Polarimetric Characteristics of Dry and Melting Hail at Different Radar Wavelengths

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Practical issues involving hail

1. Hail detection
2. Determination of hail size or discrimination between three categories of hail size: small hail ($D < 2.5$ cm), large hail ($2.5 < D < 5.0$ cm), and giant hail ($D > 5.0$ cm)
3. Attenuation correction in the presence of hail
4. Rainfall estimation in rain / hail mixture

The study includes

1. Microphysical and scattering modeling of polarimetric radar variables in melting hail at S, C, and X bands
2. Comparison with polarimetric radar observations at S and C bands
3. Recommendations to address practical issues 1 – 4.

Cloud and scattering models

Cloud models

Model 1

Extension of the1D steady state model of Rasmussen and Heymsfield (1987) for ensemble of particles

Shedding is taken into account

No interactions between particles

Spectral microphysicsis

Mass water fraction varies across the spectrum

Model 2

2D spectral bin Hebrew University of Jerusalem Cloud Model

7 classes of hydrometeors

43 size bins

All interactions between particles are treated explicitly

Mass water fraction varies across the spectra

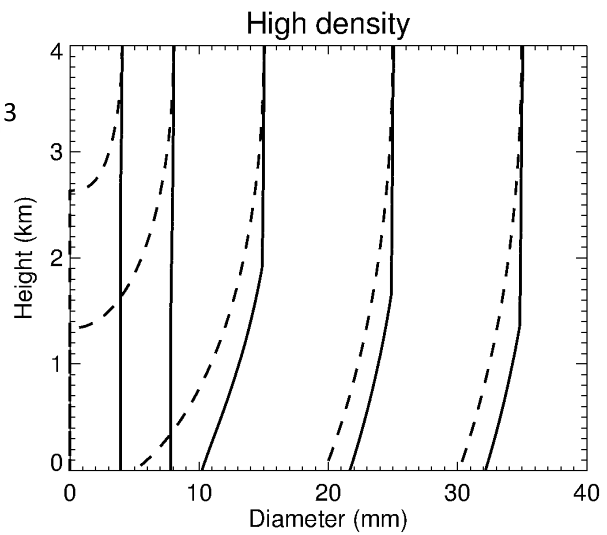
Scattering models

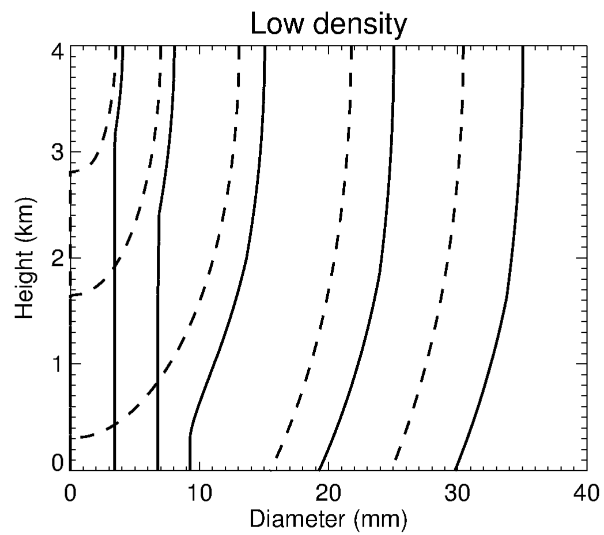
Rayleigh formulas and T-matrix codes for uniformly filled and two-layer particles

Aspect ratios and the width of canting angle distributions depend on mass water fraction. Computations are performed at S, C, and X bands

