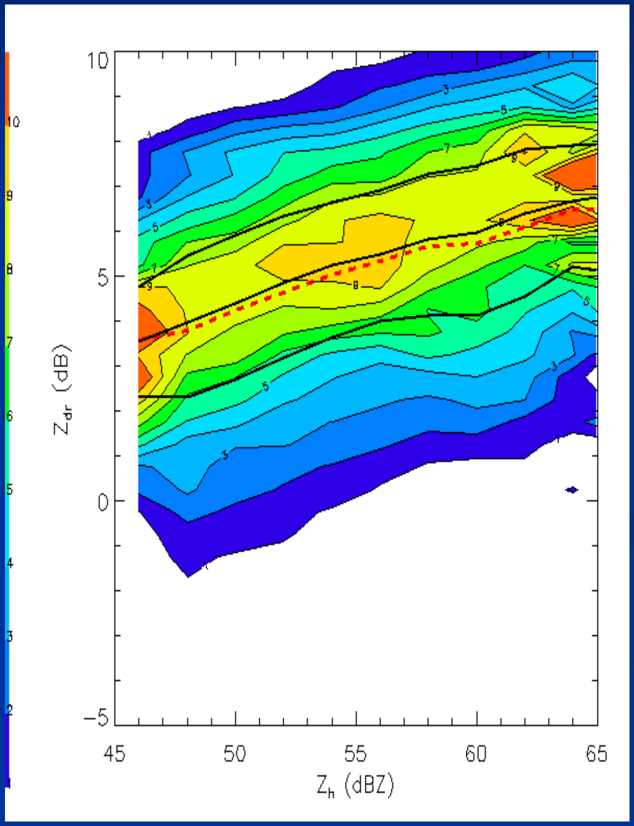


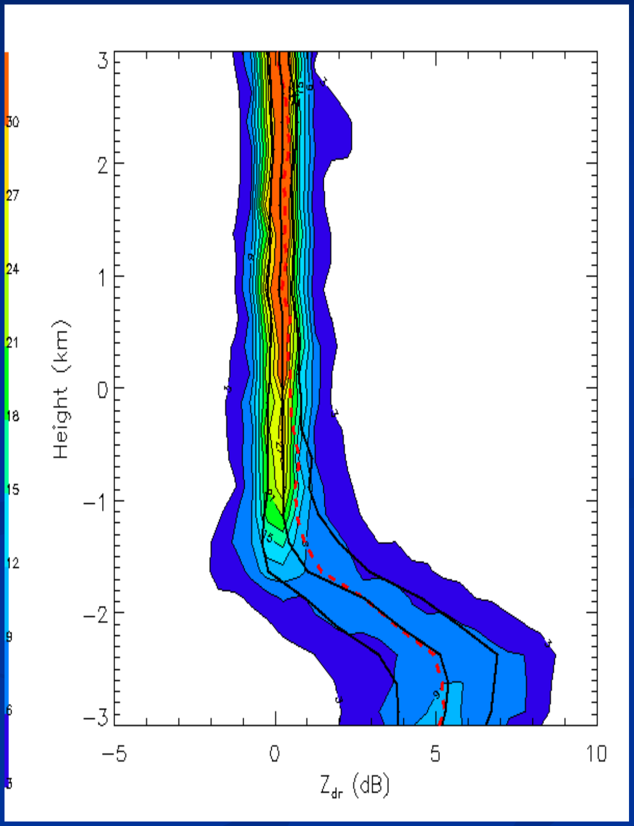


All points taken are for values of Z_h > 45 dBZ. All radar range gates are within 1 km of hail report. The images are joint absolute frequency histograms. Z_h in 2 dBZ bins, Z_{dr} 0.5 dB bins and height in 250 m bins.

Composite Analysis of Polarimetric Variables of Hail – Z_h and Z_{dr} and Height

- The Z_{dr} mode is near 5 dB at a Z_h of 55 dBZ with Z_{dr} increase as Z_h increases.
  - Results similar to those found by Meischner et al. (1991) and Ryzhkov et al. (2007).
  - Anomalously high Z_{dr} most likely due to melting hail and resonance at C-Band for particles over 5 mm.
- A clear lowering can be seen in the Z_h vs. height plot below the melting level. Clearly, a melting plays a role in this signature.

