Examining the effect of the vertical wind shear environment on polarimetric signatures in numerically-simulated supercells

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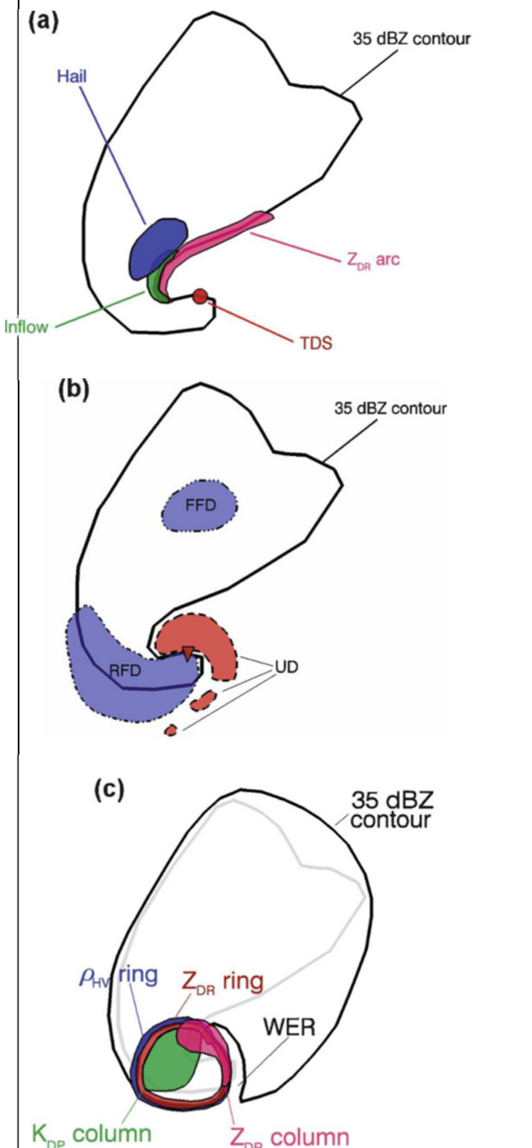
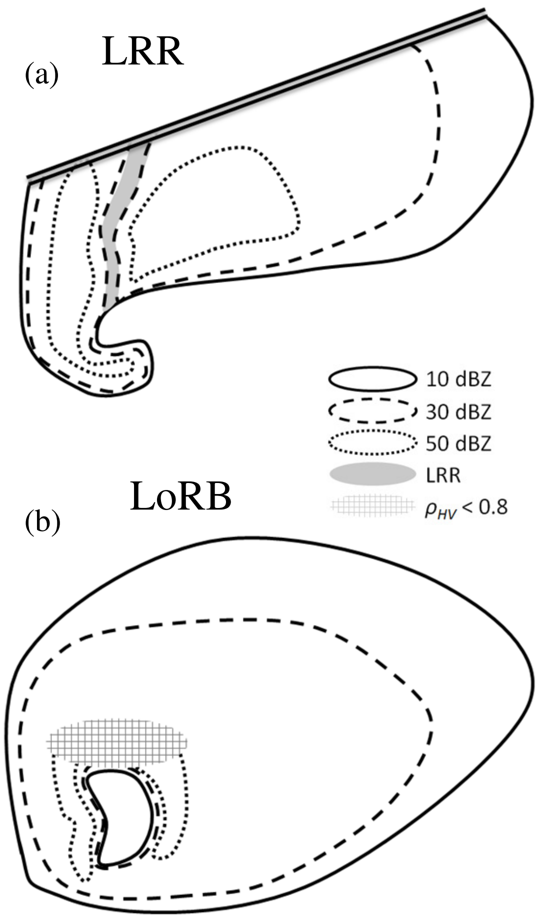
Some Overarching Questions

- What relative hydrometeor types and concentrations comprise some of the commonly-observed polarimetric signatures?
- How are the polarimetric signatures related (spatially and temporally) to the kinematic and thermodynamic structure of supercells?
- What do changes in the polarimetric structure of a supercell reveal about the evolution of the kinematic and thermodynamic fields?
  - What is happening within the supercell when the ZDR column changes height/size? Are there situations in which the mid-level ρ_{HV} ring is particularly evident/absent? Etc.
- How do polarimetric structures of simulated supercells vary in environments characterized by different shear profiles?
- How do polarimetric signatures vary by radar frequency (i.e., X, C, and S bands)? Where is this difference greatest, and which signatures are most affected?

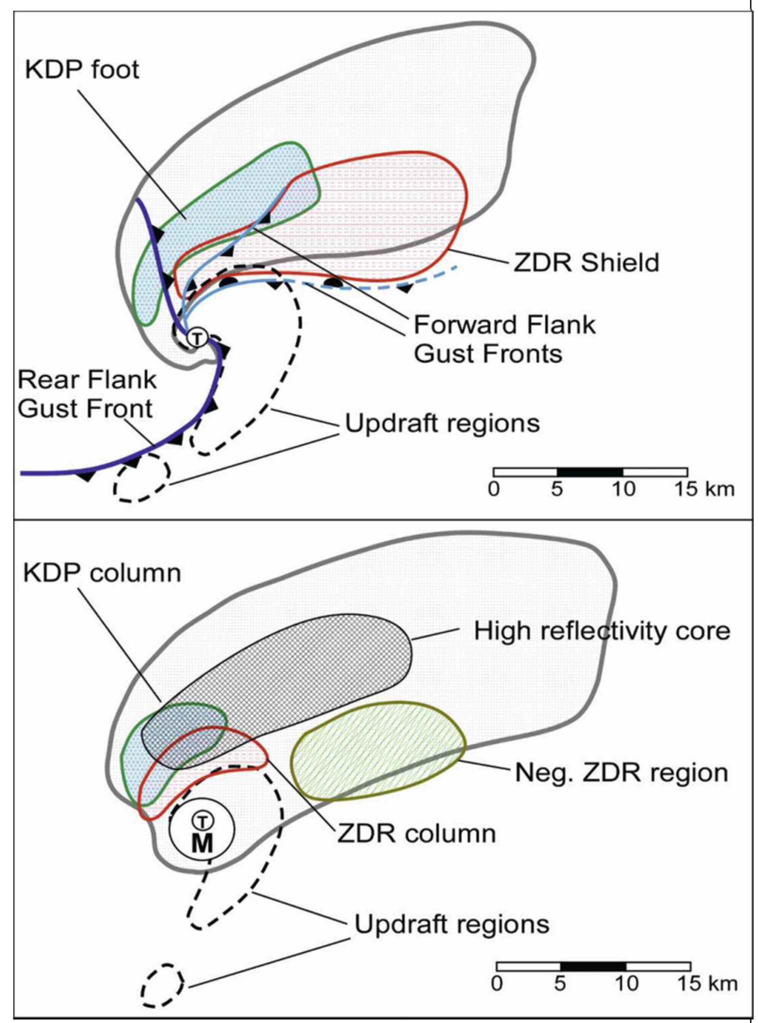
Polarimetric Signatures In Supercells



Adapted from Kumjian and Ryzhkov (2007)

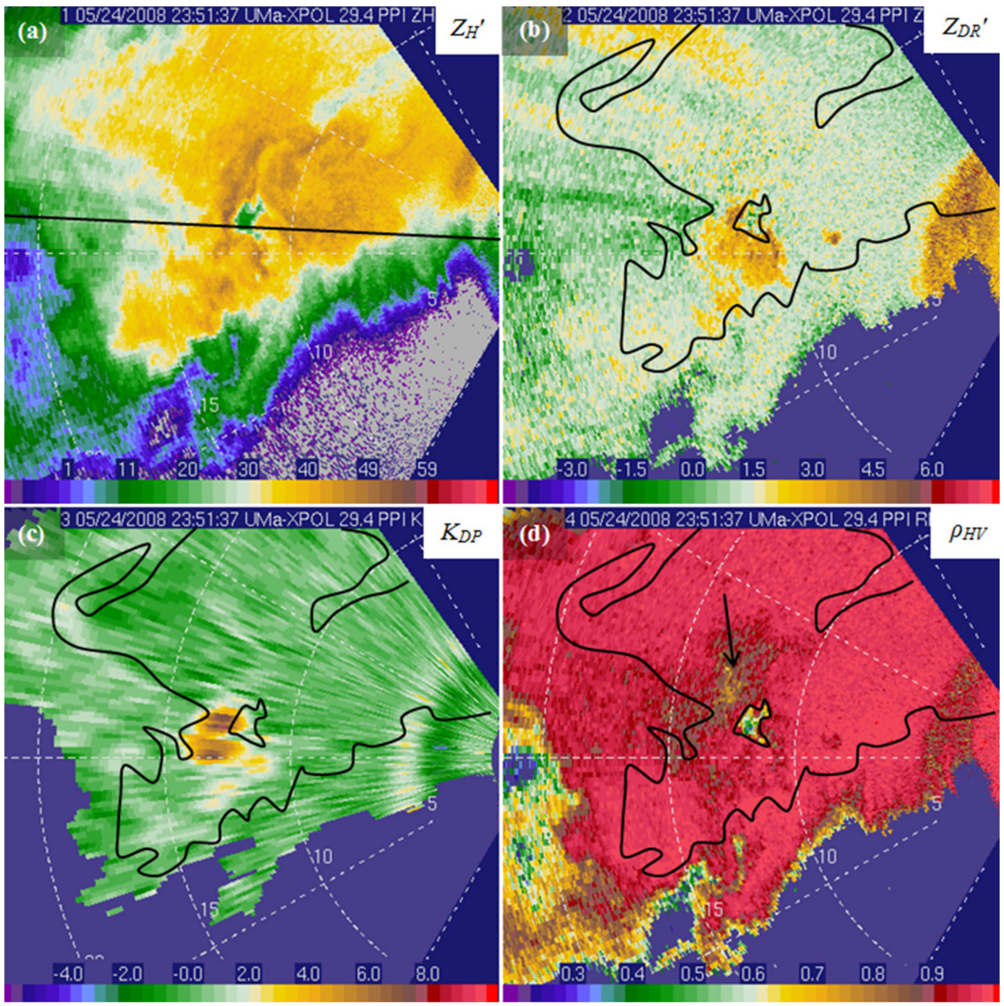


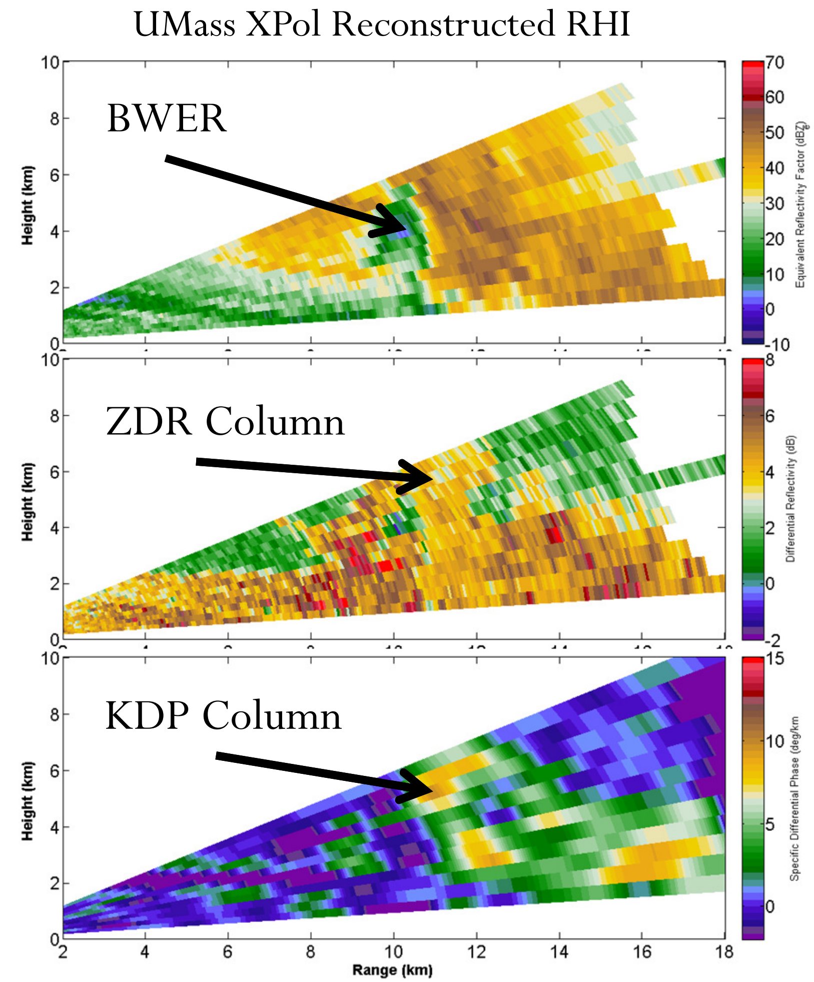
From Snyder et al. (2013)



From Romine et al. (2008)

Some X-Band Observations





From Snyder et al. (2013)

Why use numerical simulations?