Melting of individual graupel / hailstones with different density

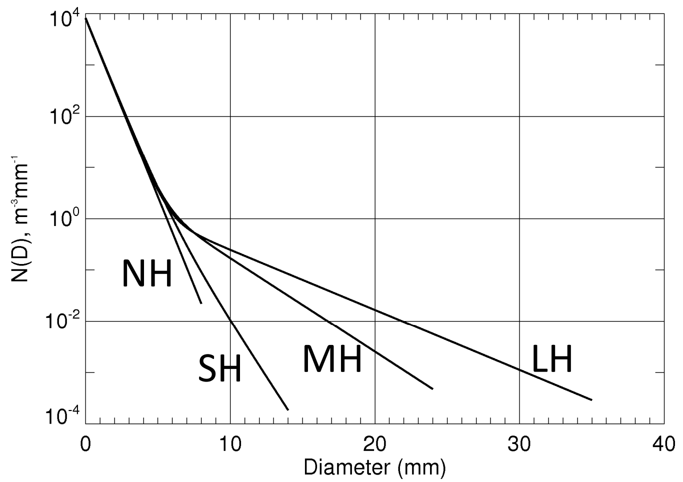
$\rho = 0.92$ g/cm^3





$\rho = 0.6$ g/cm^3

Model size distributions of ice particles aloft



1D model

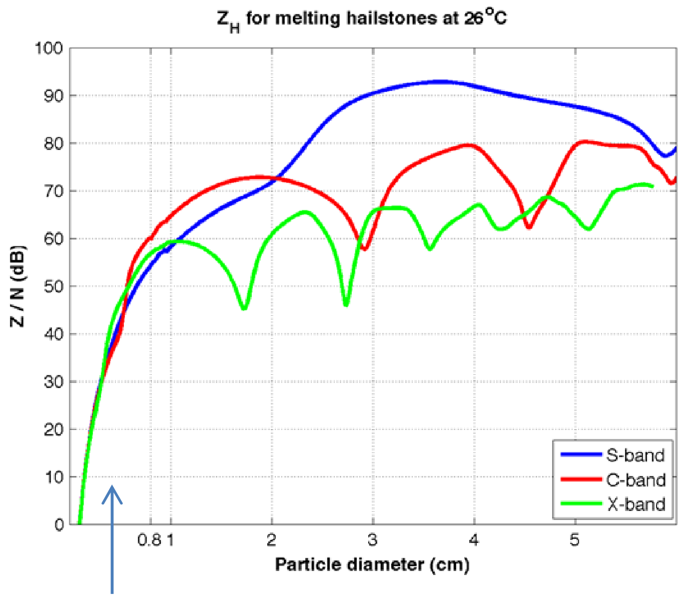
Diameter of melting hailstone

Effective diameter of ice core

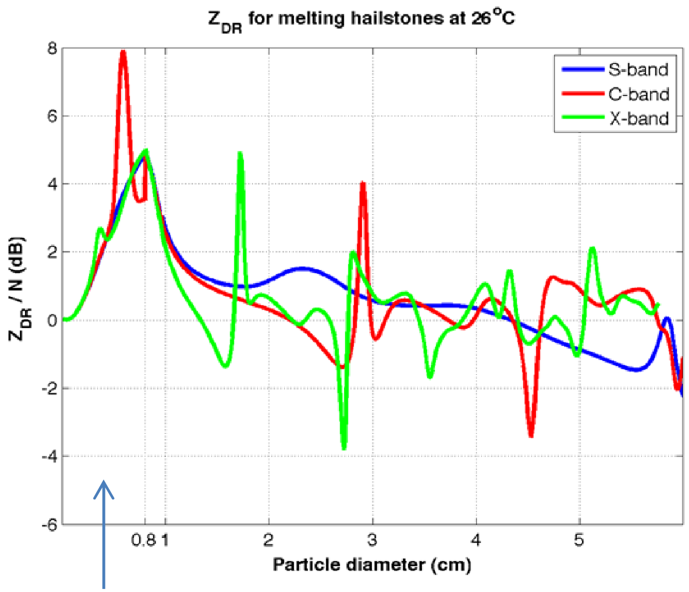
Softer hail melts faster

LH – large hail
MH – moderate hail
SH – small hail
NH – no hail

Size dependencies of normalized Z and Z_{DR} for melting hail at S, C, and X bands



rain

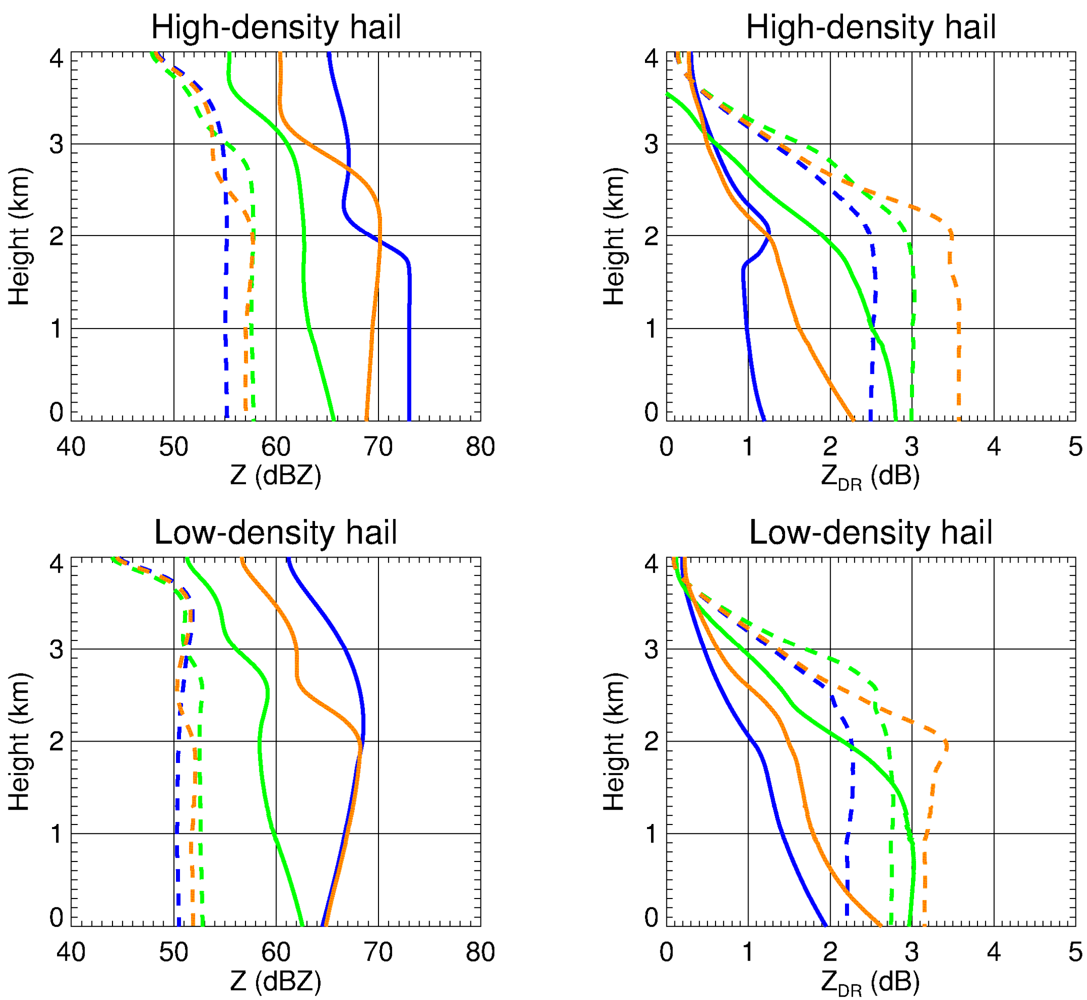


rain

Notable features

- The differences in Z at different radar wavelengths can be dramatic
- Strong Z_{DR} resonance at C band for large raindrops

Simulated vertical profiles of Z and Z_{DR} at S, C, and X bands for large and small hail of different density



