# THE DEVELOPMENT AND APPLICATIONS OF A POLARIMETRIC RADAR FORWARD OPERATOR TO IMPROVE MICROPHYSICAL PARAMETERIZATIONS AND STUDY DEEP CONVECTIVE STORMS

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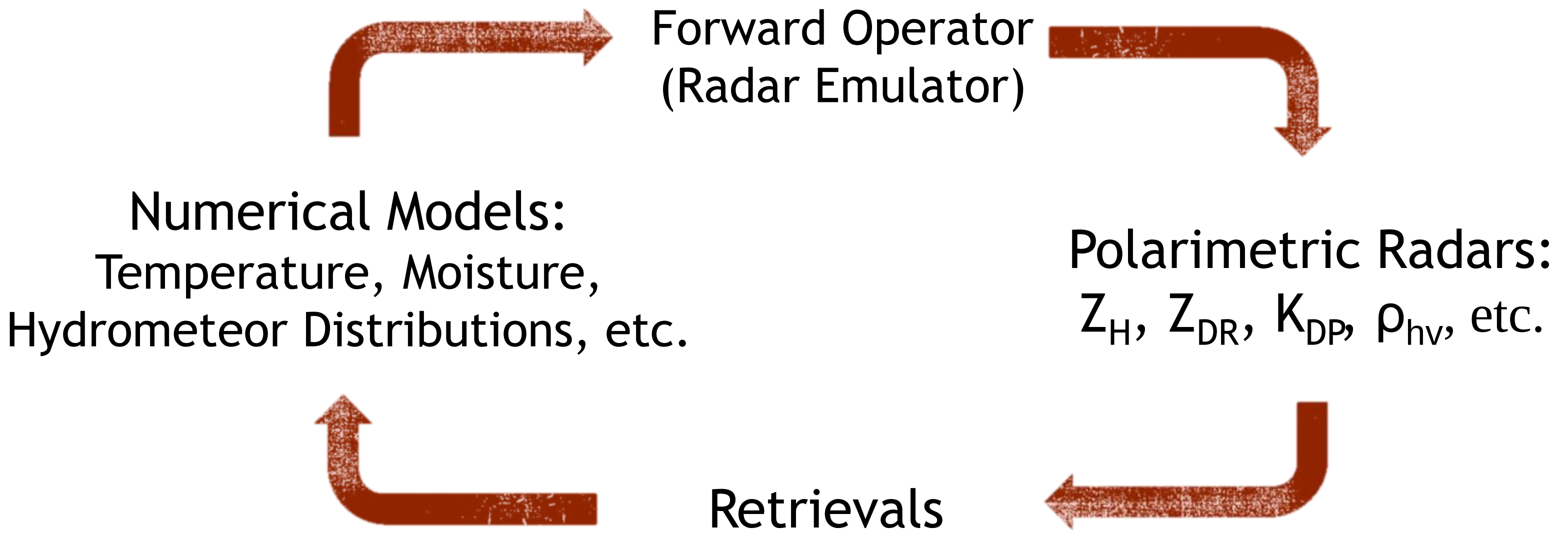
# APPLICATIONS OF POLARIMETRIC RADAR IN CONVECTIVE STORM STUDIES

- Quantitative precipitation estimation (QPE)
- Hydrometeor classification / identification (inferred or algorithmically determined)
- Microphysical retrievals
- Hail detection and hail size discrimination (e.g., HSDA)
- Tornadic debris signature detection
- Melting layer identification
- Attenuation correction
- "Feature" identification and underlying inferences about storm structure ($Z_{DR}$/$K_{DP}$ columns and updrafts, etc.)

# SELECTED TOOLS AND APPLICATIONS

- Storm-scale numerical simulations are now commonly performed, and there are ample polarimetric radar datasets
- It can be difficult to obtain in-situ observations with which to observe microphysical processes and constituents, so we need to base the calculated polarimetric radar fields off of scattering models and the more limited physical observations that exist
- Simulations of convective storms has allowed us to study, for example, $Z_{DR}$ and $K_{DP}$ columns despite the difficulty in obtaining in-situ observations
- Other areas of study including things such as (1) updraft identification relevant for localizing latent heat release and precipitation generation and (2) Cloud condensation nuclei (CCN) effects on polarimetric radar fields and “first echo”

# NUMERICAL MODEL + RADAR DATA SYNERGIES




Many of the most "polarimetrically interesting" signatures occur where complexities and uncertainties can be significant.

Radar quantities can be affected by

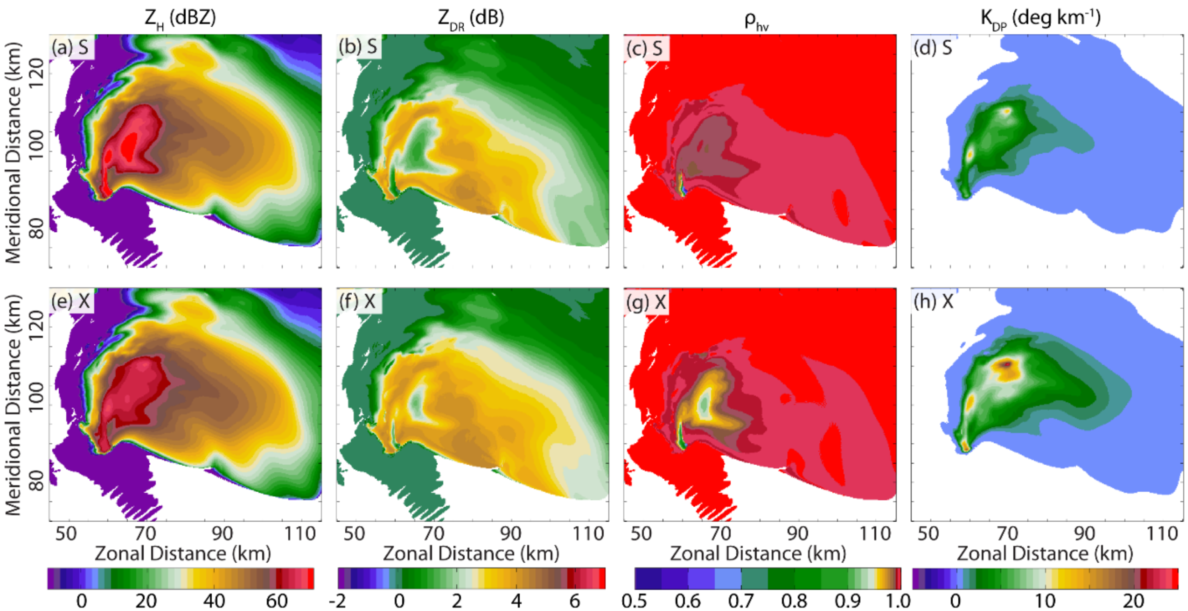
- Size distribution
- Water fraction and distribution*
- Particle density*
- Shape, canting angle, and variability*
- Radar frequency