- We have observational datasets of supercell from polarimetric mobile radars (e.g., UMass XPol and RaXPol), but practical limitations to deployment durations and strategies often complicates data collection (max height of data may not be great, attenuation is often very significant)
- Where data are available, one may be able to crudely estimate physical quantities such as temperature, rainwater mixing ratio, vertical velocity, etc.
- There are many caveats when applying idealized simulations to real-world data, but the goal is to extract meaningful signals and trends from the numerical simulations that can be used to infer processes behind observed polarimetric fields (from a nowcast/forecast perspective, etc.)

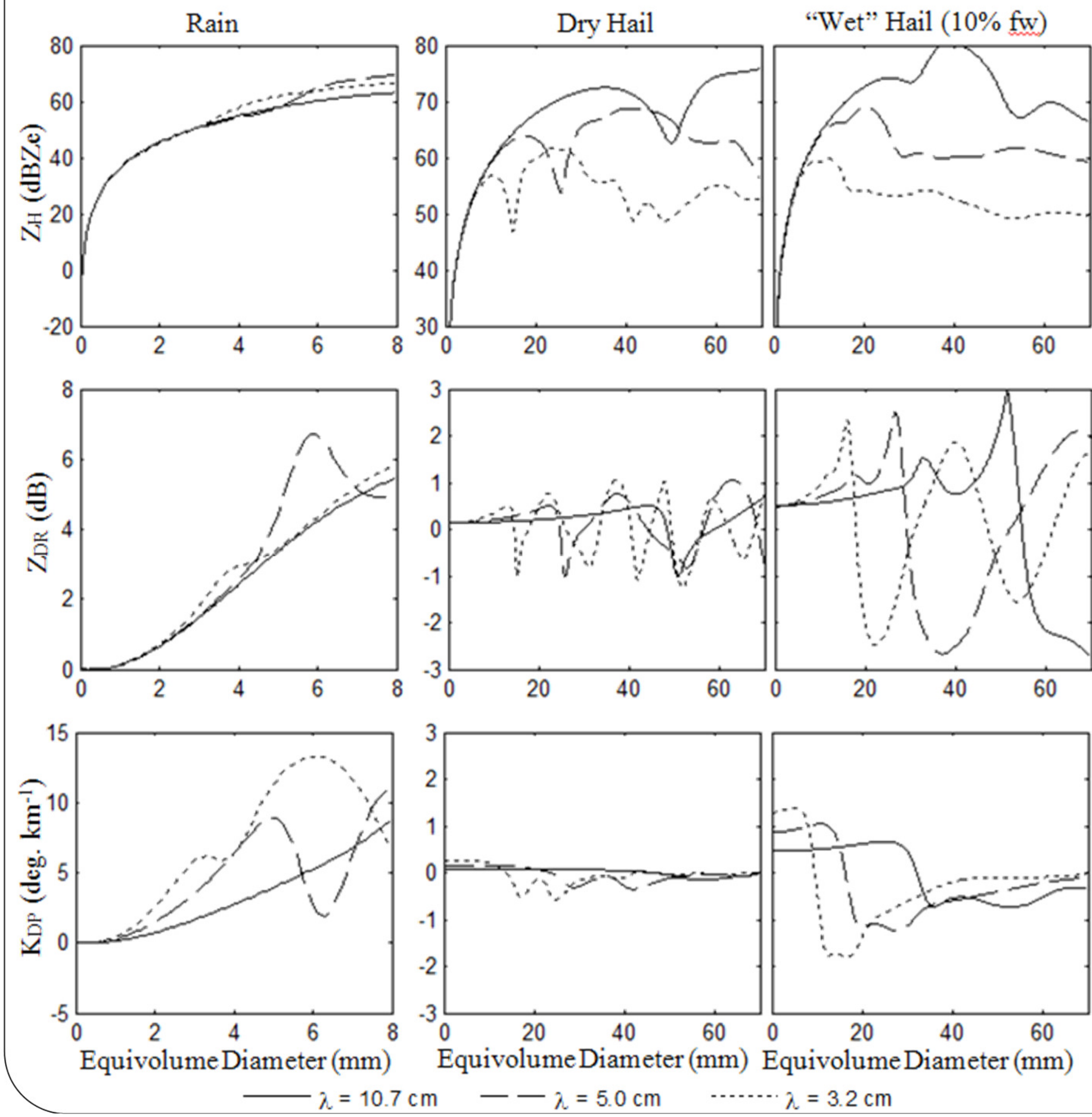
Model Configuration

- ARPS 5.3.3
- 150 km x 150 km x 20 km grid
- 200 m ΔX and ΔY, stretched vertical grid (75-350 m ΔZ)
- Horizontally-homogeneous initial conditions
- 1.0 s ΔT, run to 10800 s (output every 120 s)
- Radiation LBCs, Rayleigh damping layer at top, free-slip lower BC
- Initial soundings:
  - Weisman and Klemp (1982) thermodynamic profile
  - A suite of vertical wind profiles
    - Four "shapes" at two "intensities" (hodograph lengths)

Microphysics and Radar Emulator

- Utilized Milbrandt and Yau (2005) triple-moment bulk scheme
  - Predicts N, Q, Z (i.e. M0, M3, M6)
  - Rain water, cloud water, ice, snow, graupel, and hail
  - Multimoment scheme is needed to model sedimentation and to more accurately capture other microphysical processes
- Radar emulator used the framework of Jung et al. (2010) with updates to fractional water and dielectric constant calculations
  - Scattering matrix calculated from T-matrix method
  - Z_H, Z_{DR}, Z_{DP}, ρ_{hv}, K_{dp}
- No plots shown will include attenuation
- Desire: use a spectral bin scheme to more accurately stimulate microphysical processes. Limited schemes are available, however, and they tend to come with a high computational cost

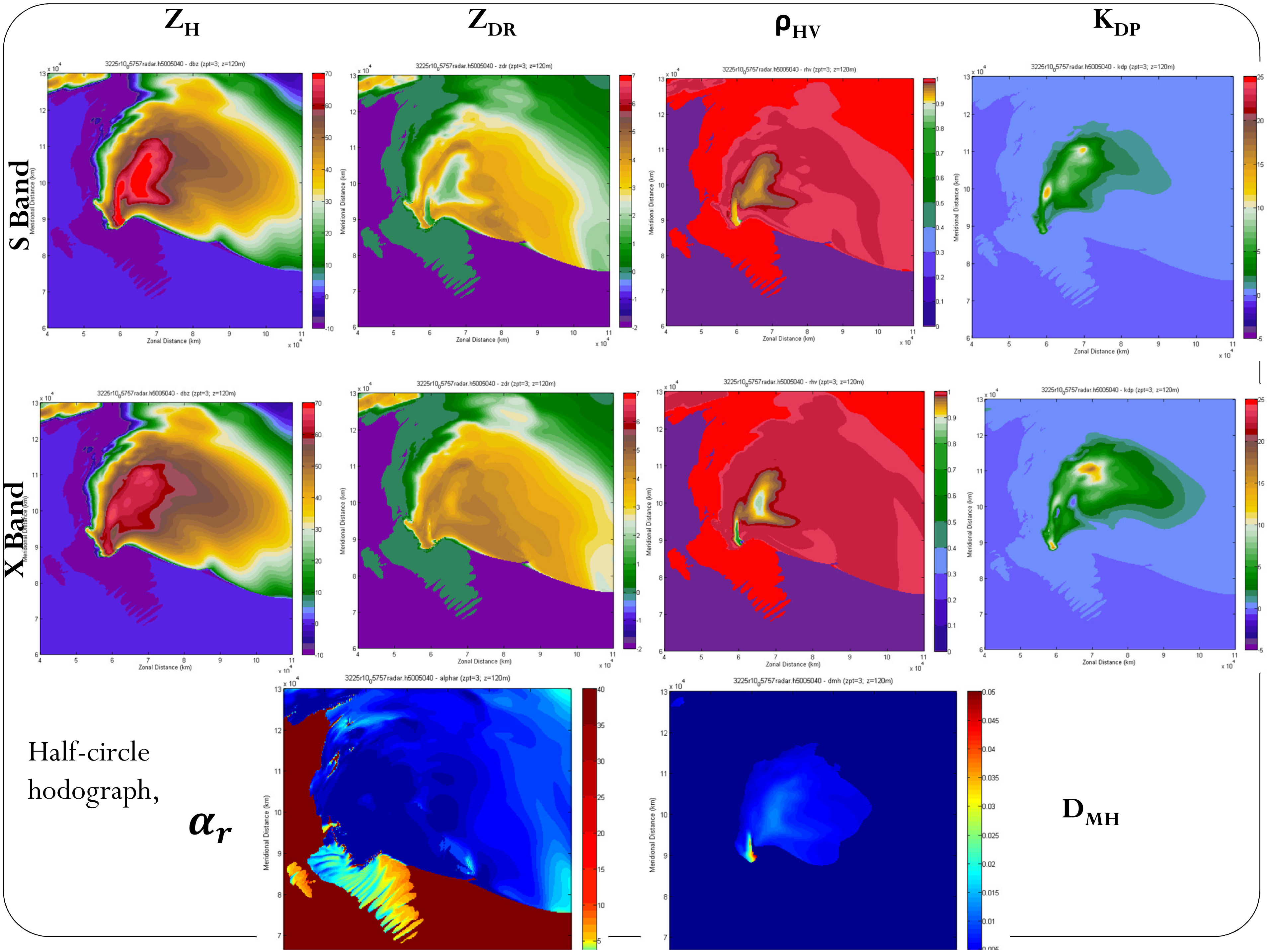
Scattering at S, C, and X bands



- Mean canting angle: 0°
- Std. deviation of canting angle:
  - Rain: 0°
  - Hail: $\begin{cases} 60°\,(1-2f_w) & f_w \le 0.5 \\ 0 & f_w > 0.5 \end{cases}$
- Aspect ratio:
  - Rain: Brandes et al. (2002)
  - Hail:

$$\begin{cases} 0.75 & f_w < 0.2 \\ 0.813 - 0.317 f_w & 0.2 \le f_w < 0.8 \\ 2.8 - 4.0 r_r + 5.0(r_r - 0.56) f_w & f_w \ge 0.8 \end{cases}$$

- Dielectric constant:
  - Rain: Cole and Cole (1941)
  - Hail: Maxwell-Garnett mixing formula (water/ice)
- In the emulator, the model of Rasmussen and Heymsfield (1987) is used to determine the allowable water mass amount, allowing f_w to vary as a function of diameter
- Observations
  - Hail @ Sband >> Hail @ Xband
  - Wet hail can have appreciable Z_{DR}<0 dB and K_{DP} < 0° km^{-1}
  - Not shown - backscatter differential phase (δ) in hail at higher frequencies can be extremely variable and significant



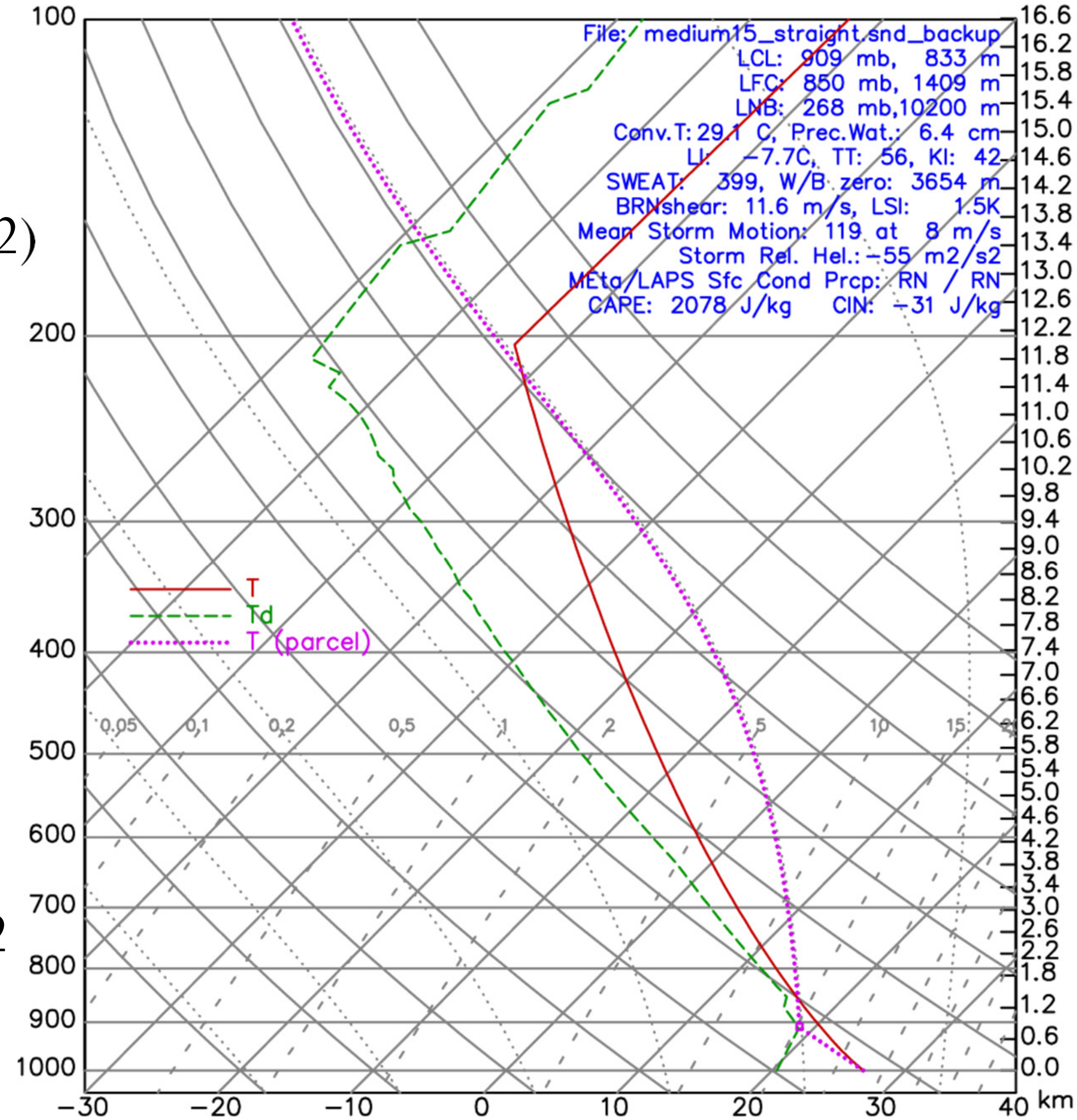
Z_H
Z_DR
ρ_HV
K_DP
S Band
X Band
Half-circle hodograph,
α_r
D_MH
Zonal Distance (km)
Meridional Distance (km)