S band

C band

X band

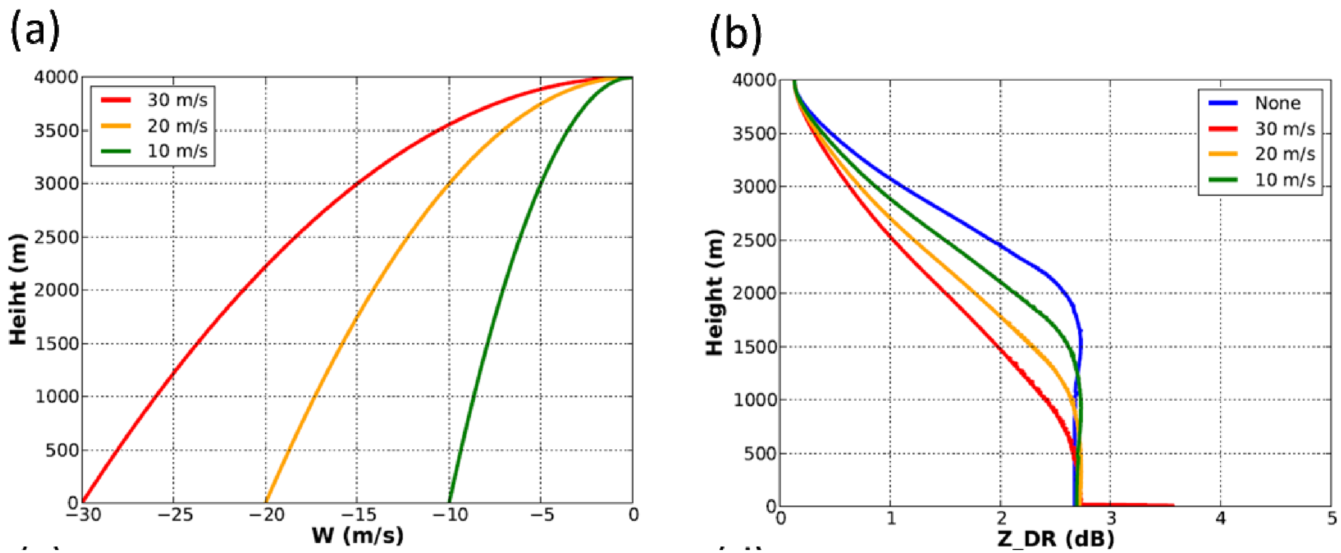
Large hail – solid lines
Small hail – dashed lines

- Soft hail has lower Z
- Soft large hail has higher Z_{DR}
- Most dramatic changes in Z and Z_{DR} occur within 2 km below the freezing level

Sensitivity to temperature lapse rate, humidity, and downdraft velocity

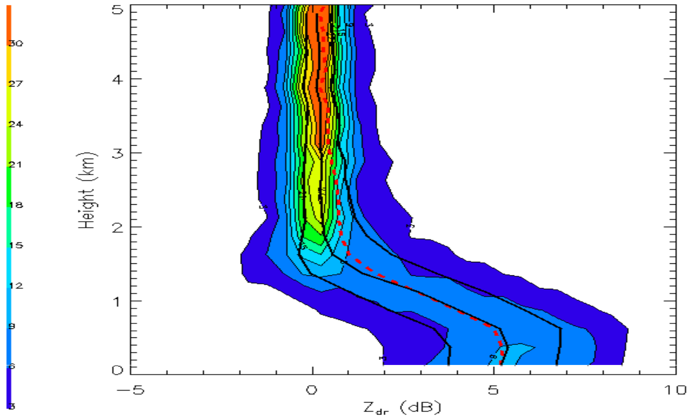
- Steeper temperature lapse rate speeds up the process of melting
- The reduction of relative humidity towards the ground slows down melting
- Downward air motion transports partially melted hailstones to lower height levels and the “Z_{DR} hole stretches down to the surface

Polarimetric microburst detection?

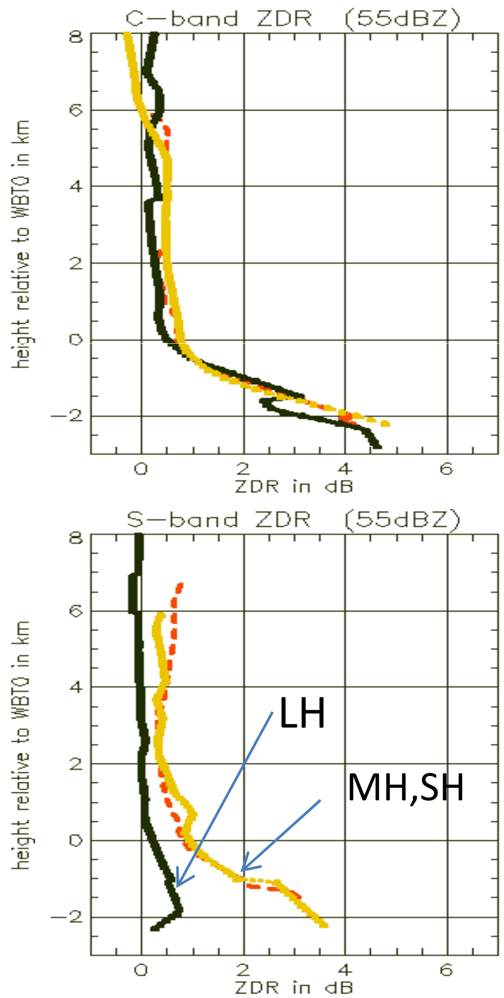


How realistically do the models reproduce observed vertical profiles of Z_{DR} at S and C bands?