* Generally not predicted

# A TWO-WAY STREET

- Comparing radar observations to forward operator-provided output can provide important insight that can directly lead to changes in the microphysics
  - $Z_{DR}$ columns were initially too short until a "freezing drops" category was added)
  - Near-ground $Z_{DR}$ was originally too large, indicating that there were too many large drops being produced
- Can subsequently use the models to help us learn about quantities and processes that we cannot directly observe
  - Microphysical composition of $Z_{DR}$ and $K_{DP}$ columns
  - Effect of cloud condensation nuclei concentration on polarimetric representation

# FORWARD OPERATORS




From Snyder et al. (2016a,b) in review in JAMC

Several have been developed in the past several years (e.g., Jung et al. (2010); Ryzhkov et al. (2011); others presented at this meeting)

Valuable uses:

- Evaluation of models
- Study of relationships between radar signatures and microphysical processes, etc.
- Development of data assimilation

Many potential error sources in:

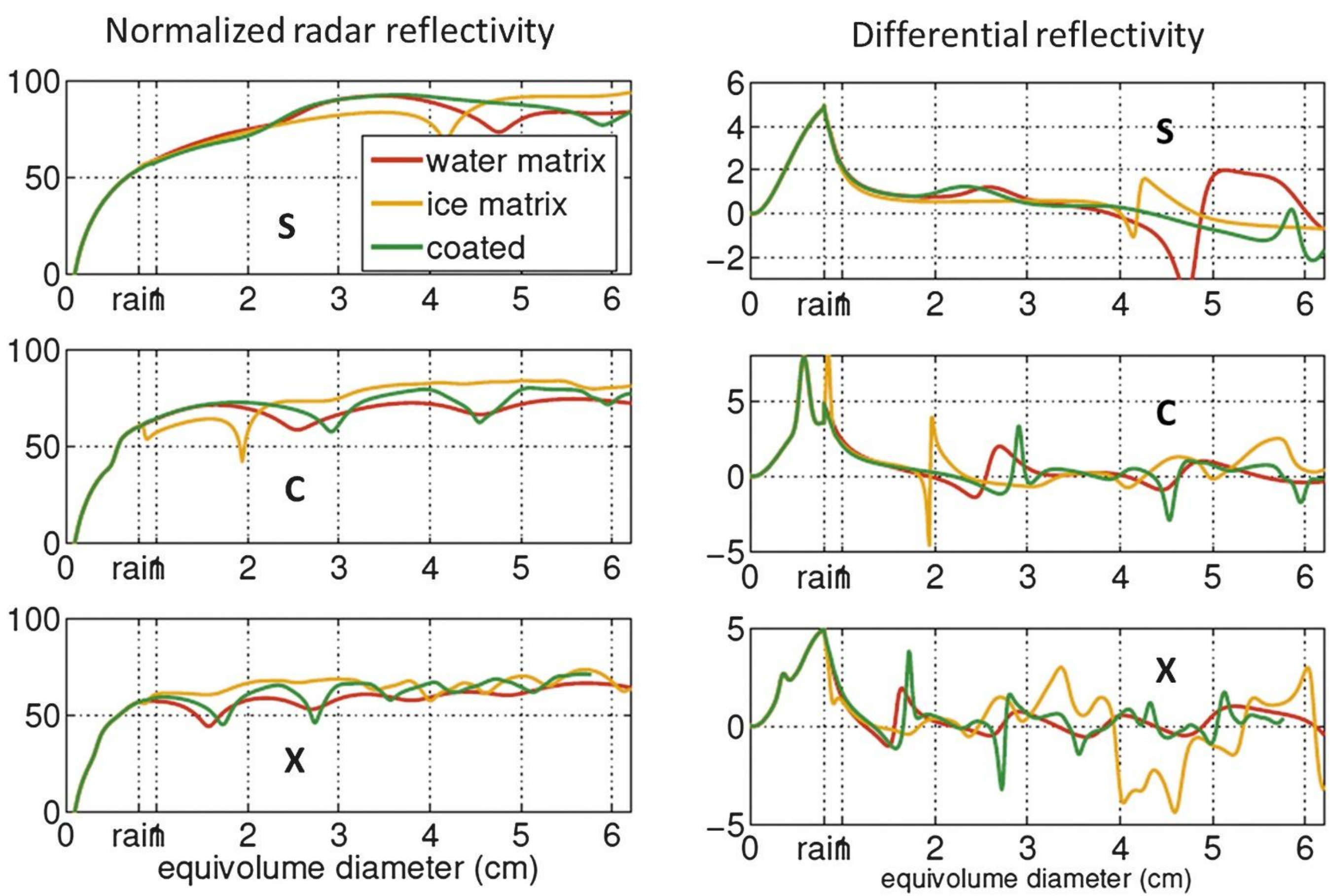
- Model (fixed density, no water fraction/wet ice, “simple” distributions)
- Forward operator (e.g., fixed temp., diagnostic or no water fraction)

# CIMMS/HUJ POLARIMETRIC FORWARD OPERATOR

- Based upon the work published in Ryzhkov et al. (2011)
- Originally written into the Hebrew University Cloud Model (HUCM) and its spectral bin microphysics, but it is currently being ported to WRF
  - 43 mass-doubling bins
  - Liquid water (cloud and rain), freezing drops, hail, graupel, snow aggregates, columns, plates, and dendrites
  - Liquid water fraction and snow rimed fraction tracked and prognosed
- Quantities calculated include $Z_H$, $Z_{DR}$, $K_{DP}$, $\rho_{hv}$, $A_H$, $A_{DP}$, LDR, and CDR
- Ongoing focus is to generalize the forward operator to work with other microphysics schemes and numerical models, broadening its utility to the community
  - This requires a diagnostic water fraction method when microphysics do not predict mixed-phase hydrometeors (polarimetric variables can be very highly sensitive to mass water fraction!)
  - Want the forward operator to be compatible with model microphysics (e.g., species density, etc.)