Reasonable Expectations

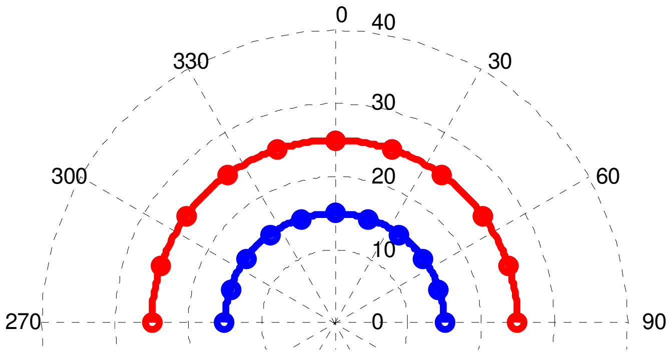
- Potential limitations
  - Each species must still fit a gamma distribution (multimodal distributions cannot be simulated), may variably affect Z_H, Z_{DR}, and ρ_{HV} when different processes affect different parts of the DSD
  - Very seldom is a BWER simulated
    - Perhaps related to the use of a bulk scheme instead of a spectral bin scheme (producing rain too quickly; Khain and Lynn 2009; Straka 2009).
  - Currently only one rain category being used
    - Would be more preferable to have multiple rain categories to account for, e.g., shedding from melting hail

Sounding

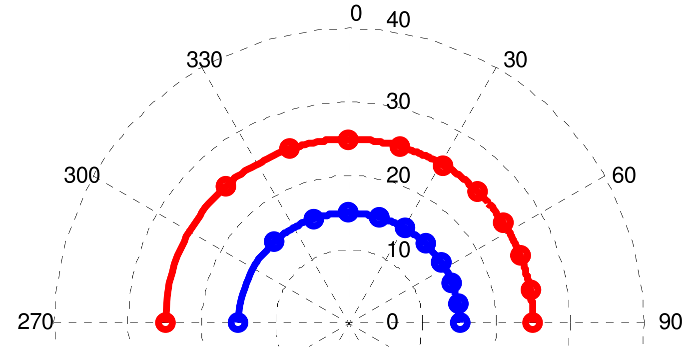
- Analytical sounding from Weisman and Klemp (1982)
- $SBCAPE_{TV}$: 2078 j/kg
- $SBCIN_{TV}$: -31 j/kg
- LCL: 833 m
- LFC: 1409 m
- Env. 0°C: ~3800 m
- Parcel 0°C: ~4800 m
- Very moist troposphere characteristic of the WK82 sounding (64 mm PW)



Hodographs



Half-Circle

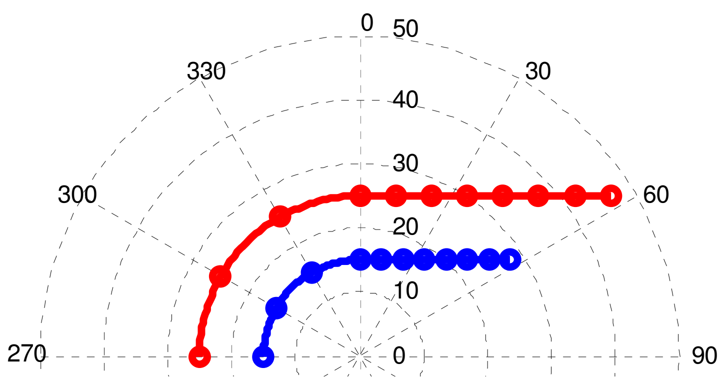


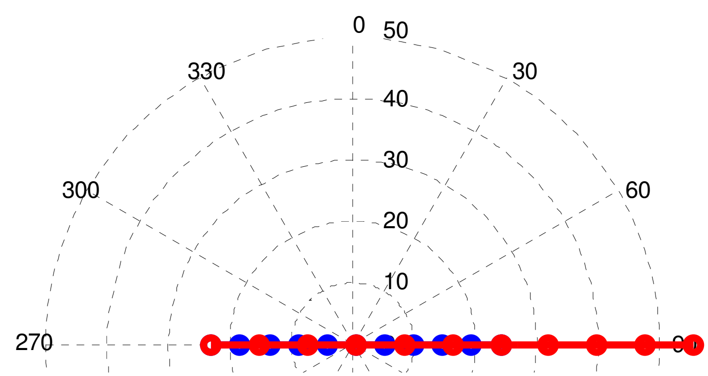
Weak

$$\left|\frac{\partial V_H}{\partial z}\right| \approx 4.7 \times 10^{-3} s^{-1}$$

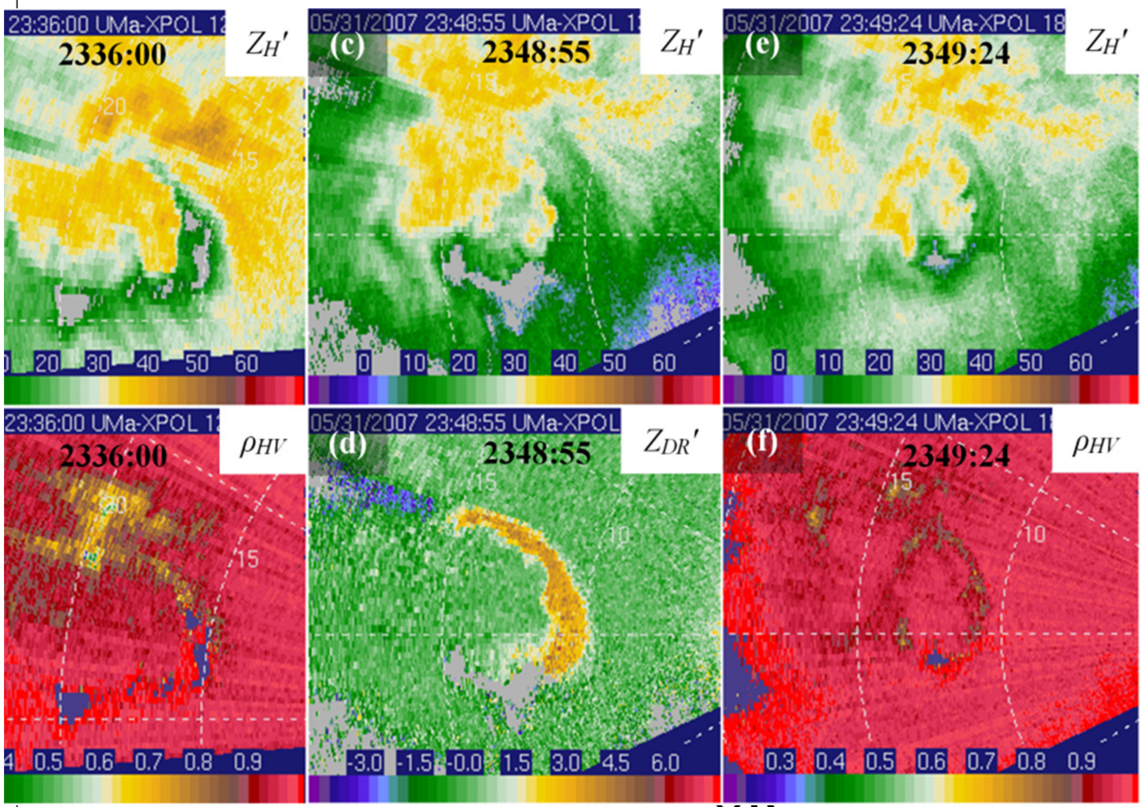
$$\left|\frac{\partial V_H}{\partial z}\right| \approx 7.8 \times 10^{-3} s^{-1}$$