Anderson et al. 2011; C band , Alabama

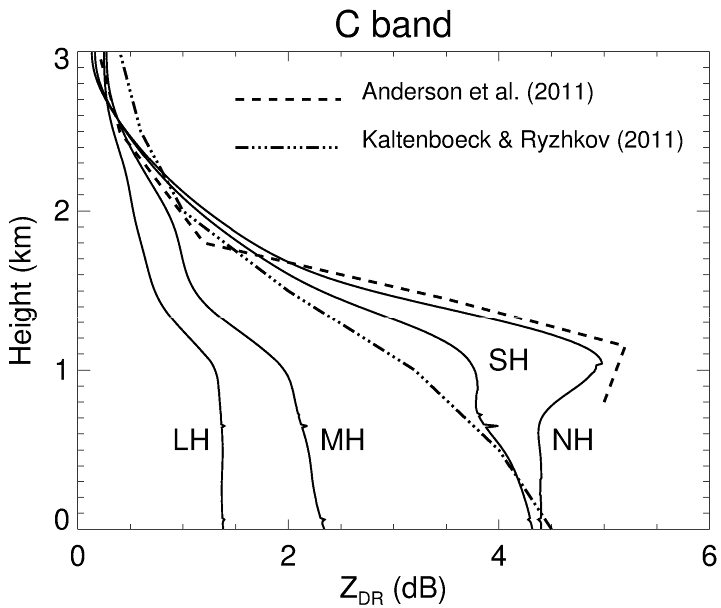


Kaltenboeck and Ryzhkov 2011; S and C bands , Oklahoma

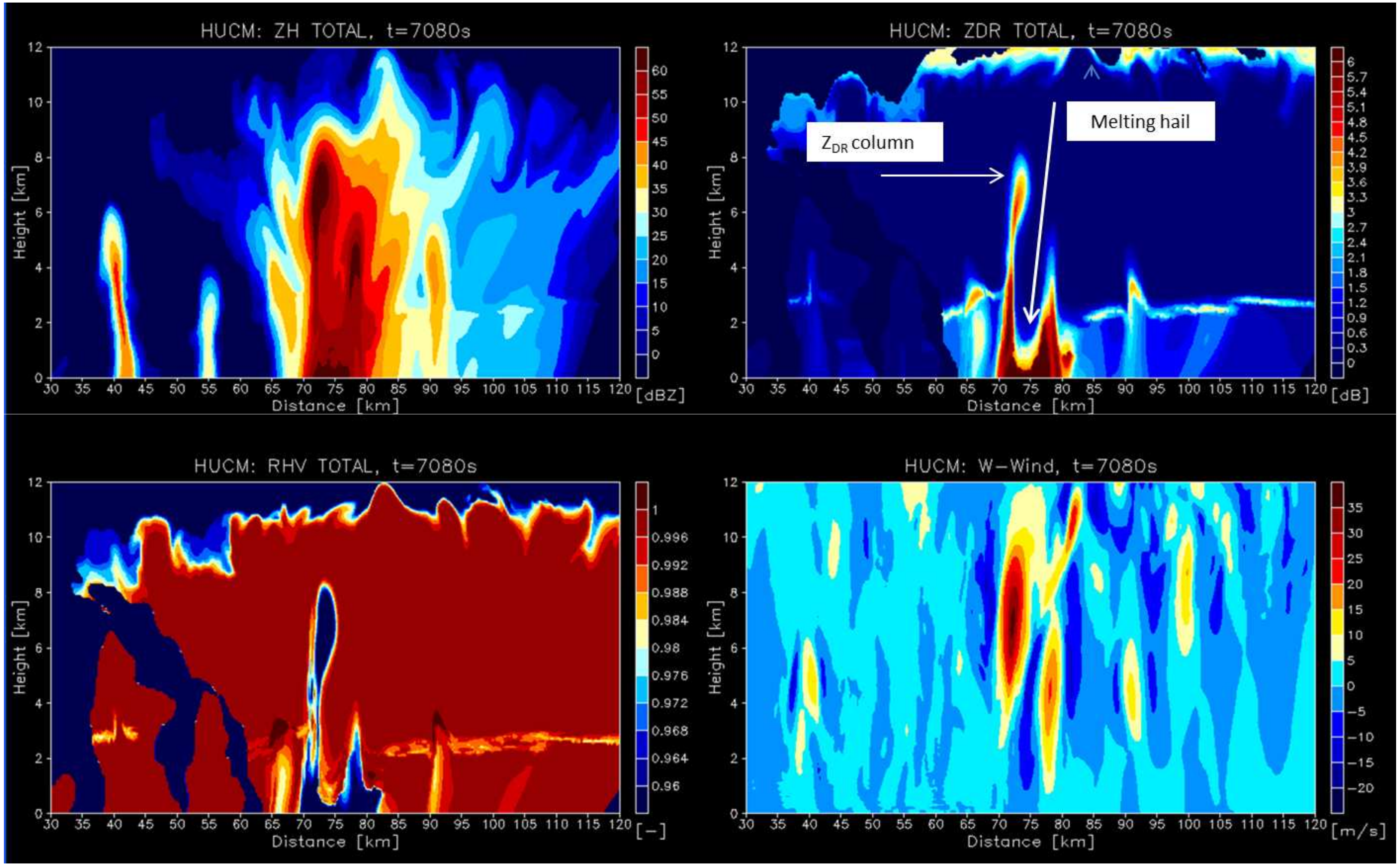


As opposed to S band, Z_{DR} at C band is very high in melting hail mixed with rain

Comparison of simulated and observed vertical profiles of Z_{DR} at C band



Example of vertical cross-section of Z, Z_{DR}, ρ_{hv}, and w simulated by the 2D HUCM model in a typical case of severe hail