# SCATTERING SPECIFICS

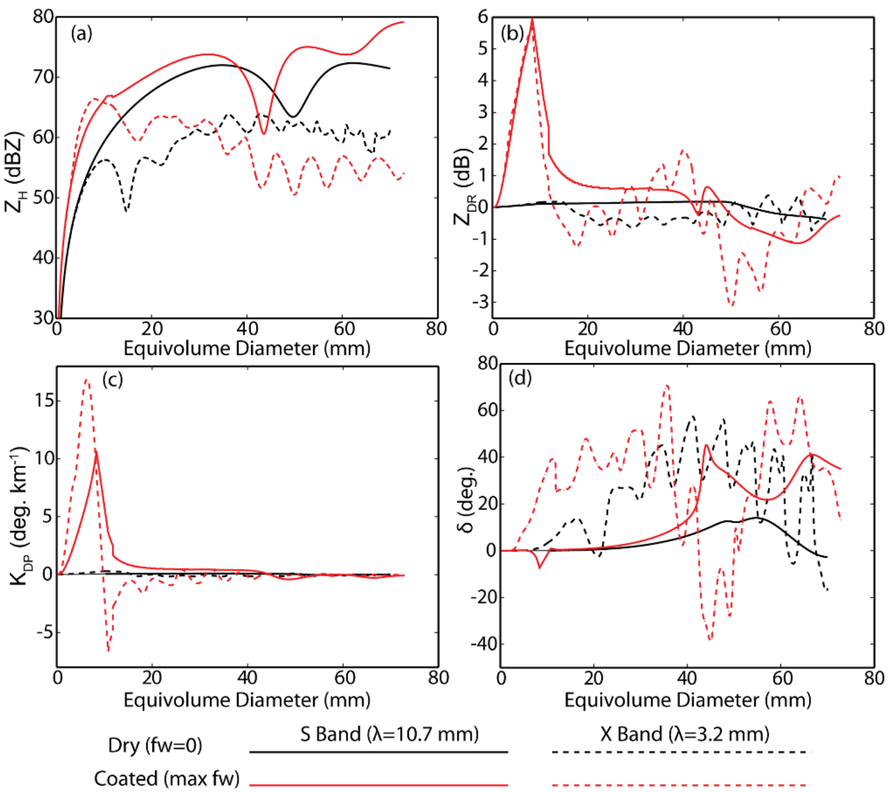
- Scattering amplitudes can be calculated at run time (slow but most accurate) or before hand and used as lookup tables (fast but less accurate)
- Currently using both “homogeneous mixture” and two-layer T-matrix scattering codes for all mixed-phased hydrometeors

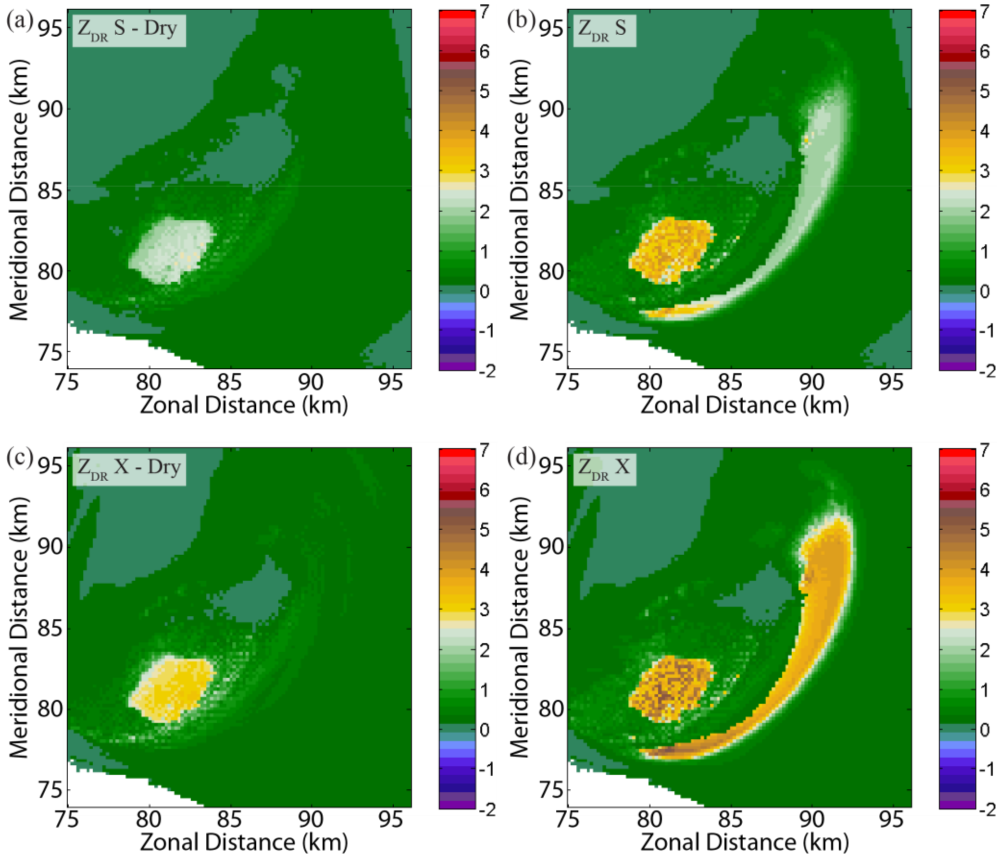



From Ryzhkov et al. (2011)

# MIXED-PHASE HYDROMETEORS

- Prognosing, or at least diagnosing (e.g., Dawson et al. 2014,2015), liquid water fraction may be a necessity to reproduce some polarimetric signatures (e.g., melting layer)