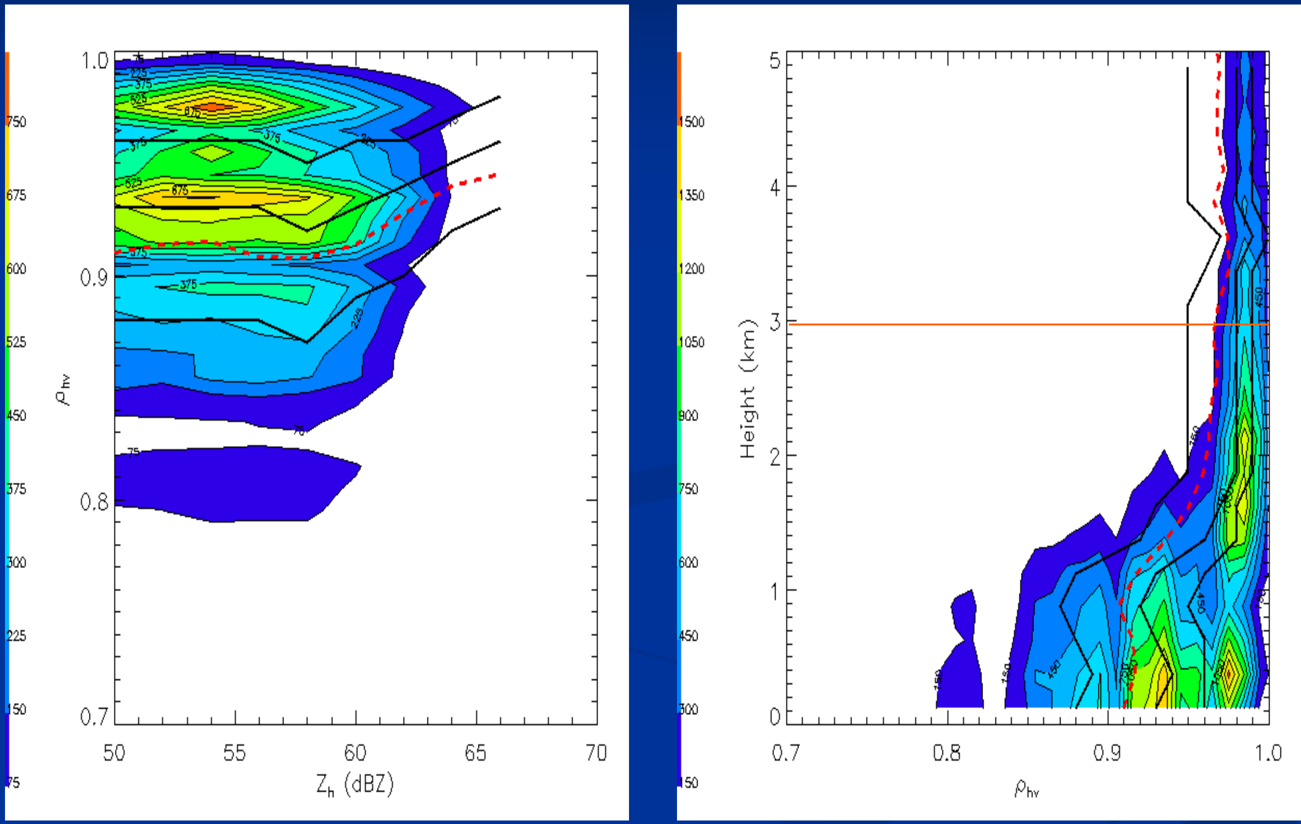




All points taken are for values of Z_h > 45 dBZ. All radar range gates are within 1 km of hail report. The images are composite joint relative frequency histograms in percent. Z_h in 2 dBZ bins, Z_{dr} 0.5 dB bins and height in 250 m bins.

April 10, 2009 Comparison of Polarimetric Variables of Hail – Z_h and ρ_{hv} and Height

- The ρ_{hv} mode is near 0.925 with a minimum as low as 0.80.
  - The ρ_{hv} values are similar to those at S-Band for identifying hail (Balakrishnan and Zrnic 1990b).
- Below the melting level (3 km) there is a clear lowering of ρ_{hv}.
- Studies at C-Band have found ρ_{hv} values in pure rain as low as 0.94-0.95 (e.g. Carey et al. 2000, Keenan et al. 2000).