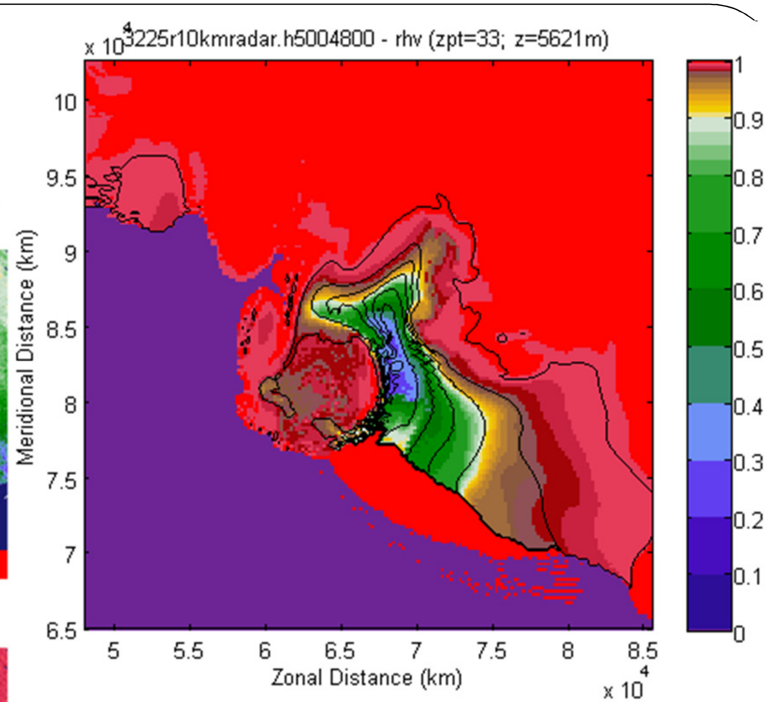
Strong

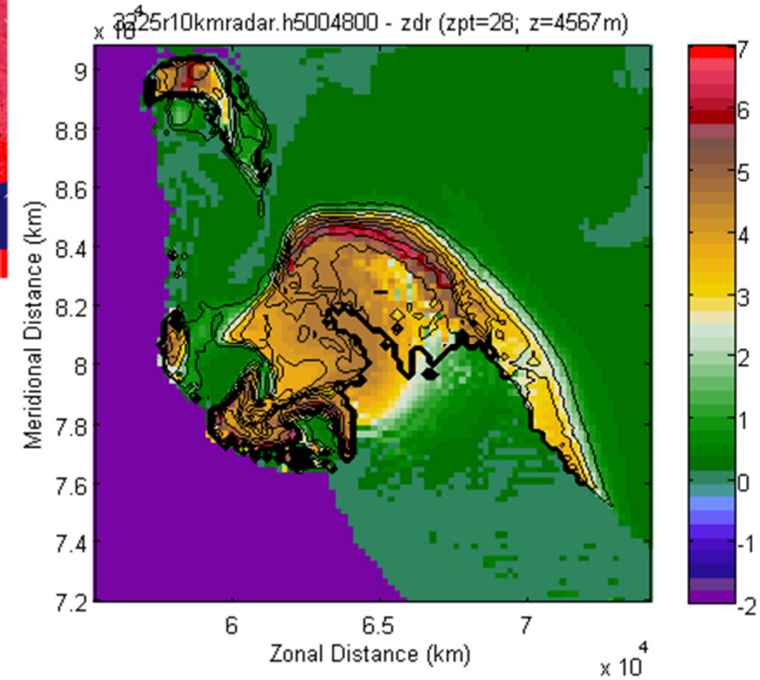




Z_{DR} & ρ_{HV} Rings

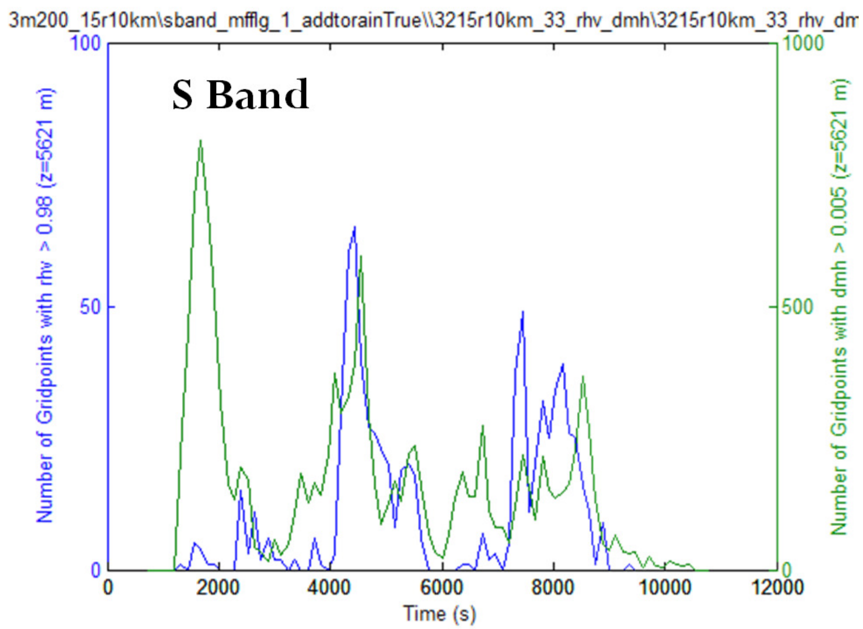


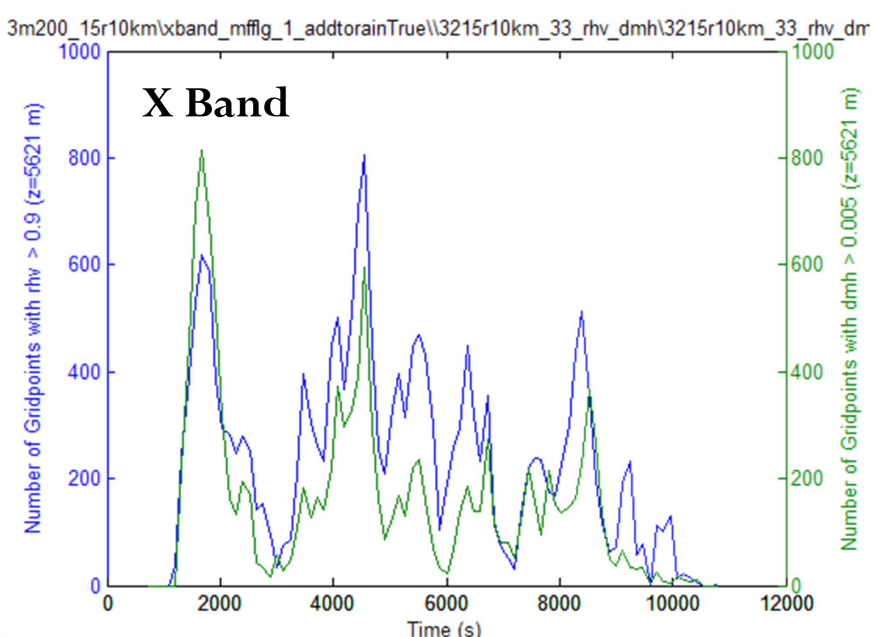




ρ_{HV} ring primarily modeled coincident with very large hail aloft along the downshear side of the updraft

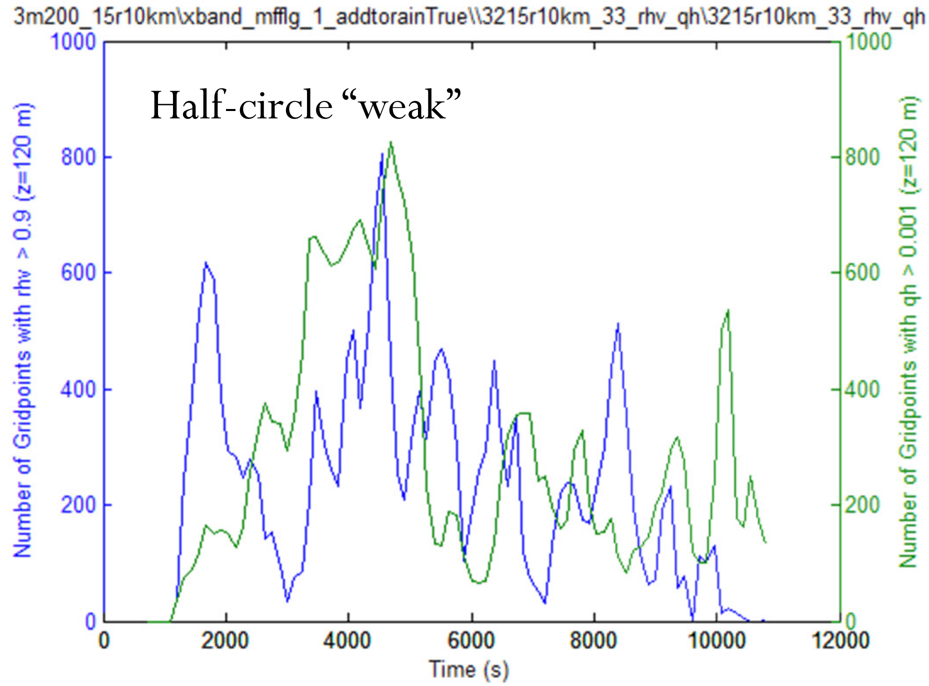
ZDR half-rings seen near edge of updraft, comprised of hail and graupel with high fractional water content

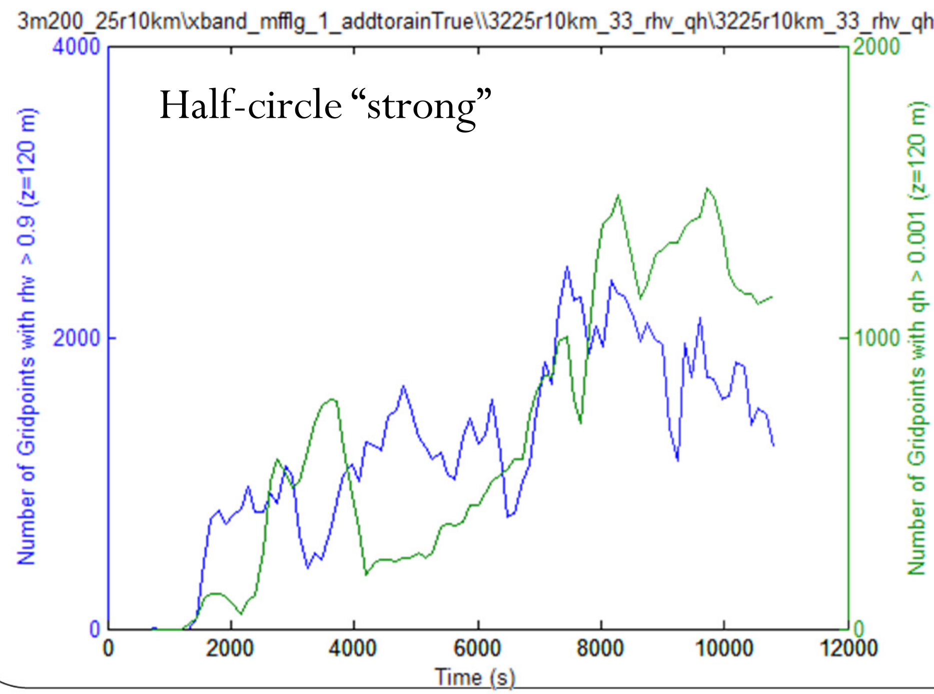




ρ_{HV} Rings

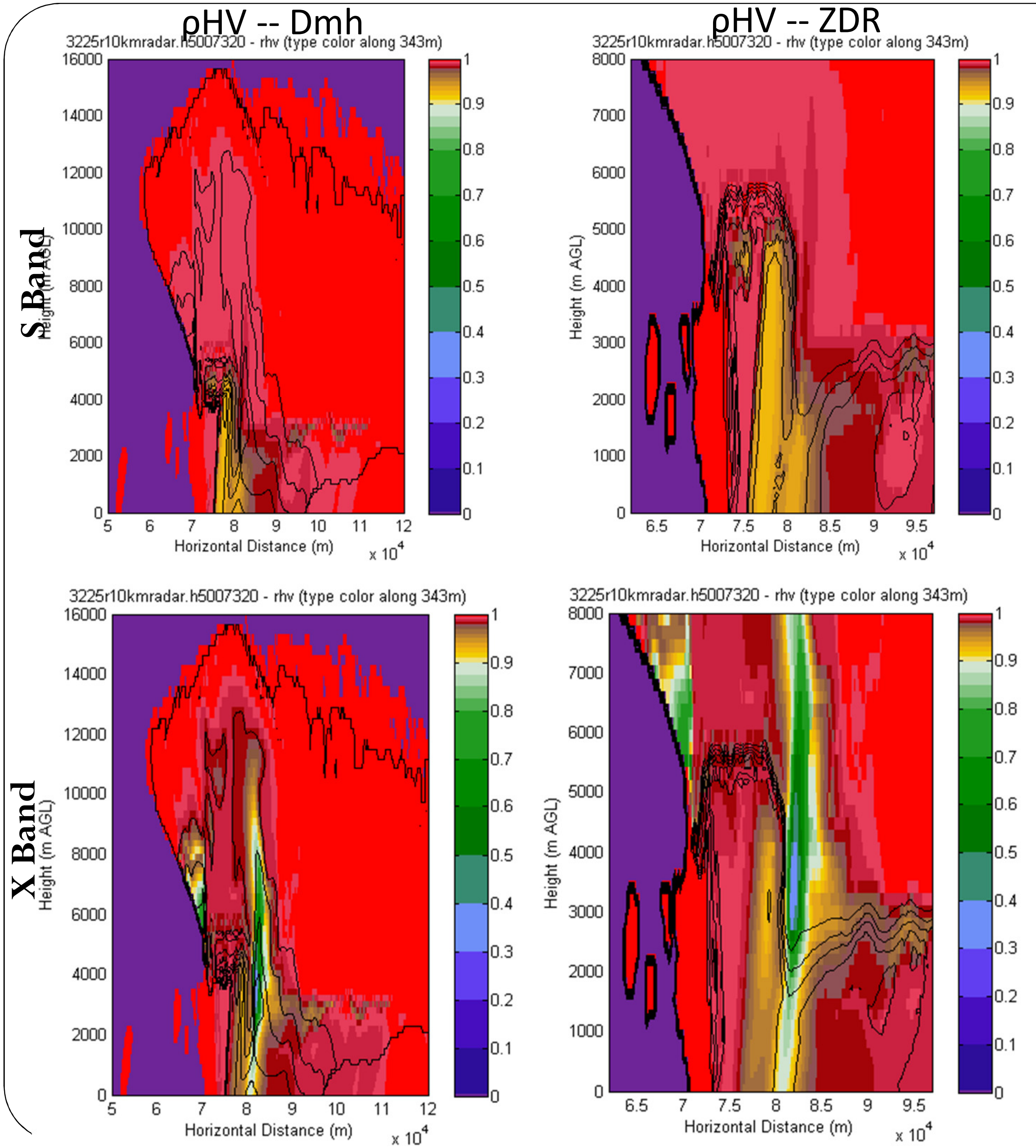
- Half-circle, “weak” shear example
- Number of gridpoints with low ρ_{HV}
  - S band : $\rho_{HV} < 0.98$
  - X band: $\rho_{HV} < 0.9$
- Number of gridpoints with $D_{mh} > 5$ mm
- Generally much more obvious (larger, lower rhohv) at higher frequencies (e.g., X band).





ρ_{HV} rings -> Hail at the surface?