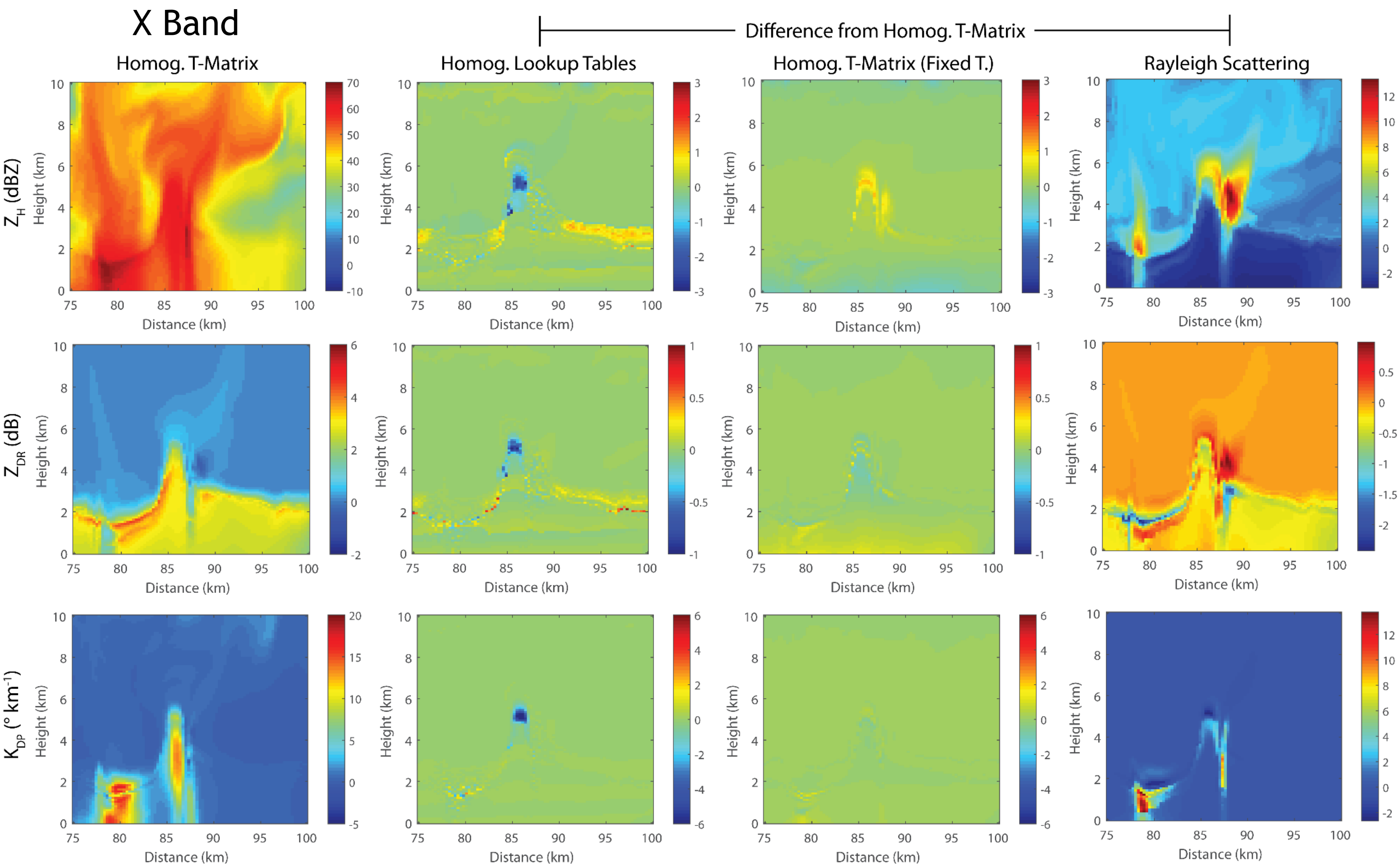


# WHEN YOU ASSUME YOU MAKE…

- ... potentially poor results
- Different quantities have different sensitivities to things like temperature, mass water fraction, water distribution, and hydrometeor density
- The granularity of the lookup tables required for "accurate" calculations depends upon the quantity being calculated
- For electromagnetically large particles, highly nonlinear scattering behavior can mean that a large number of lookup tables should be used (e.g., 1% mass water fraction increments, ≤ 5 °C increment, etc.)
- Simulated polarimetric quantities only as good as underlying microphysics (can the microphysics model all relevant processes?) and forward operator