All points taken are for values of Z_h > 45 dBZ. All radar range gates are within 1 km of hail report. The images are joint absolute frequency histograms. Z_h in 2 dBZ bins, ρ_{hv} in 0.05 bins and height in 250 m bins.

Composite Anaylsis of Polarimetric Variables of Hail – Z_h and ρ_{hv} and Height

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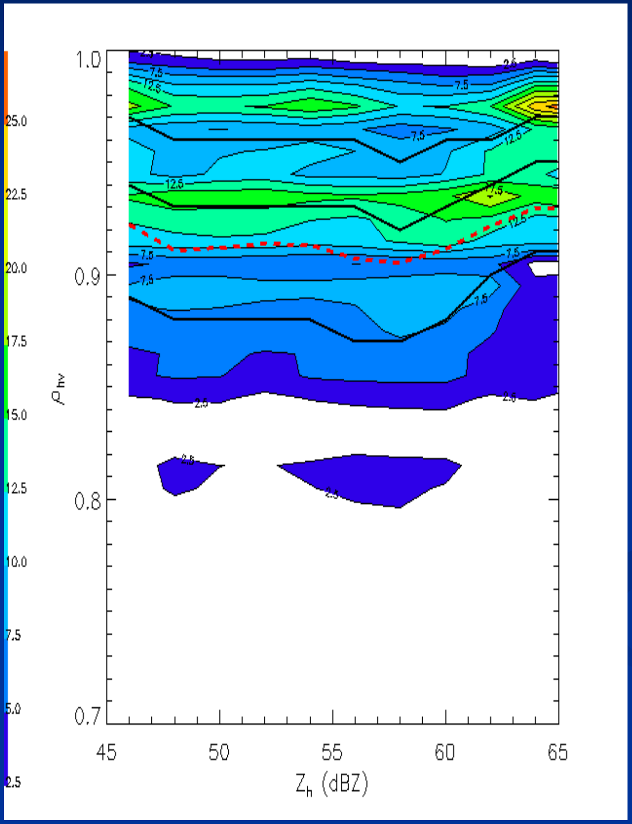
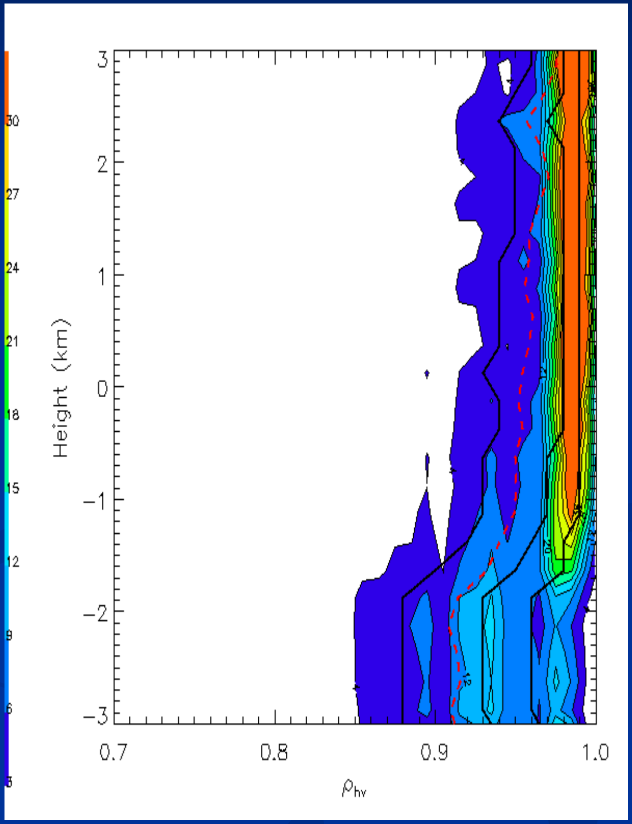




All points taken are for values of $Z_h > 45$ dBZ. All radar range gates are within 1 km of hail report. The images are composite joint relative frequency histograms in percent. Z_h in 2 dBZ bins, ρ_{hv} in 0.05 bins and height in 250 m bins.