- X Band
- Left: Area of X-band ρ_{HV} < 0.9 at ~5600 m and area of qh > 0.001
- Some "hail dumps" at the surface are preceded by increases in the size of the ρ_{HV} rings aloft, but not all

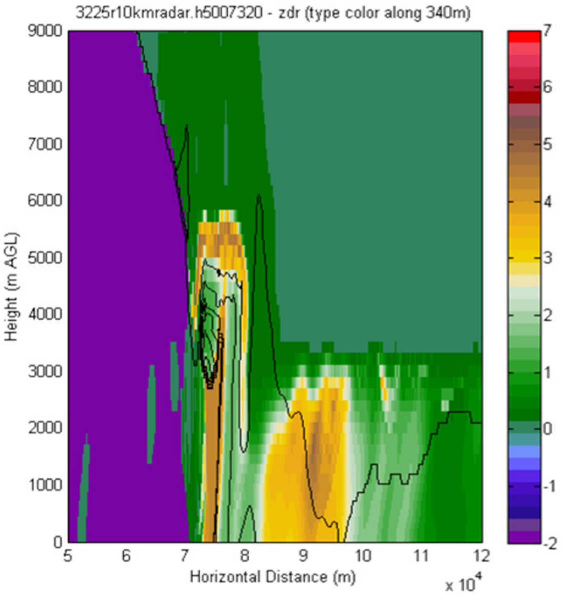


- Half-circle, "strong" shear example
- X band shows greater sensitivity to large graupel and hail along
- Number of gridpoints with $D_{mh} > 5$ mm
- Generally much more obvious (larger, lower rhohv) at higher frequencies (e.g., X band).