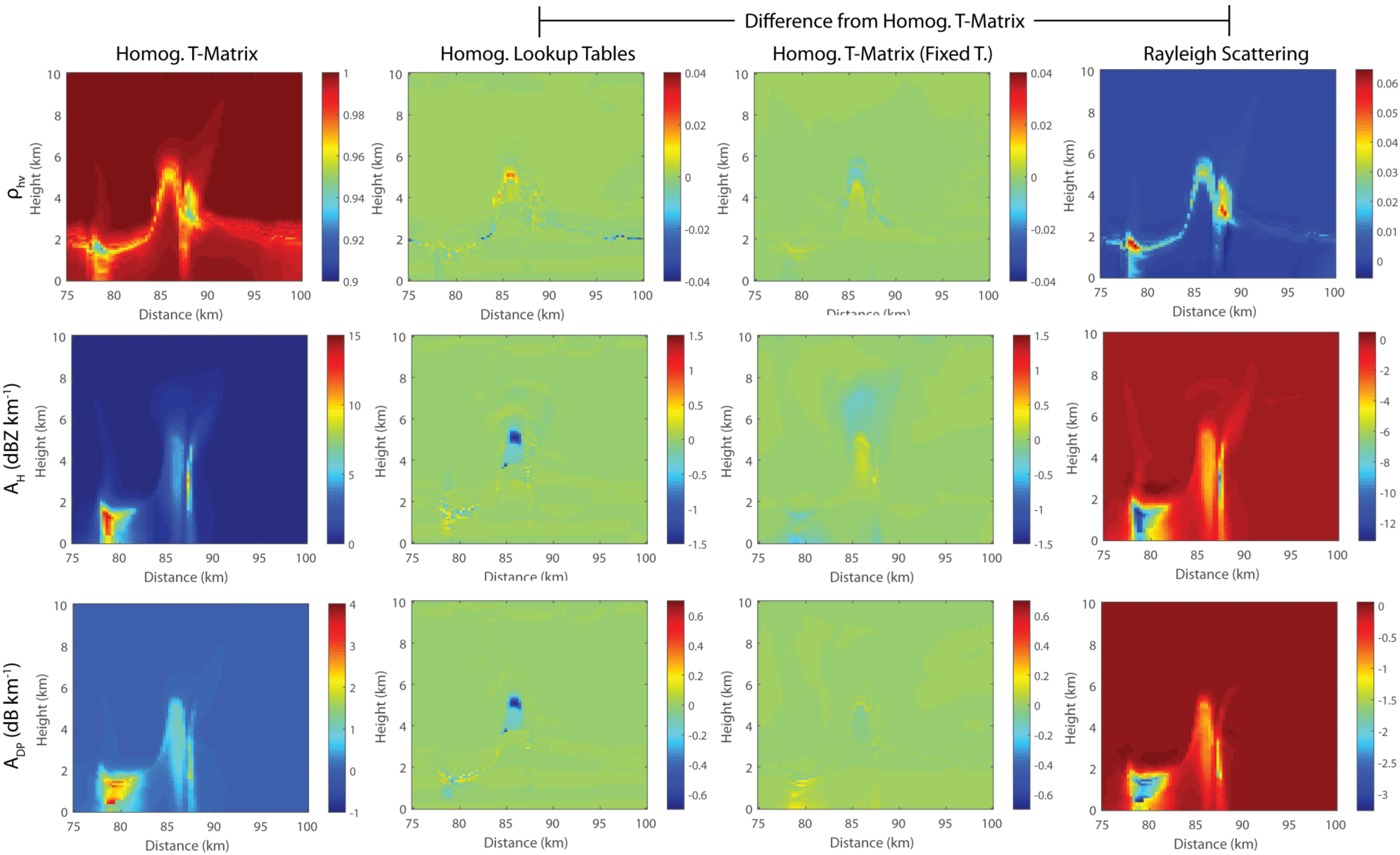
# FORWARD OPERATOR ASSUMPTIONS




Treat this as "Truth"

LUTs – Every 10° C and every 5% FW
Fixed T – 10° C (Water) and 0° C (Ice)

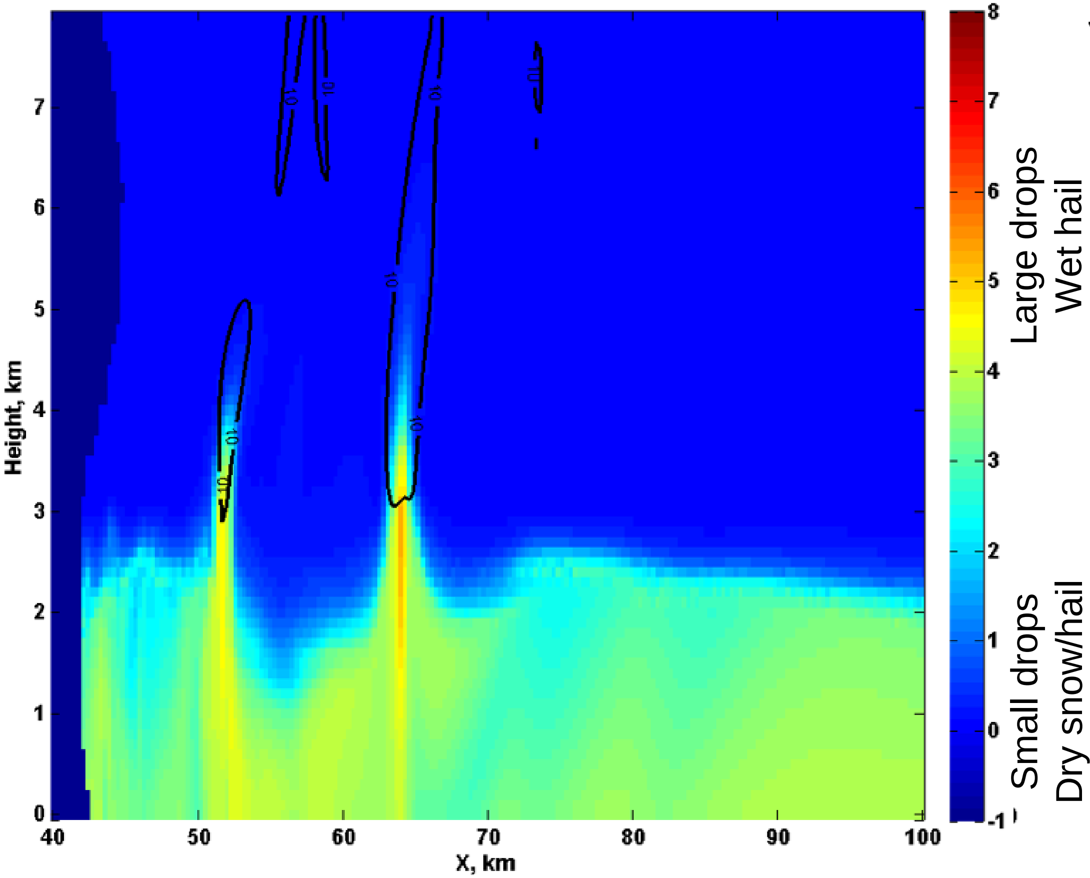
# FORWARD OPERATOR ASSUMPTIONS

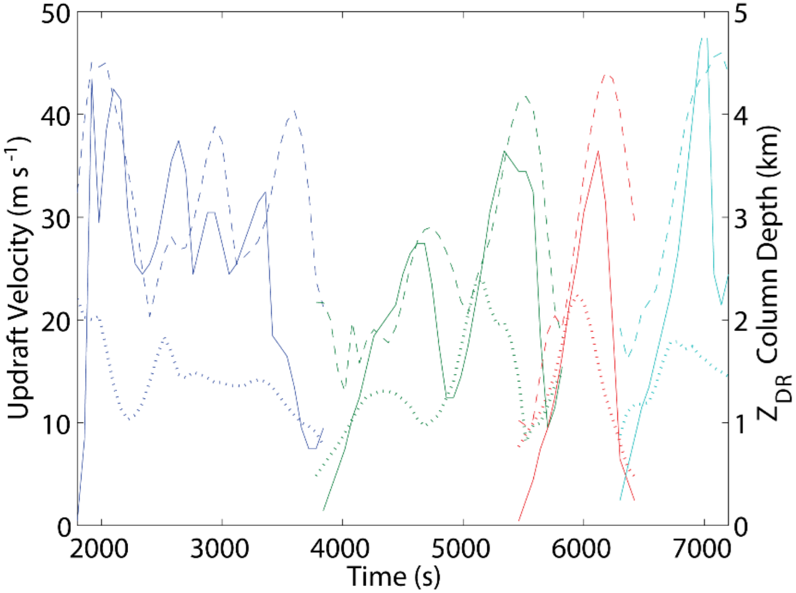


# USING A FORWARD OPERATOR TO STUDY $Z_{DR}$ COLUMNS

Hebrew University Cloud Model

$Z_{DR}$ (dB) W (contoured)