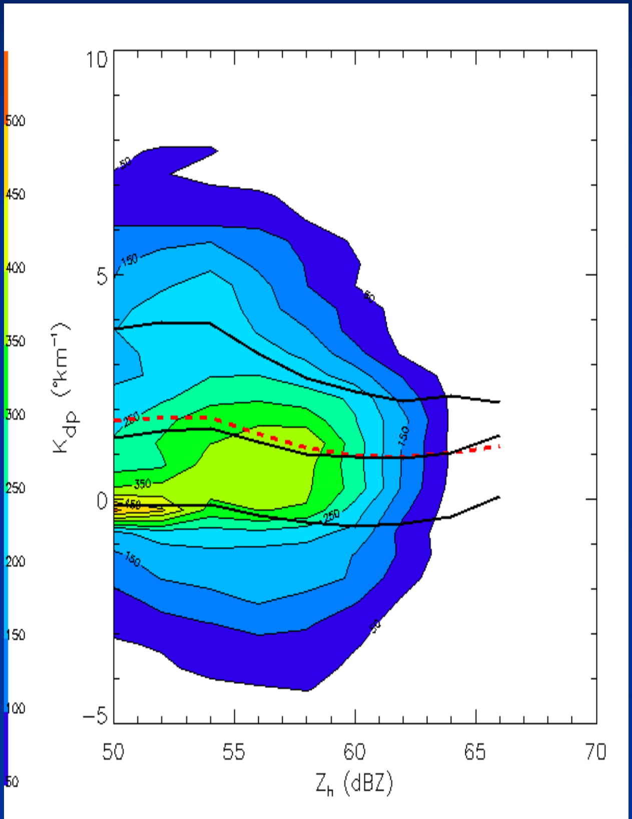
April 10, 2009 Comparison of Polarimetric Variable of Hail – Z_h and K_{dp} and Height

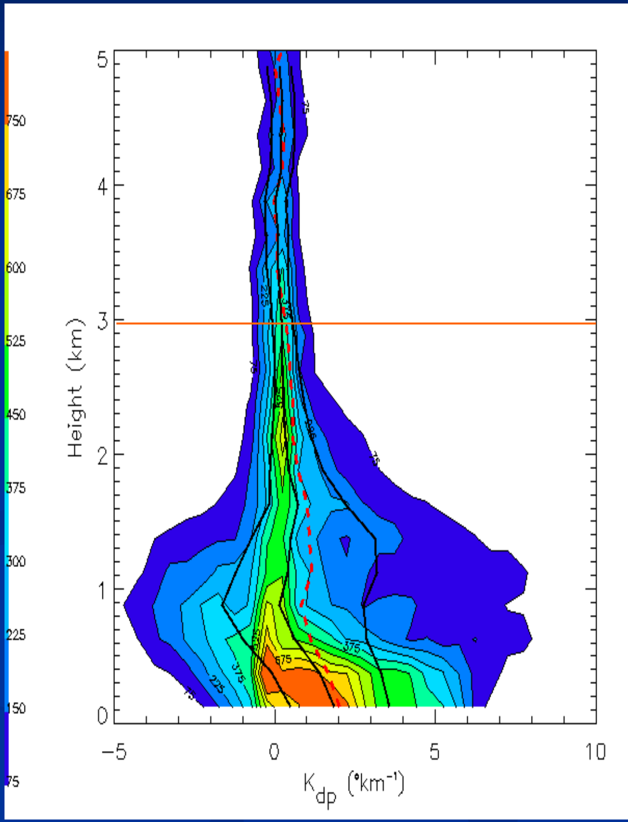
- Mode of K_{dp} near the surface and aloft is near 0 $^{o}km^{-1}$.

- It has been observed that Kdp near 0 ºkm-1 with high Zh can be associated with hail (Balakrishnan and Zrnic 1990a).

- Below the melting level K_{dp} is rather noisy ranging from values of -5 to 7 $^{o}km^{-1}$.