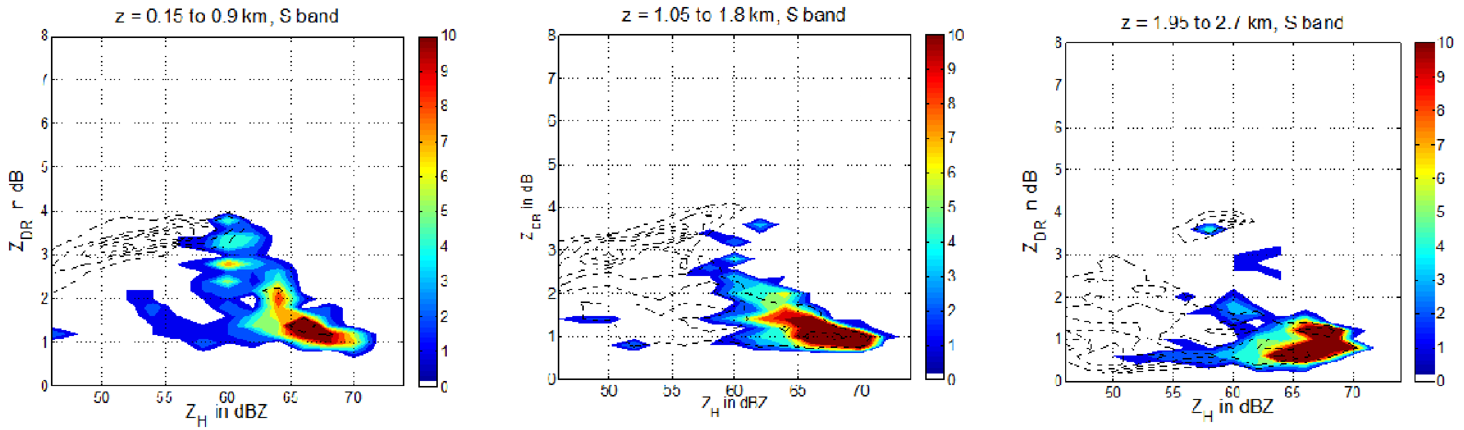
Simulated fields at C band

Frequency distribution of large hail mass (LHM, shading) and small hail mass (SHM, dashed contours) as functions of Z and Z_{DR} in different height intervals at S and C bands.