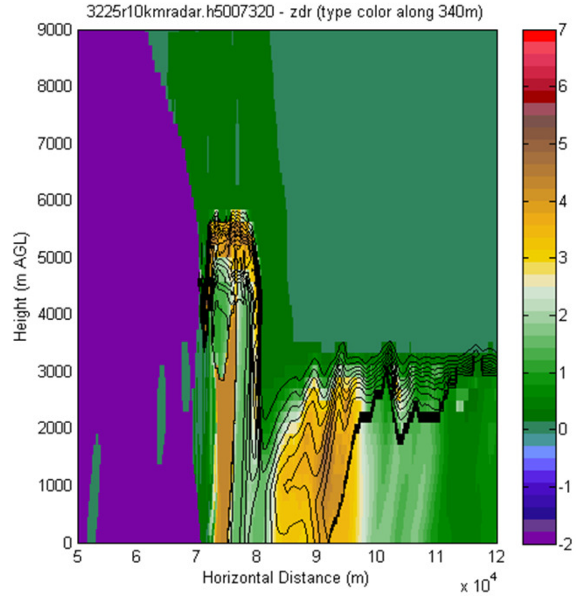
ZDR Column Cross-Section

S Band

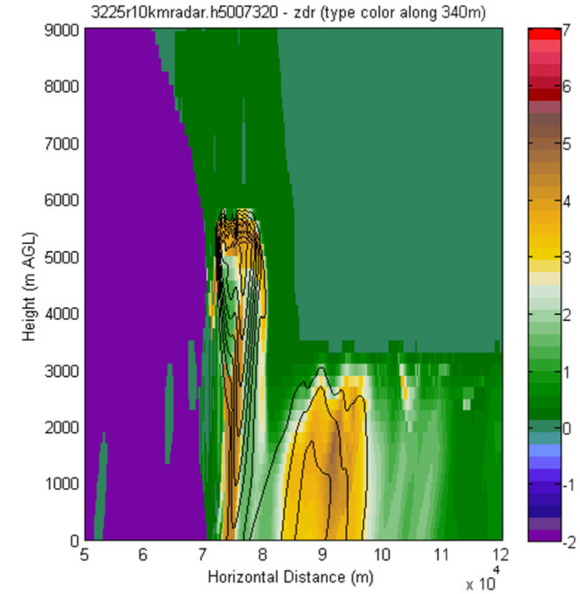
Contour: Dmh



Contour: Fwh

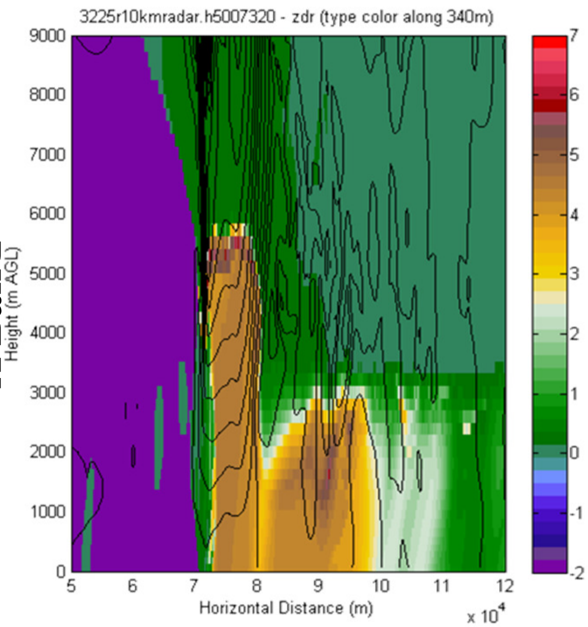


Contour: Qr

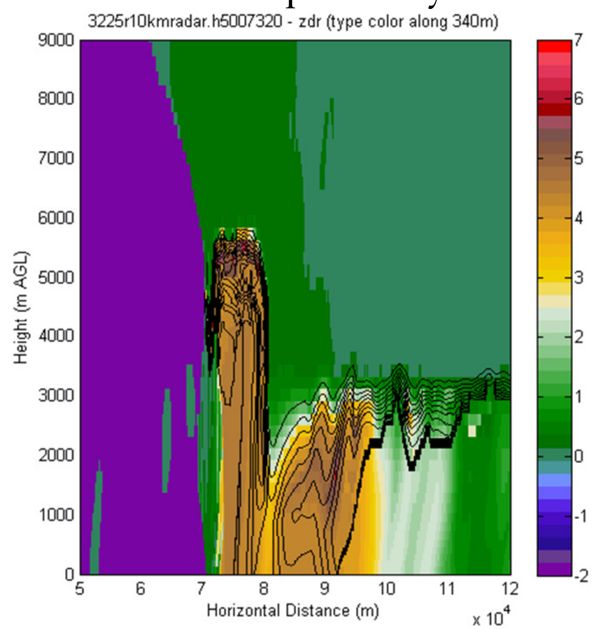


Inner section primarily wet hail – low ZDR at S, high at X

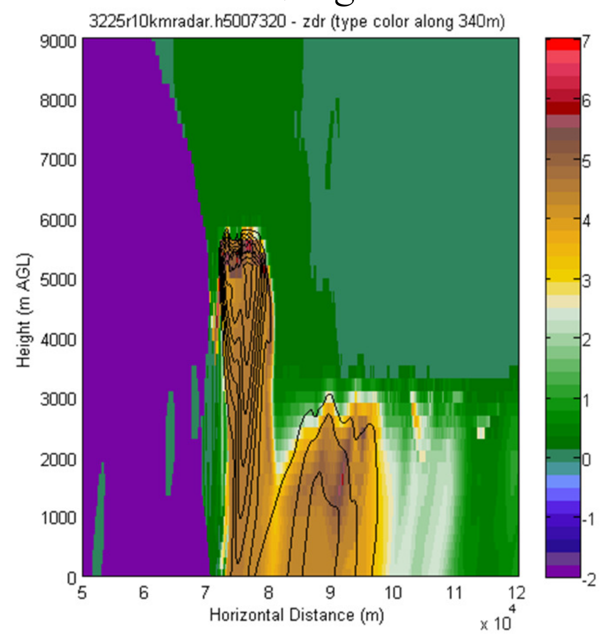
X Band



Contour: W

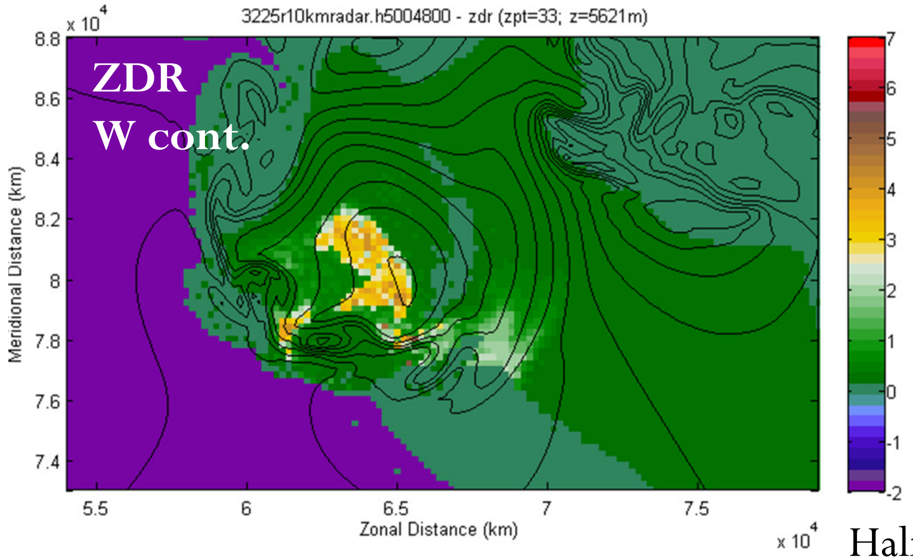


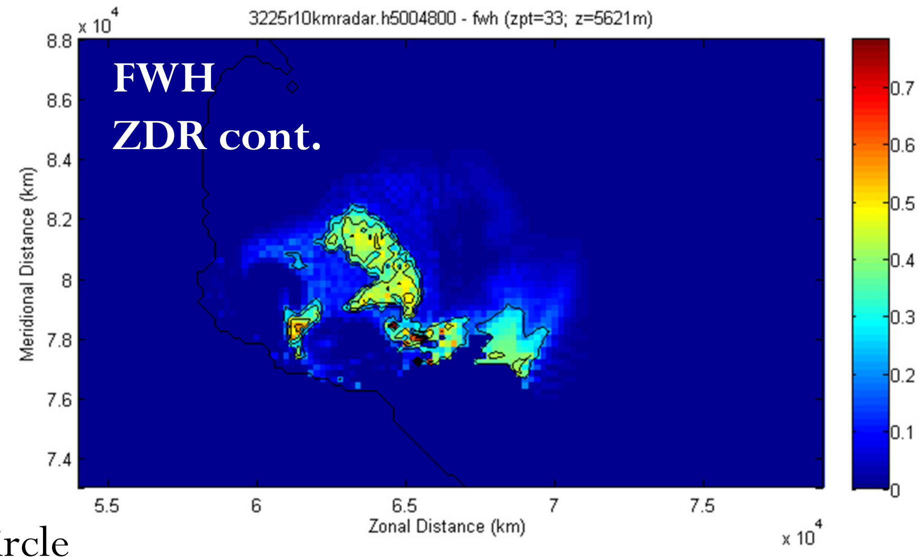
Contour: Fwh



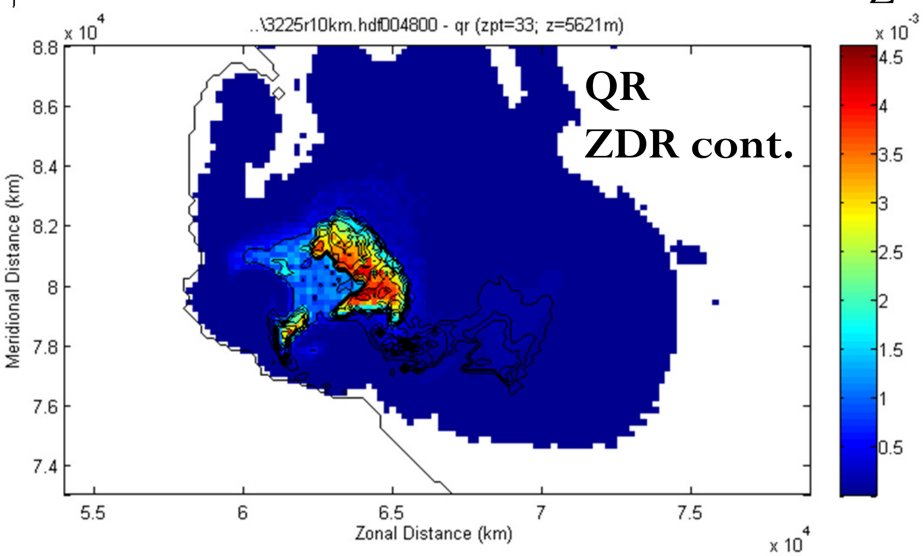
Contour: Qr

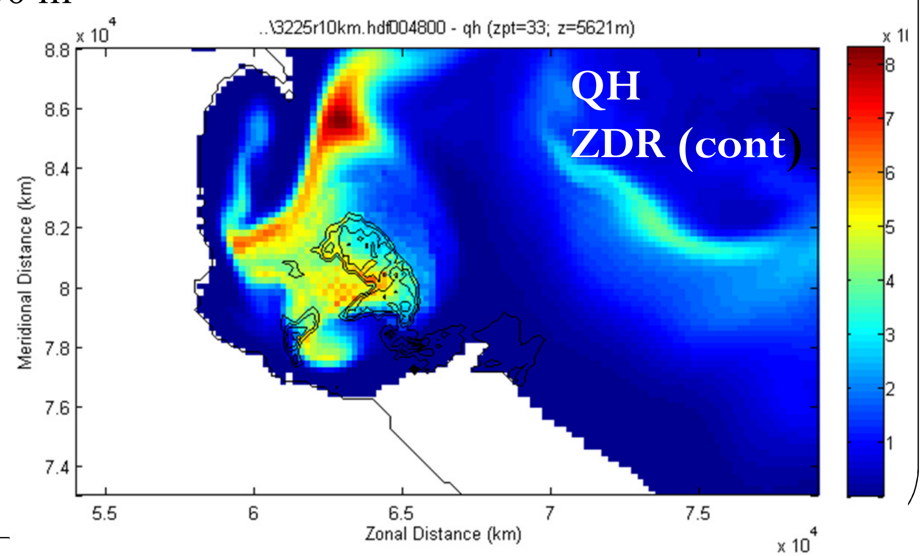
Physical Insight– Z_{DR} Column

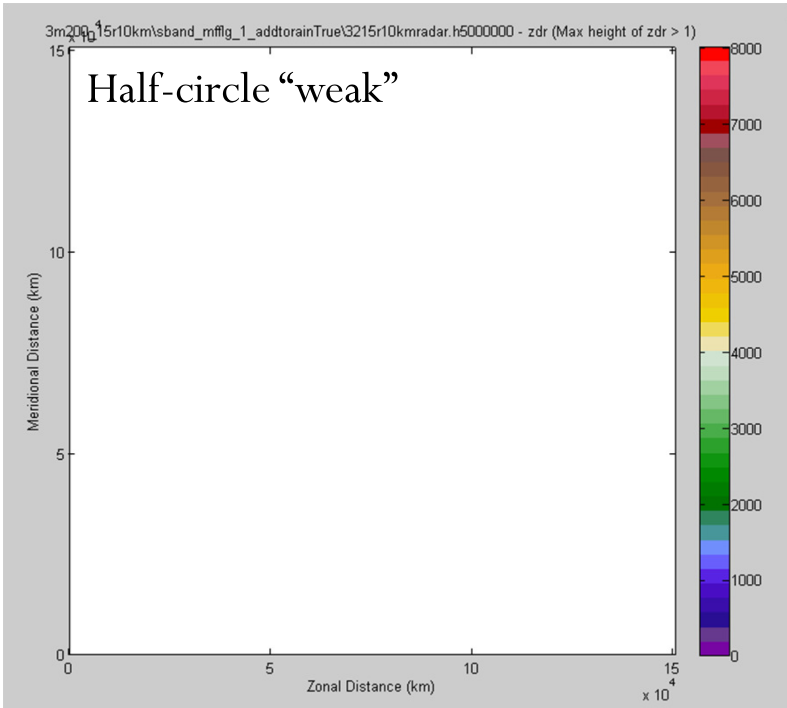


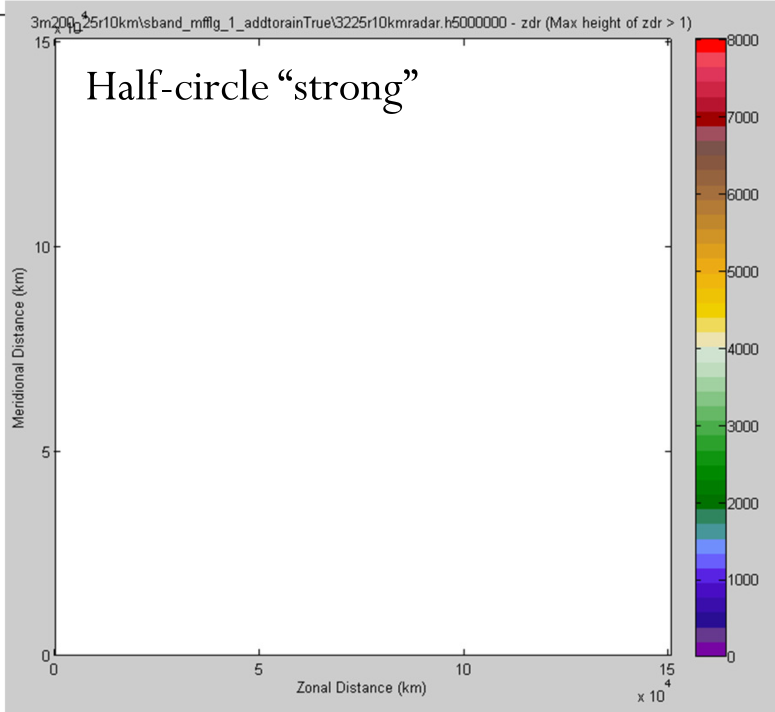


Half-circle
"weak" shear