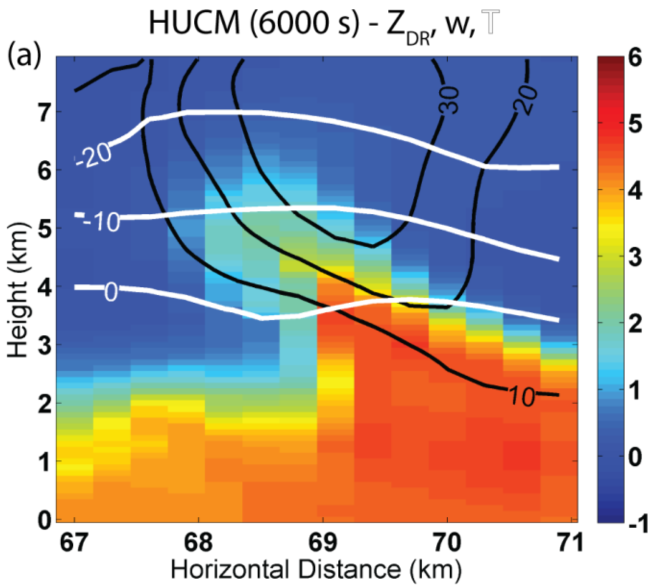


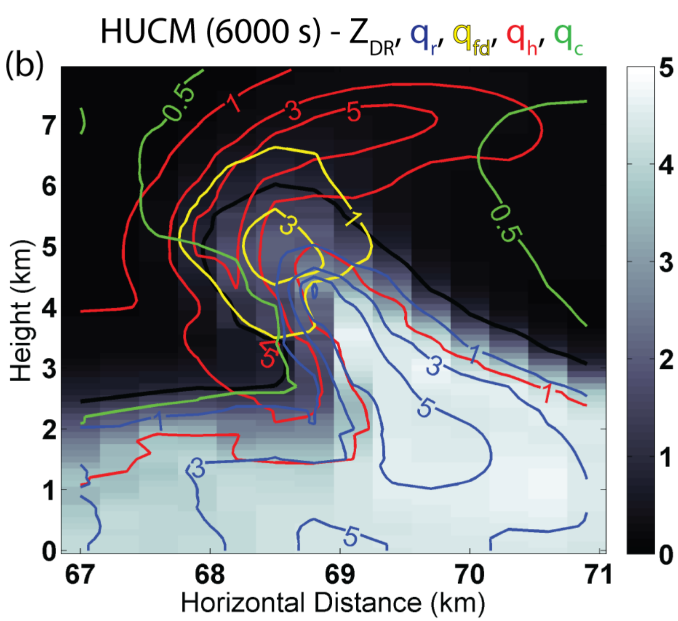



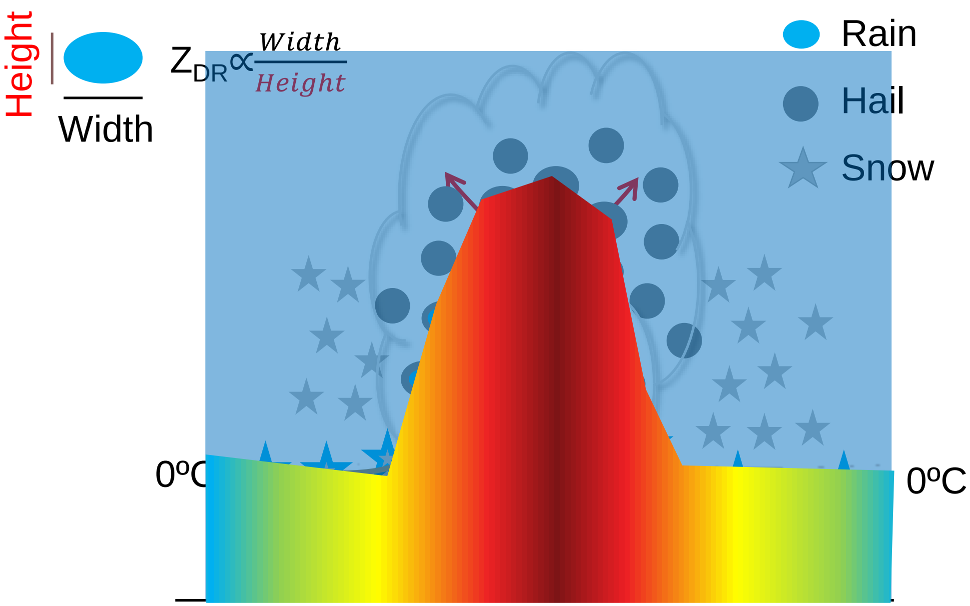

A $Z_{DR}$ column consistent with observations and idealized 1D modeling of raindrops in an updraft was not obtained until the "freezing drops" category was added to HUCM.

See Kumjian et al. (2014) and Snyder et al. (2015)