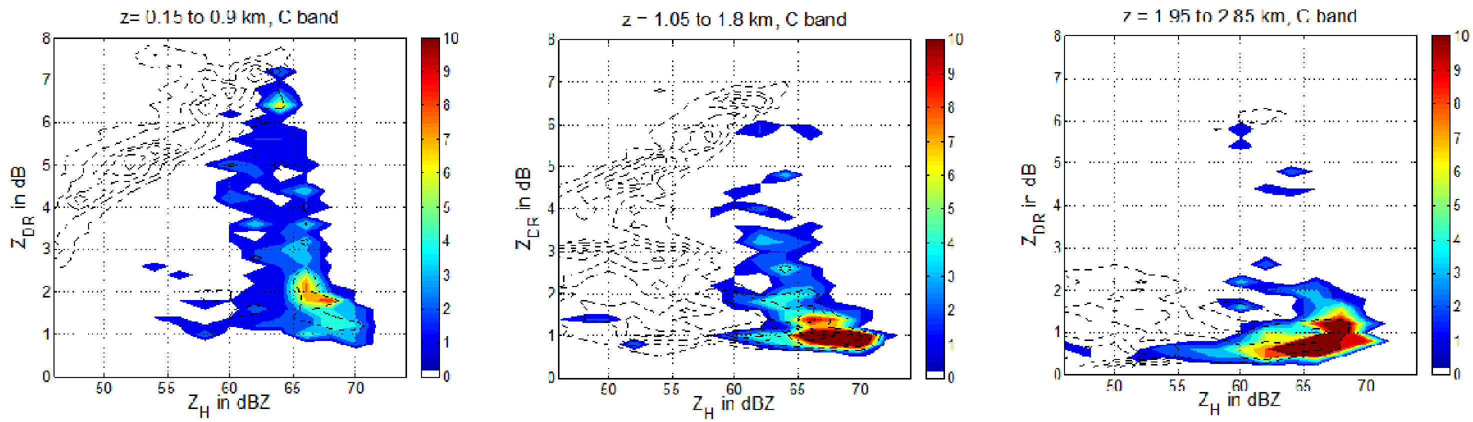
Simulations with HUCM

Freezing level is at 2.5 km

S band



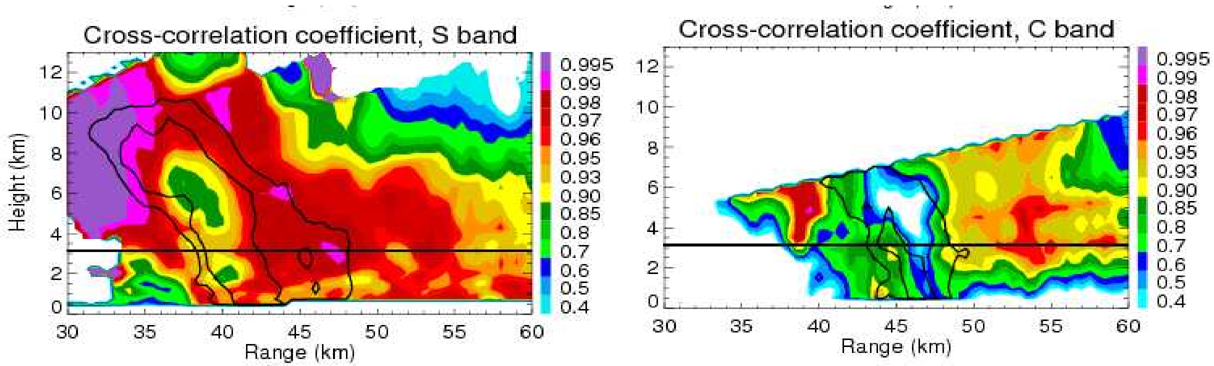
C band



LHM – D > 2.5 cm   SHM – D < 2.5 cm

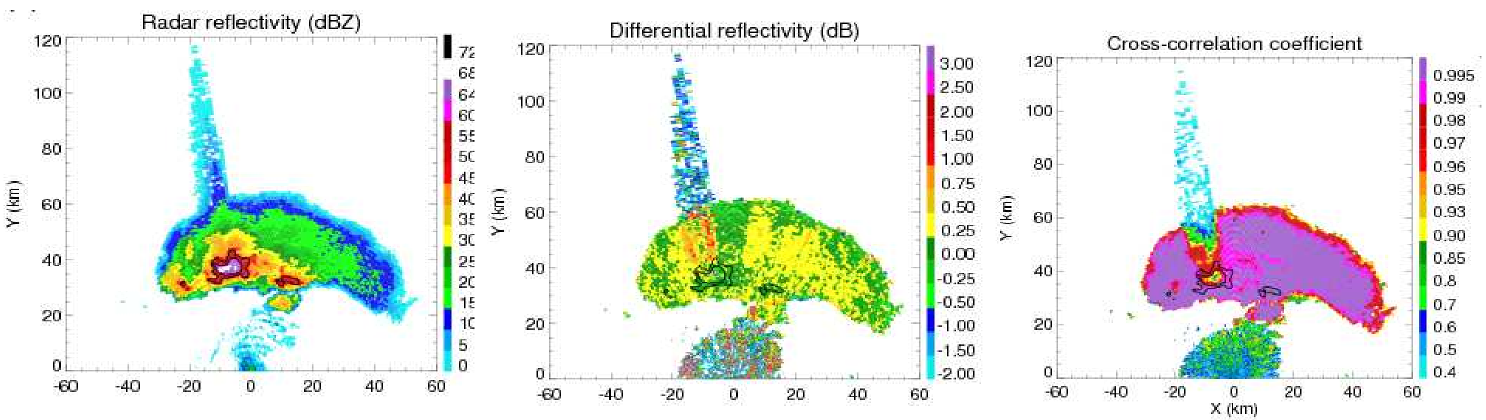
Additional signatures for identification of giant hail

1. Depression of ρ_{hv} above the freezing level



KOUN (S-band) – OU PRIME (C-band), 2010/05/16 (Picca and Ryzhkov 2012)

2. Three-body scattering spike



KOUN (S-band), 2010/05/16

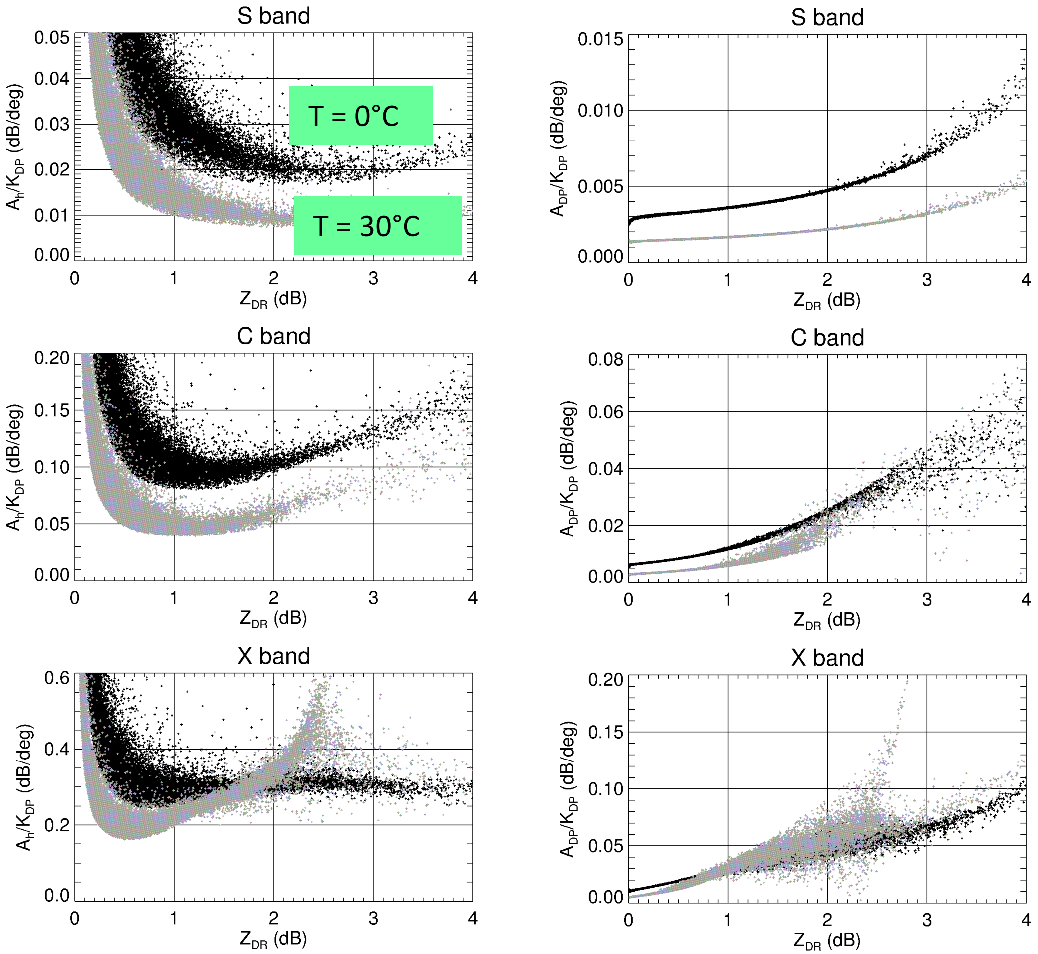
3. Spatial variability of Z_{DR} and ρ_{hv} within high-reflectivity cores