Z~5600 m

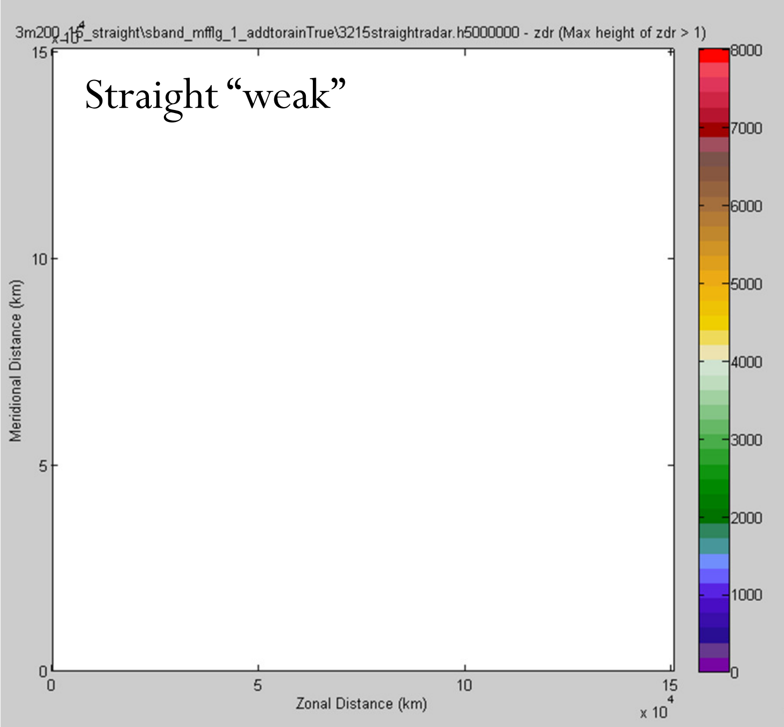


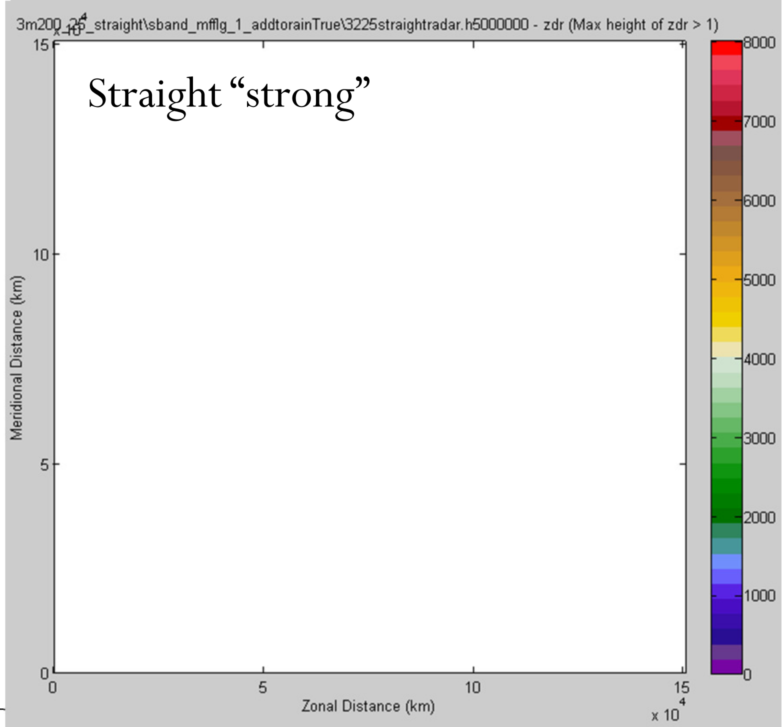




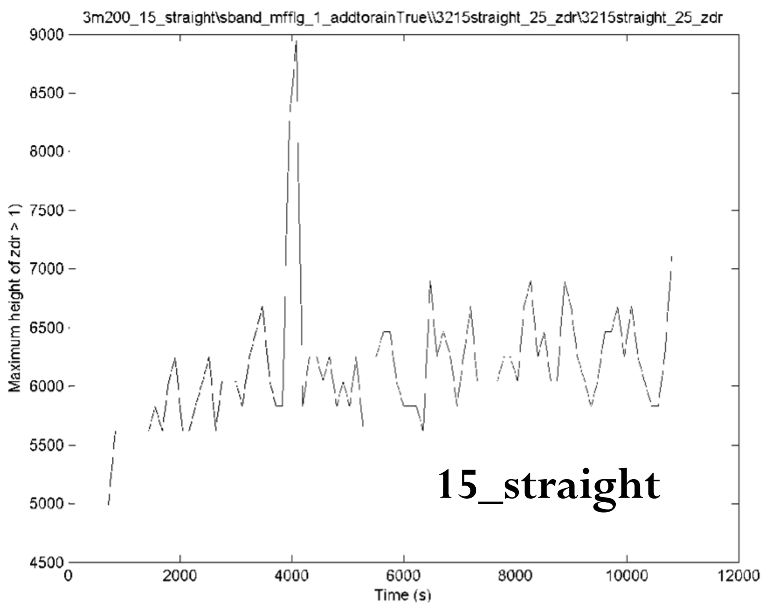


Maximum Height of Z_{DR} v 1 dB

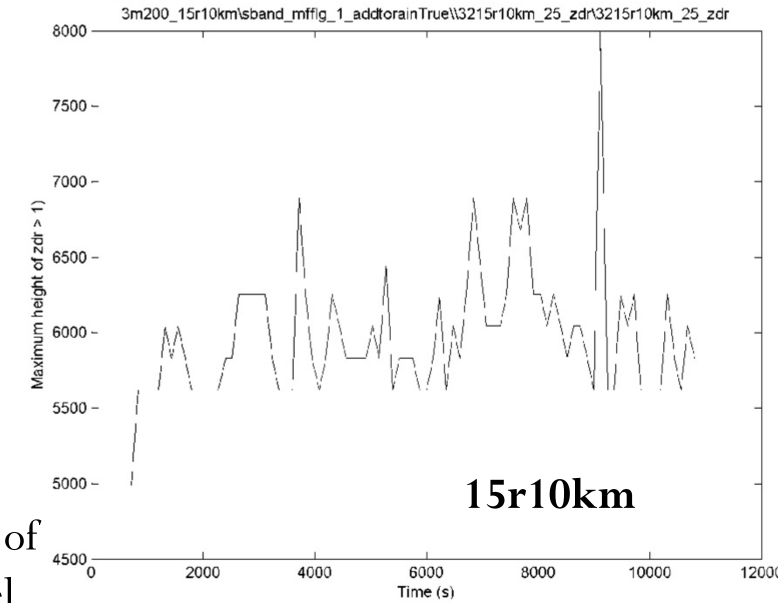




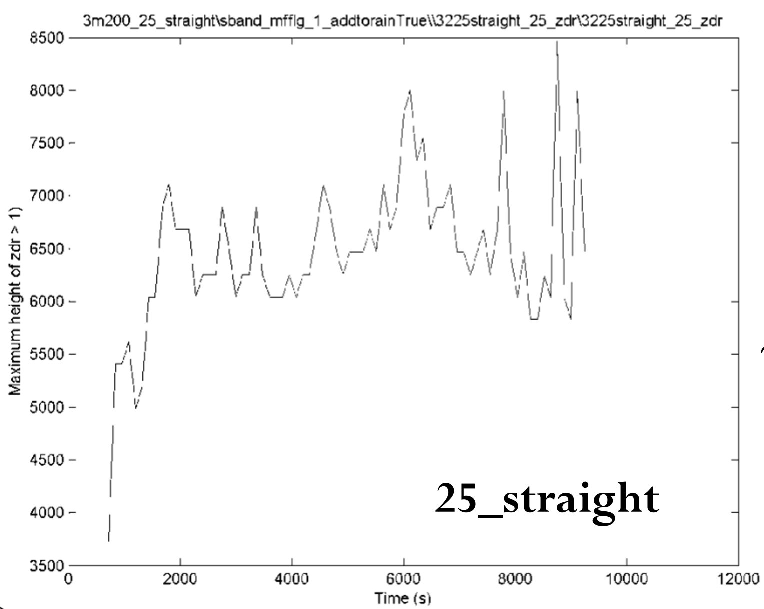
Maximum Height of Z_{DR} > 1 dB



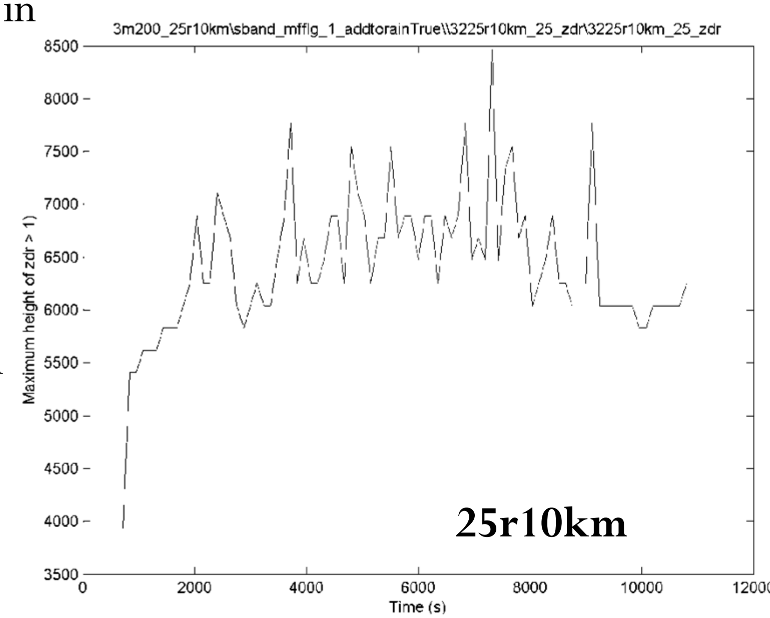
~6000 m



Reminder: Freezing level of surface parcel ~4800 m AGL in sounding

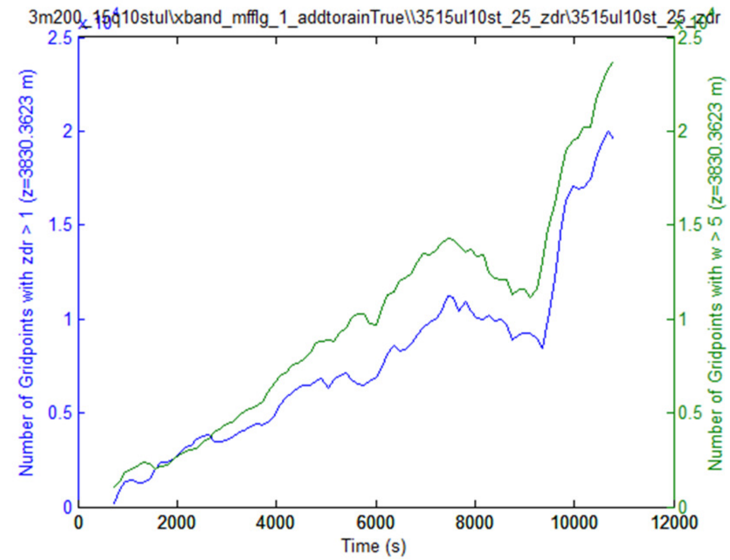


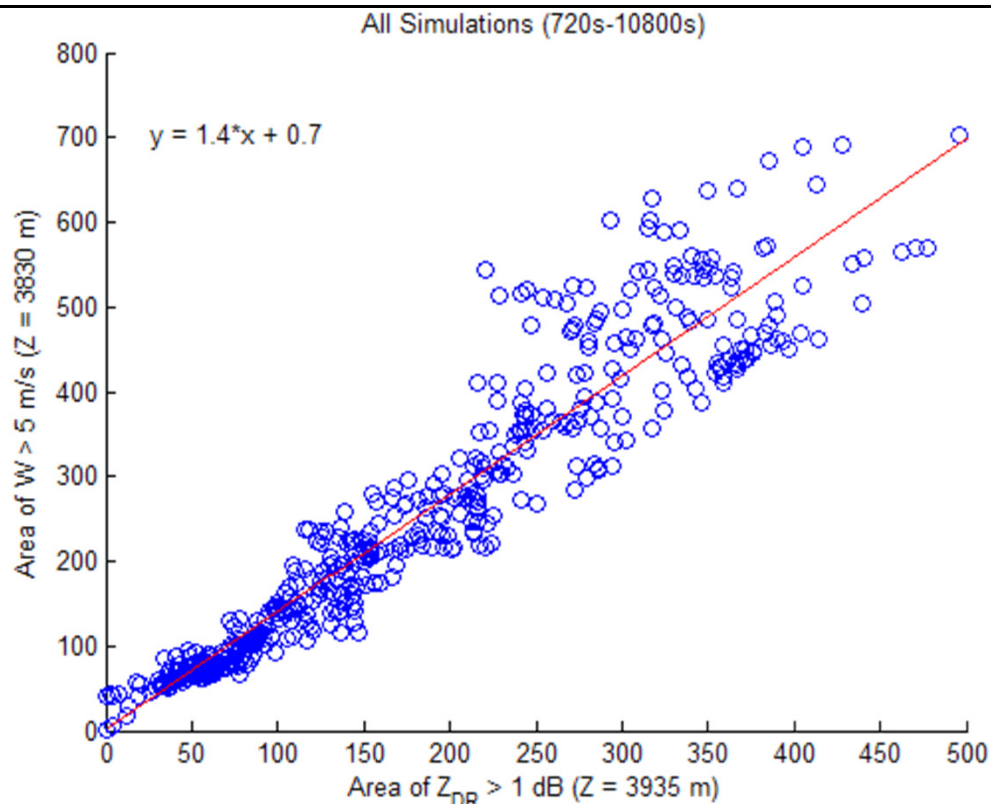
~6500-7000 m



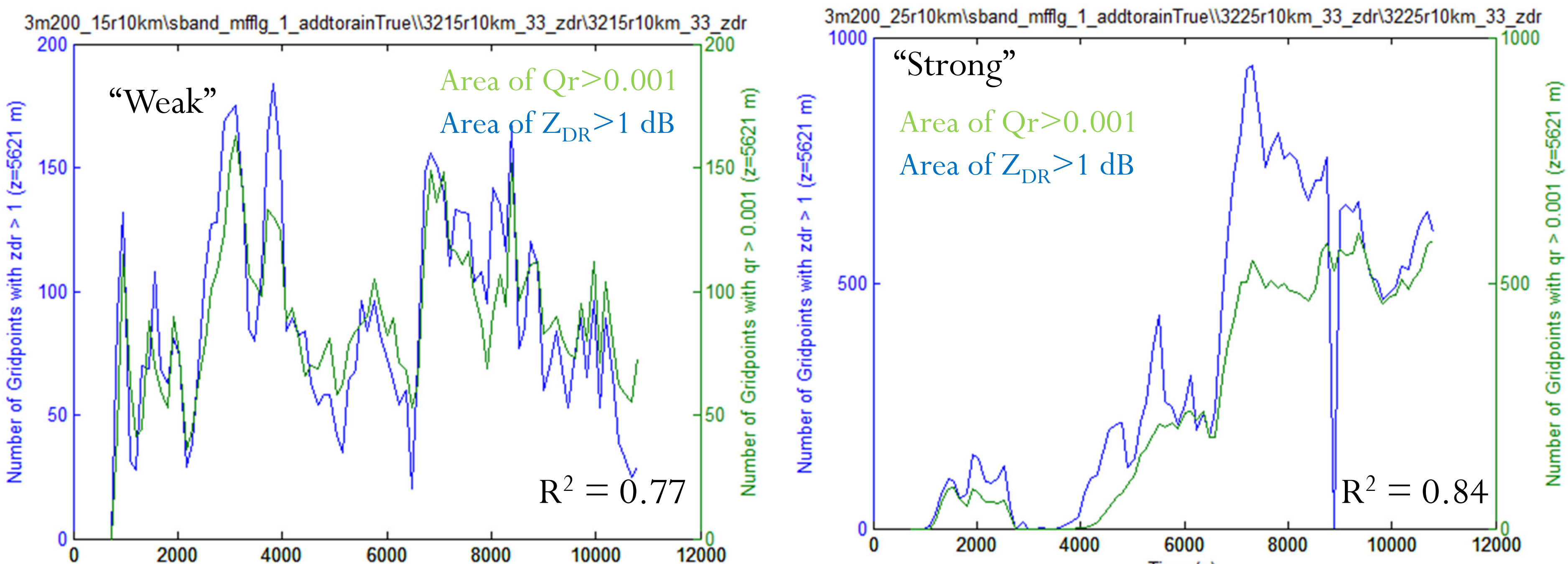
Z_{DR} Column Size

- One simulation to the right
- Number of gridpoints with Z_{DR}>1 dB vs. W >5 m/s at z grid-point 25 (3800-3900 m)
- $R^2 = 0.85$