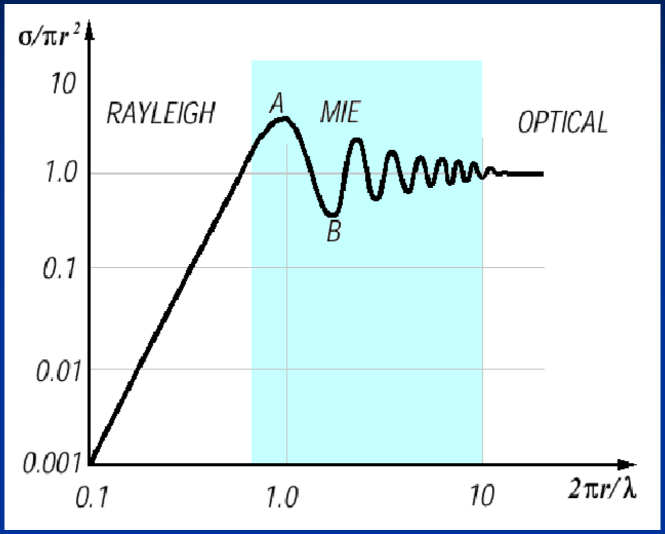
- The overall noisiness of Kdp suggests it may have limitations in distinguishing between areas of rain, hail, and their mixtures.





All points taken are for values of Z_h > 45 dBZ. All radar range gates are within 1 km of hail report. The images are joint absolute frequency histograms. Z_h in 2 dBZ bins, K_{dp} in 0.5 $°km^{-1}$ bins and height in 250 m bins.

Reasons for High Z_{dr}



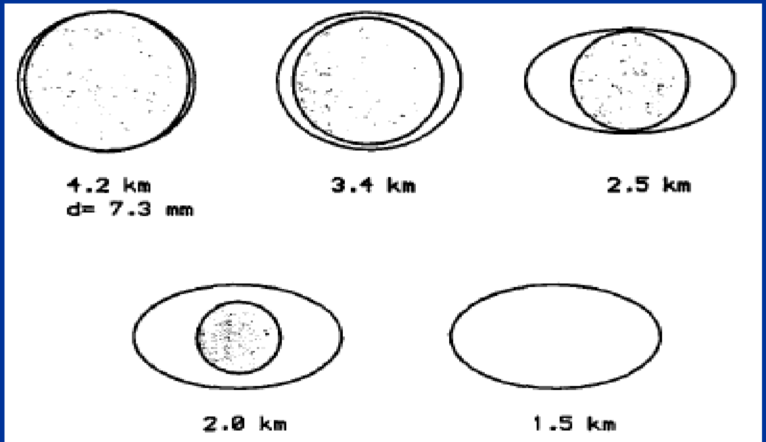


FIG. 11. Diagram of melting hail shapes for initial diameter of 7.3 mm. The various heights MSL are 4.2, 3.4, 2.5, 2.0, and 1.5 km. Inner ice core is spherical and concentric with the oblate particle.

Meischner et al. 1991 Figure 11

Three cases for objects with diameters:

1.) D >> λ, (e.g., D ≥ 10λ), **σ** ≈ geometric area cross section of object.

2.) D << λ (e.g., D ≤ 0.1λ), **Rayleigh-Gans** scattering: **σ ∝ D6**

S-band: 10 mm drop diameter

C-band: 5 mm drop diameter

X-band: 3 mm drop diameter

3.) D between geometrical and Rayleigh approximations, **Mie** regime

$$\sigma = \frac{\pi^5 |K|^2 D^6}{\lambda^4}$$

$\sigma \rightarrow Z_h \rightarrow Z_{dr}$

Melting can also cause the hailstone to become more oblate and the water torus can act to stabilize preventing it from tumbling (Rasmussen and Heymsfield 1987 and Aydin and Zhao 1990).

General Conclusions

- C-Band polarimetric signatures of hail are not the same as S-Band.
- Resonance or Mie scattering and melting play a role in producing the large Z_{dr} observed at C-Band for hail.
- The resonance sizes of 0.5 – 0.8 mm most likely contribute to the high Z_{dr} (Ryzhkov et al. 2009).
- Can also conclude the hail falls with its major axis horizontal to produce the signatures observed on April 10, 2009.
- Different climate regimes may produce different hail signatures due to the amount of melting.

Future Work

- Examine more hail cases to better evaluate the melting hail signature.
- Better understand the processes involved in hail and melting hail(i.e. fall mode, canting angle, distributions).
- Evaluate S-and C-band signatures to determine if the high Z_{dr} signature is more a function of the radar or climate regime.

Questions?