Attenuation / differential attenuation

Pure rain

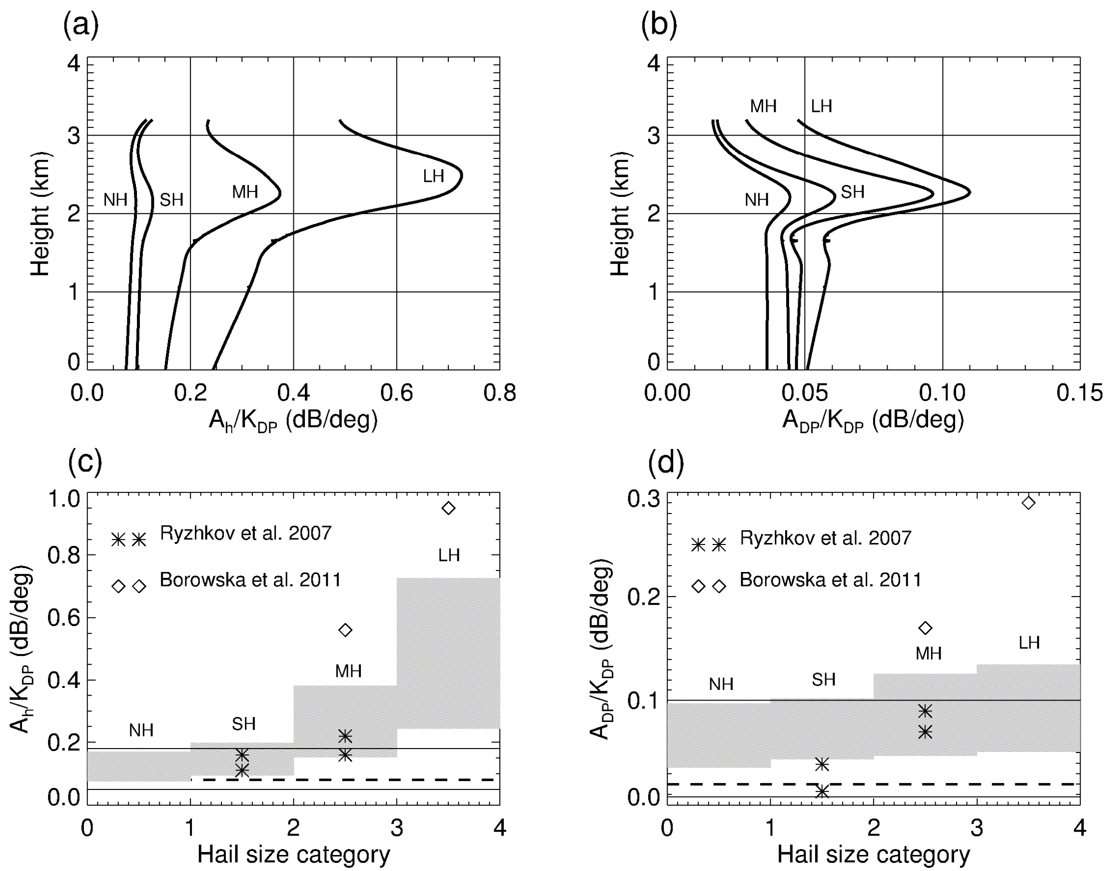
$$\Delta Z = \alpha \Phi_{DP} \qquad \Delta Z_{DR} = \beta \Phi_{DP}$$

$\alpha = A/K_{DP}$ $\beta = A_{DP}/K_{DP}$



Attenuation / differential attenuation

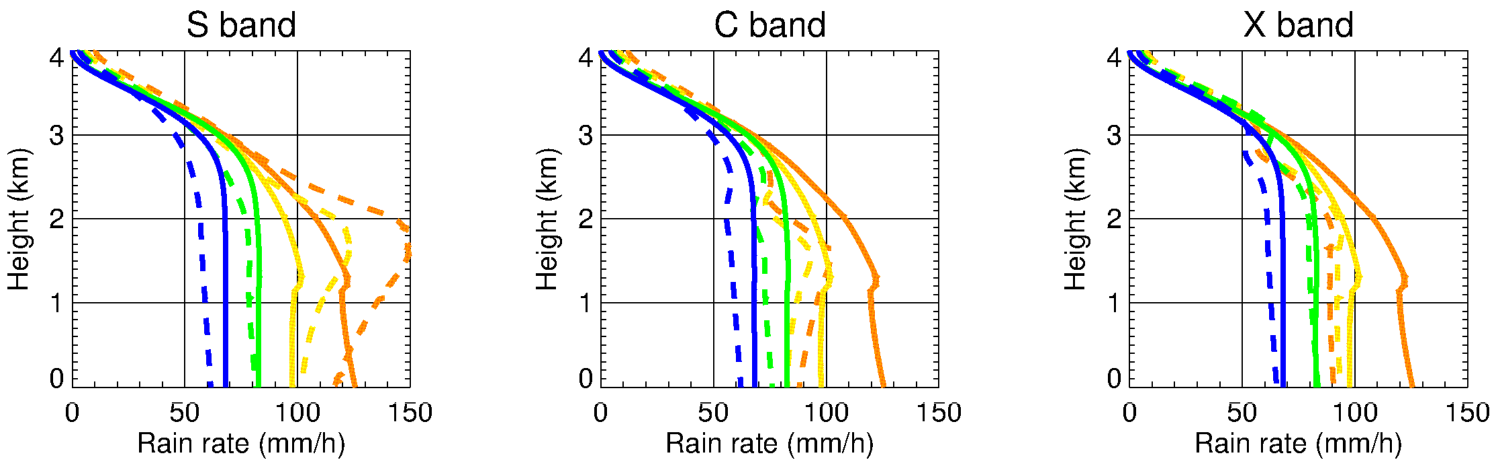
Melting hail (C band)