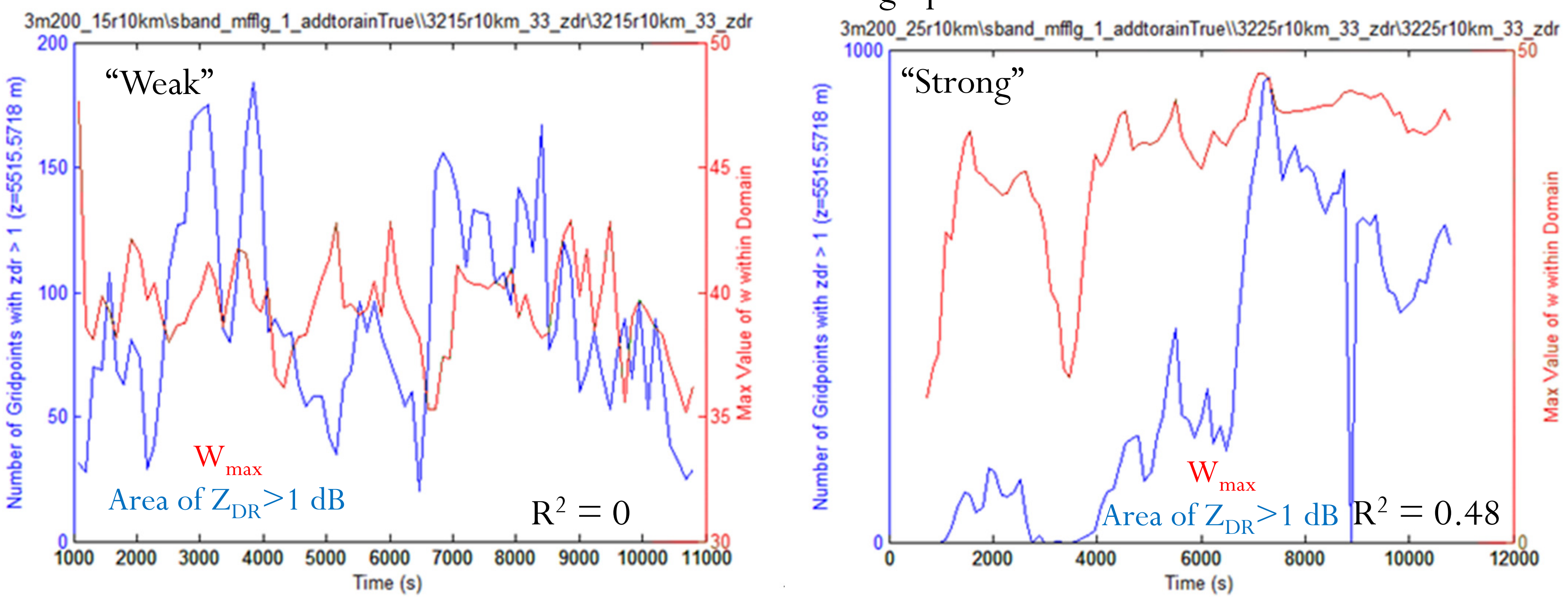


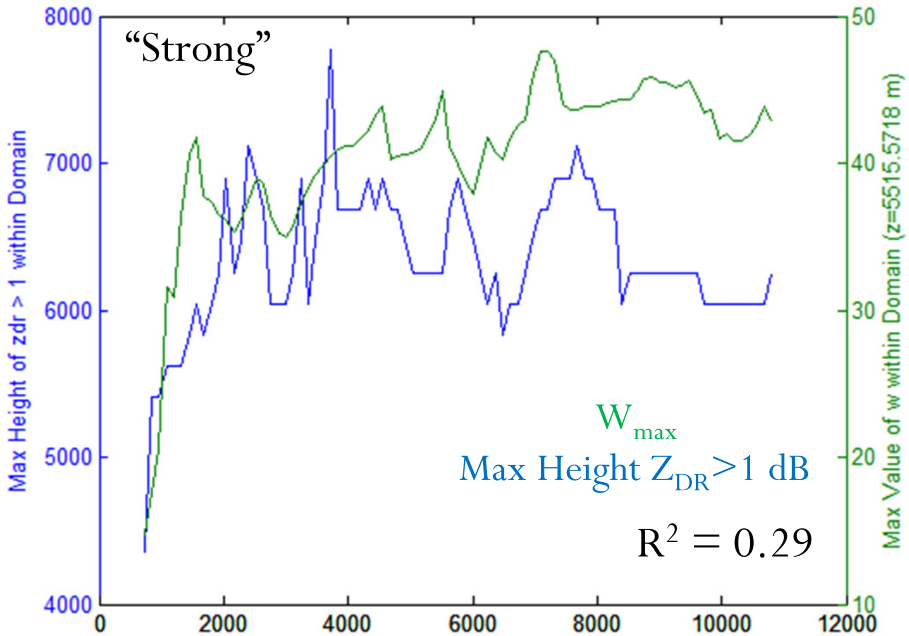


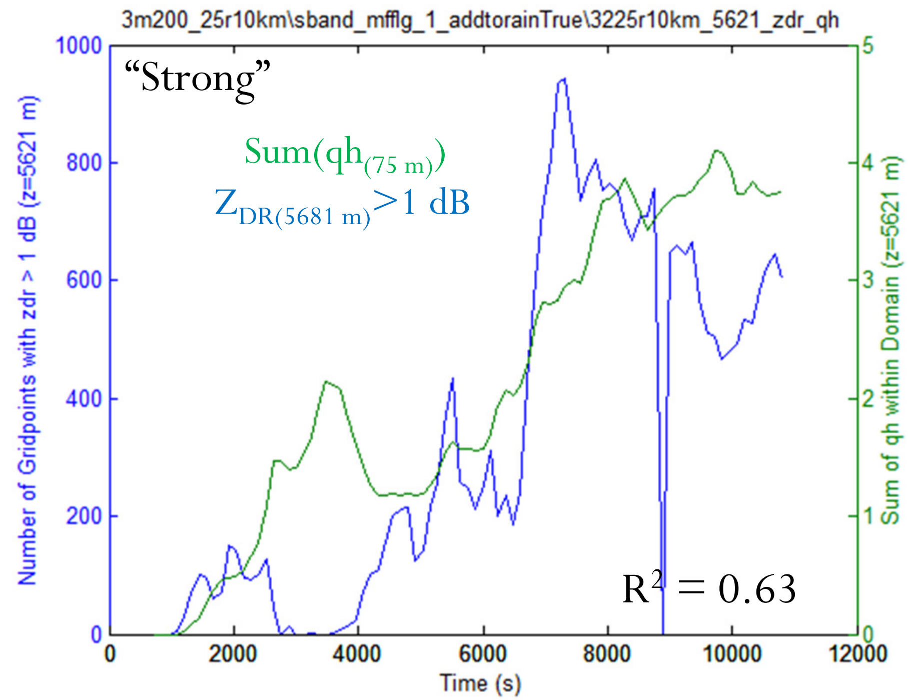
- Each mark is from a 2-minute history file
- Domain-wide area of Z_{DR}>1 dB vs. W >5 m/s at z grid-point 25 (~3900 m AGL)
- In the aggregate, larger updraft yields larger Z_{DR} column
- Correlation stronger with "weak" shear cases than "strong" shear cases

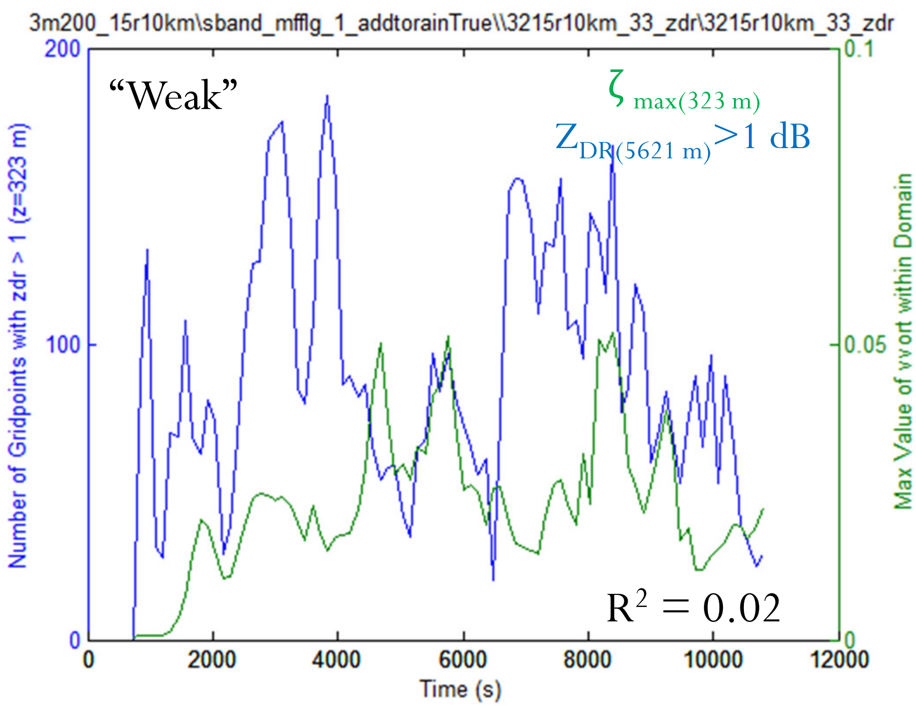


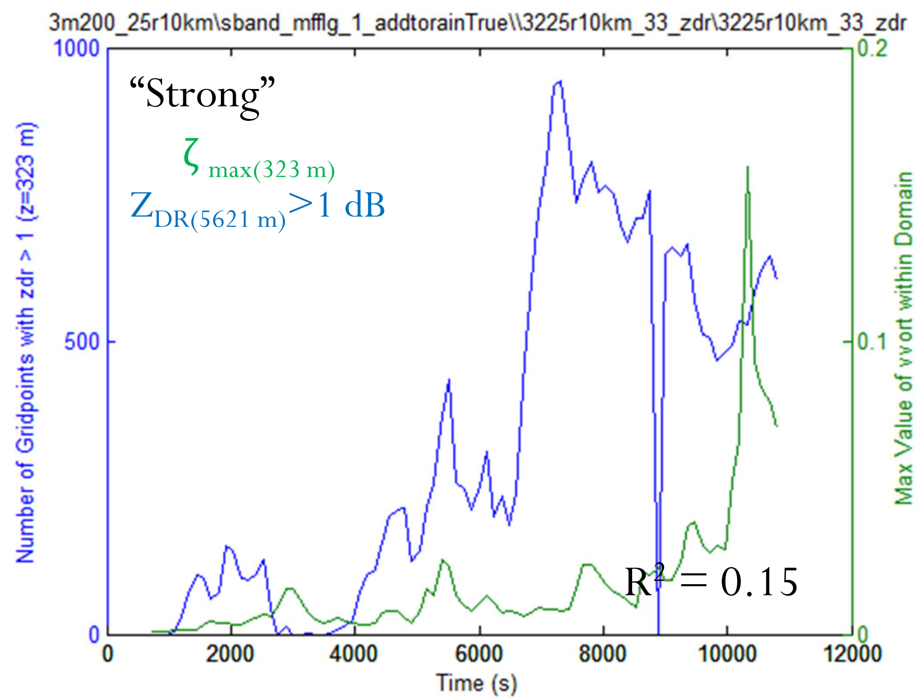
Half-circle Hodograph




"Strong"
Max Height of zdr > 1 within Domain
Max Value of w within Domain (z=5515.5718 m)
W max
Max Height ZDR>1 dB
R2 = 0.29
8000
7000
6000
5000
4000
50
40
30
20
10
0
2000
4000
6000
8000
10000
12000


3m200_25r10km\sband_mfflg_1_addtorainTrue\3225r10km_5621_zdr_qh
"Strong"
Sum(qh(75 m))
ZDR(5681 m)>1 dB
R2 = 0.63
Number of Gridpoints with zdr > 1 dB (z=5621 m)
Sum of qh within Domain (z=5621 m)
Time (s)
1000
800
600
400
200
0
5
4
3
2
1
0
2000
4000
6000
8000
10000
12000


3m200_15r10km\sband_mfflg_1_addtorainTrue\\3215r10km_33_zdr\3215r10km_33_zdr
"Weak"
ζ max(323 m)
ZDR(5621 m)>1 dB
R2 = 0.02
Number of Gridpoints with zdr > 1 (z=323 m)
Max Value of vvort within Domain
Time (s)
200
100
0
0.1
0.05
0
2000
4000
6000
8000
10000
12000


3m200_25r10km\sband_mfflg_1_addtorainTrue\\3225r10km_33_zdr\3225r10km_33_zdr
"Strong"
ζ max(323 m)
ZDR(5621 m)>1 dB
R2 = 0.15
Number of Gridpoints with zdr > 1 (z=323 m)
Max Value of vvort within Domain
Time (s)
1000
500
0
0.2
0.1
0
2000
4000
6000
8000
10000
12000

Z_{DR} Columns Continued

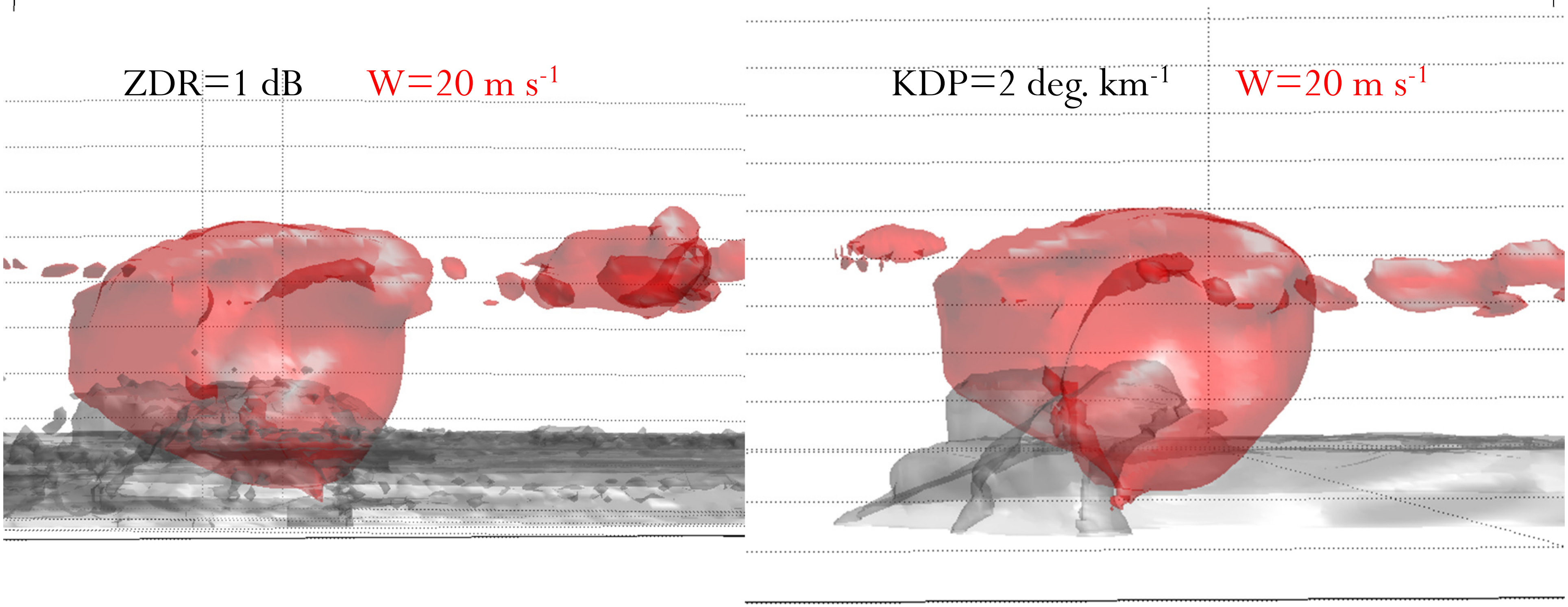
- Poor correlations between Z_{DR} column height or cross-sectional area and near-surface hail properties
  - Area(Qh > 0.0254 cm)
  - Sum(Qh)
  - Max(Qh)
- The Z_{DR} column in these runs is shorter than seen in more sophisticated modeling suites (e.g., Kumjian et al. 2012)
  - Drops freezing too quickly

Reviewing the Guiding Questions

- The focus of this study is to expand our understanding of often-seen polarimetric signatures (in particular the Z_{DR} and K_{DP} columns and the ρ_{HV} and Z_{DR} rings)
  - What is the relationship between polarimetric signatures and kinematic, microphysical, and thermodynamic fields
  - What is the relationship between the evolution of these signatures to unobserved quantities
  - How does vertical wind shear affect the appearance and the evolution of these signatures

- Special Acknowledgments
  - The computing for this project was performed at the OU Supercomputing Center for Education & Research (OSCER) at the University of Oklahoma (OU).
  - This research is being supported by NSF grant ATM-0934307

Spatial Associations



In general, upward protrusion of ZDR > 0 dB an KDP > 0 deg. km-1 above the ambient and upward-perturbed updraft freezing level is positively associated with the west / upshear part of the updraft.