# SIMULATING $Z_{DR}$ COLUMNS



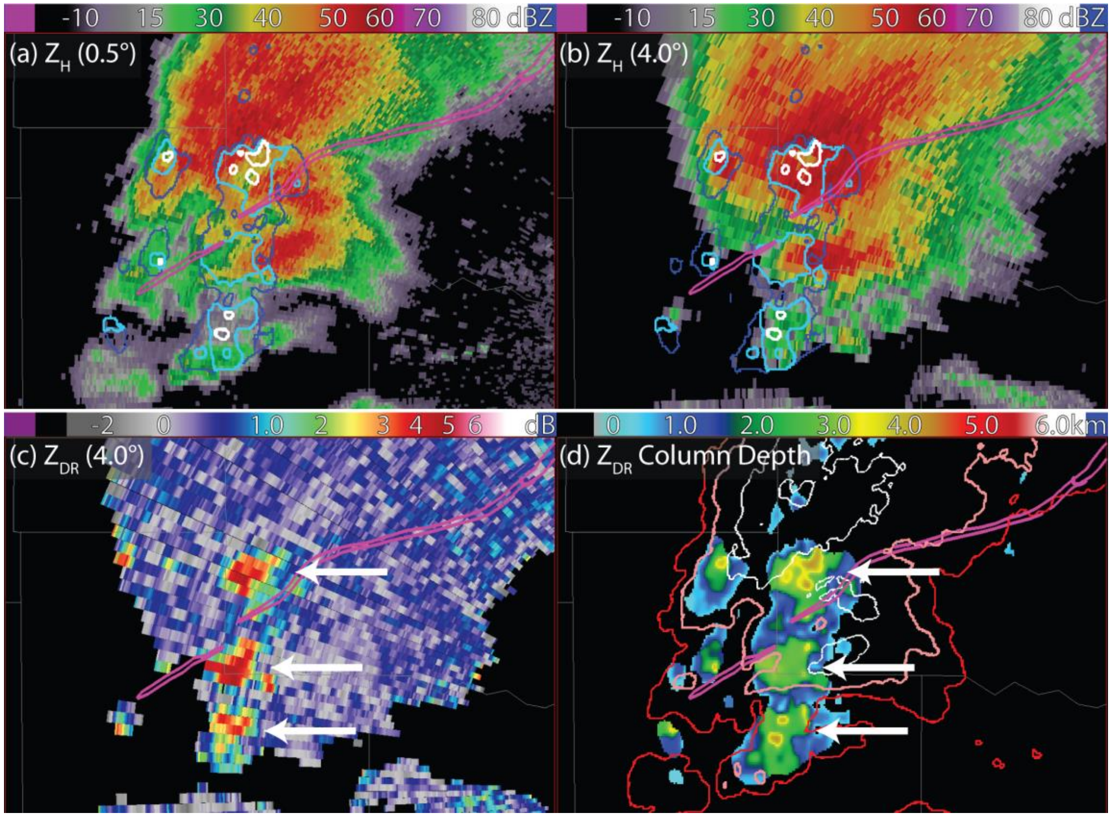




Obvious relevance: latent heating and much of the precipitation generation occurs in the updraft