- The ratio A/K_{DP} is much more affected by melting hail than A_{DP}/K_{DP}
- The bulk of variability of the ratio A_{DP}/K_{DP} is due to changes in rain DSD
- Melting hail dramatically increases the concentration of large raindrops which are responsible for anomalously high differential attenuation
- Maximal A and A_{DP} are 1.5 – 2 km below the freezing level

Polarimetric rainfall estimation in the presence of hail

$R = 44.0K_{DP}^{0.822}$ $R = 25.3K_{DP}^{0.776}$ $R = 16.9K_{DP}^{0.801}$



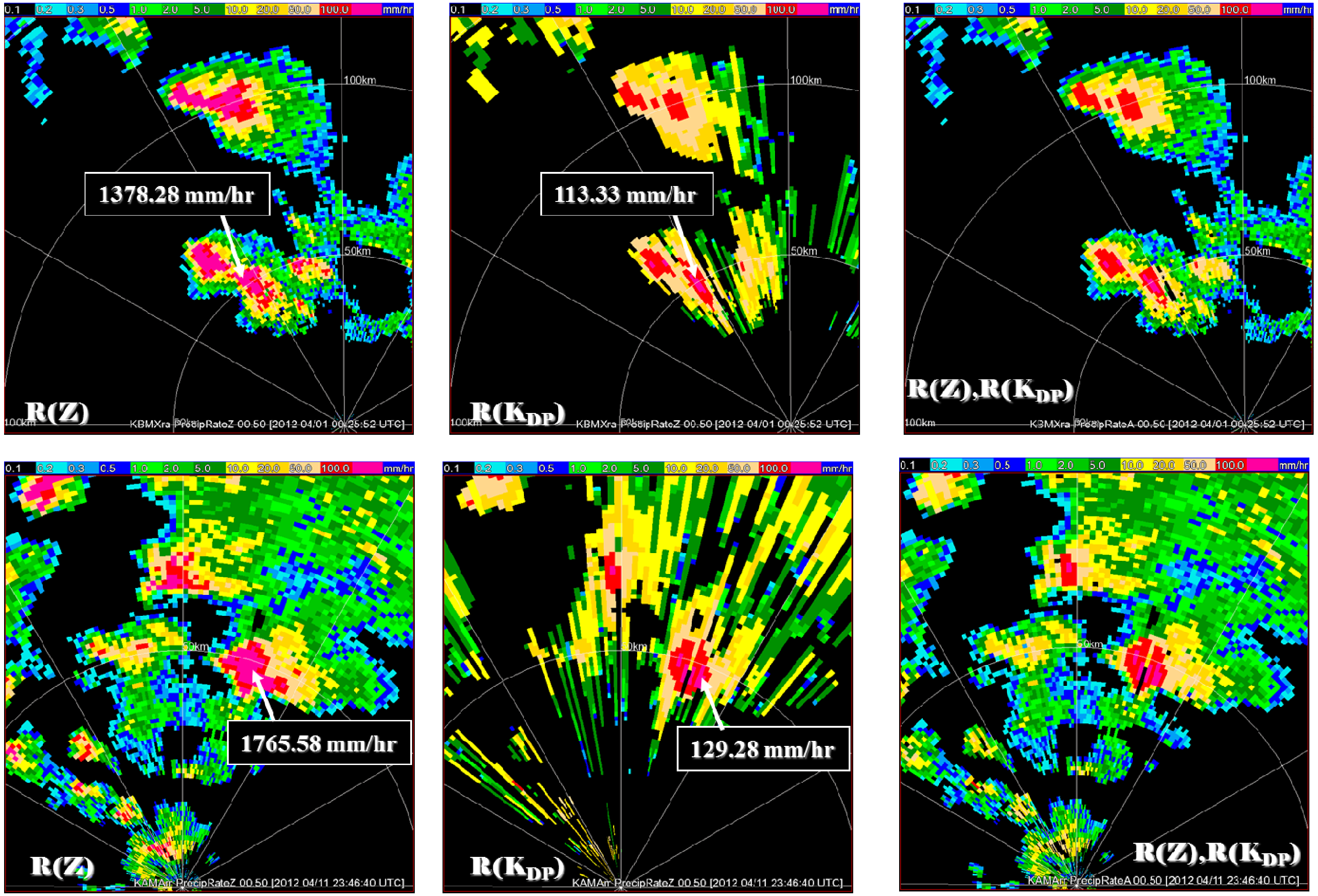
No hail Small hail Moderate hail Large hail

Solid line – actual rate; dashed line – R(K_{DP}) estimate

Vertical profiles of R(K_{DP}) follow actual profiles of rain rate quite well, although with underestimation which progresses for larger hail sizes

Polarimetric rainfall estimation in the presence of large hail

WSR-88D examples



KBMX
2012/04/01

KAMA
2012/04/11

The combination of $R(K_{DP})$ (for $Z > 45$ dBZ) with R(Z) or $R(Z,Z_{DR})$ (for $Z < 45$ dBZ) works best of all at S band in the presence of hail

CONCLUSIONS

- The polarimetric model of melting hail offers a theoretical basis for development of practical algorithms for hail detection and determination of its size, attenuation correction, and rainfall estimation in the presence of hail at different wavelengths.

- These algorithms are essentially wavelength-dependent and should take into account the height of the radar resolution volume with respect to the freezing level.

- Melting hail may significantly enhance attenuation of radar signal, whereas differential attenuation is not affected by hail so much.

- The $R(K_{DP})$ relation is a good choice for estimating rainfall in the presence of hail but it may produce negative bias which increases with increasing hail size