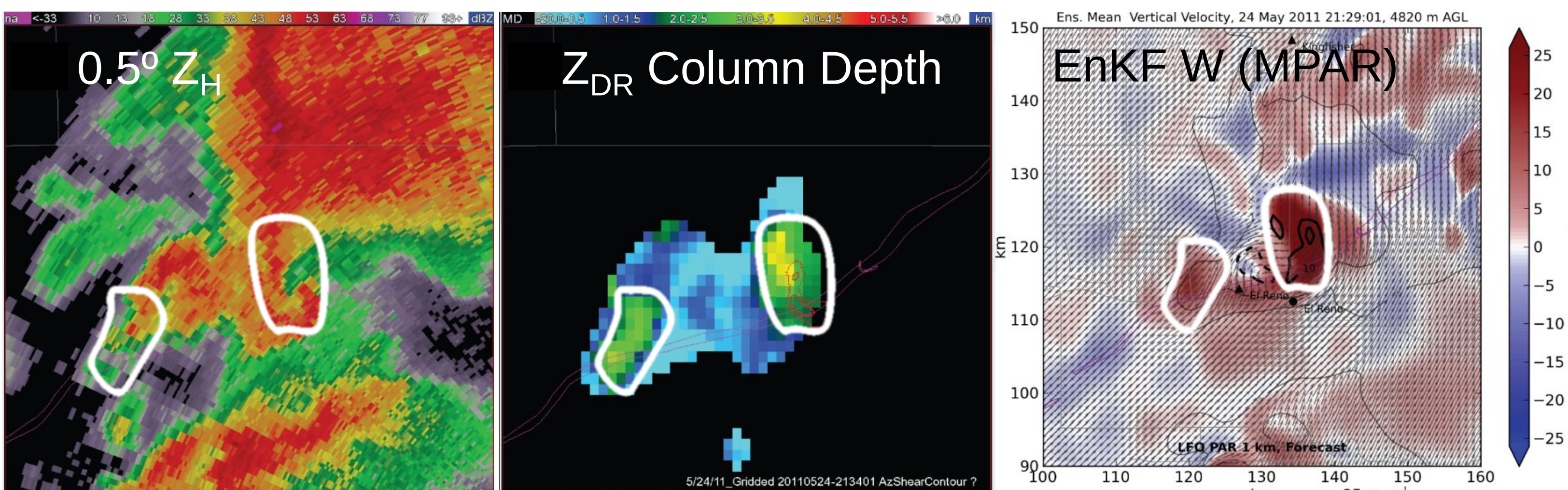
# $Z_{DR}$ COLUMN ALGORITHM

24 May 2011
Violent tornado in OK



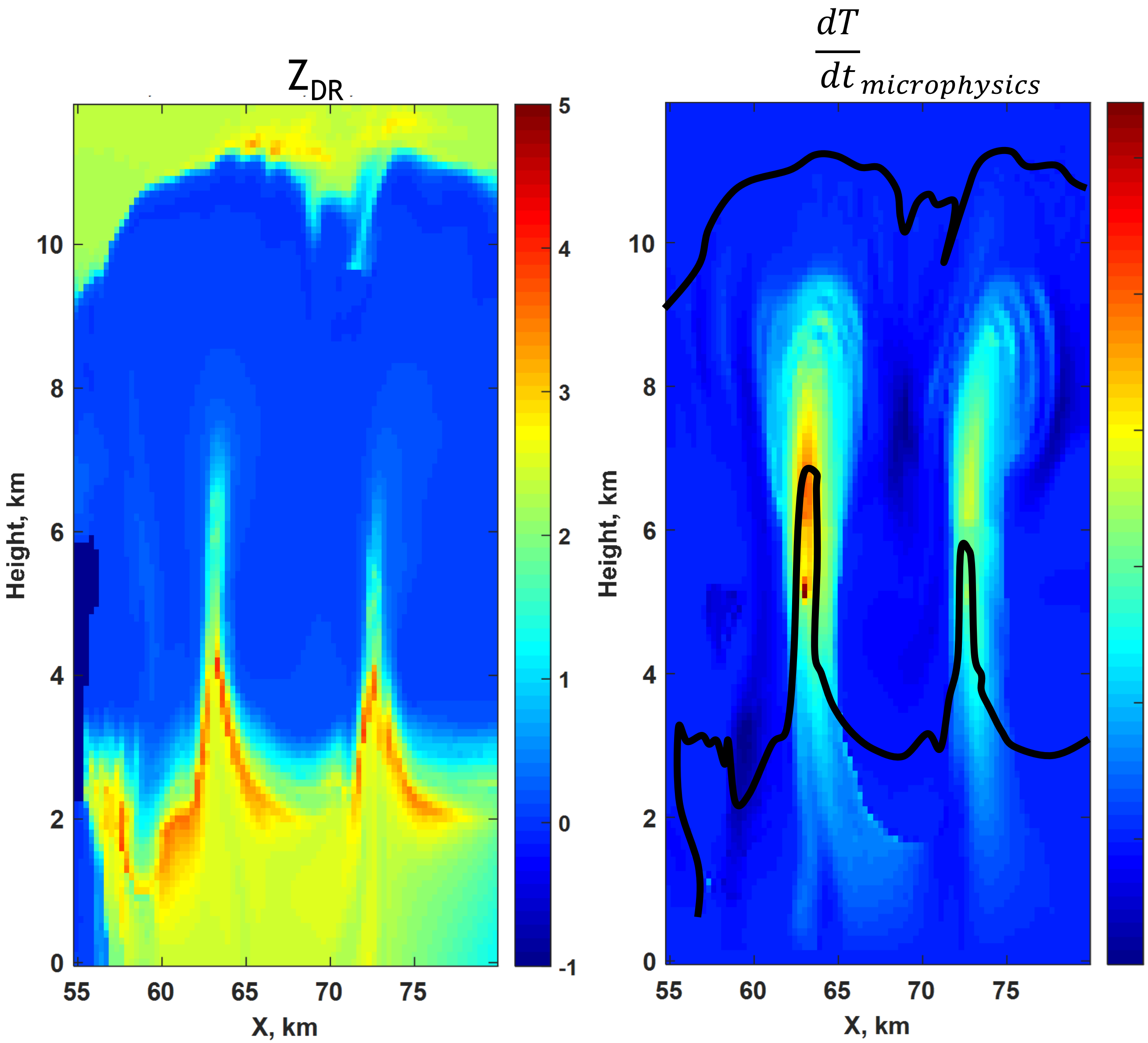

The $Z_{DR}$ column algorithm provides a measure of the height of the top of the $Z_{DR}$ column above a given location.

See Snyder et al. (2015) in WAF for details




Courtesy Robin Tanamachi

# $Z_{DR}$ COLUMNS AND LATENT HEATING




- 1 dB $Z_{DR}$ contoured in black
- ZDR columns may allow us to further quantity latent heat release (relevant to cloud analysis / data assimilation, etc.)
- Can also look for anomalously high $Z_{DR}$ below the melting layer (i.e., nearer the ground) to identify regions of size sorting and potential updrafts

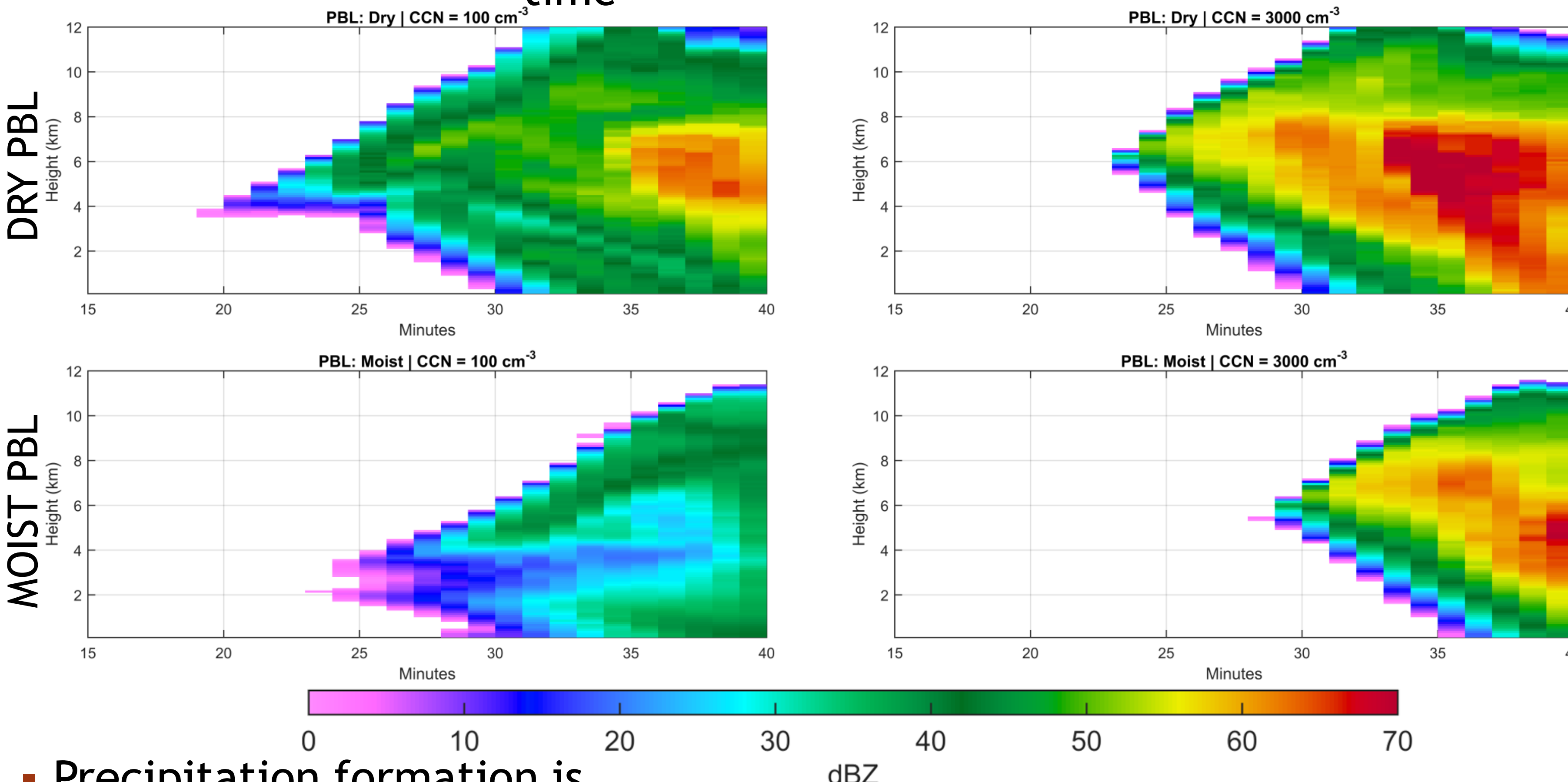
# IMPACTS OF CCN ON CONVECTIVE STORMS

- Can use modeling results to tease out the effect of CCNs on the polarimetric structure of convective storms
- Highly complex and nonlinear (e.g., van den Heever and Cotton 2007)
- When determining impact of CCN, environment matters!
  - Moisture, shear, etc.
  - Uncertainty as to what priority CCN play
- Introduction of giant and ultragiant aerosols can modify aerosol-storm relationships
- We seek to test impact of CCN on polarimetric characteristics of early echoes

# DEVELOPMENT DIFFERENCES
# CCN Concentrations and Low-Level Moisture

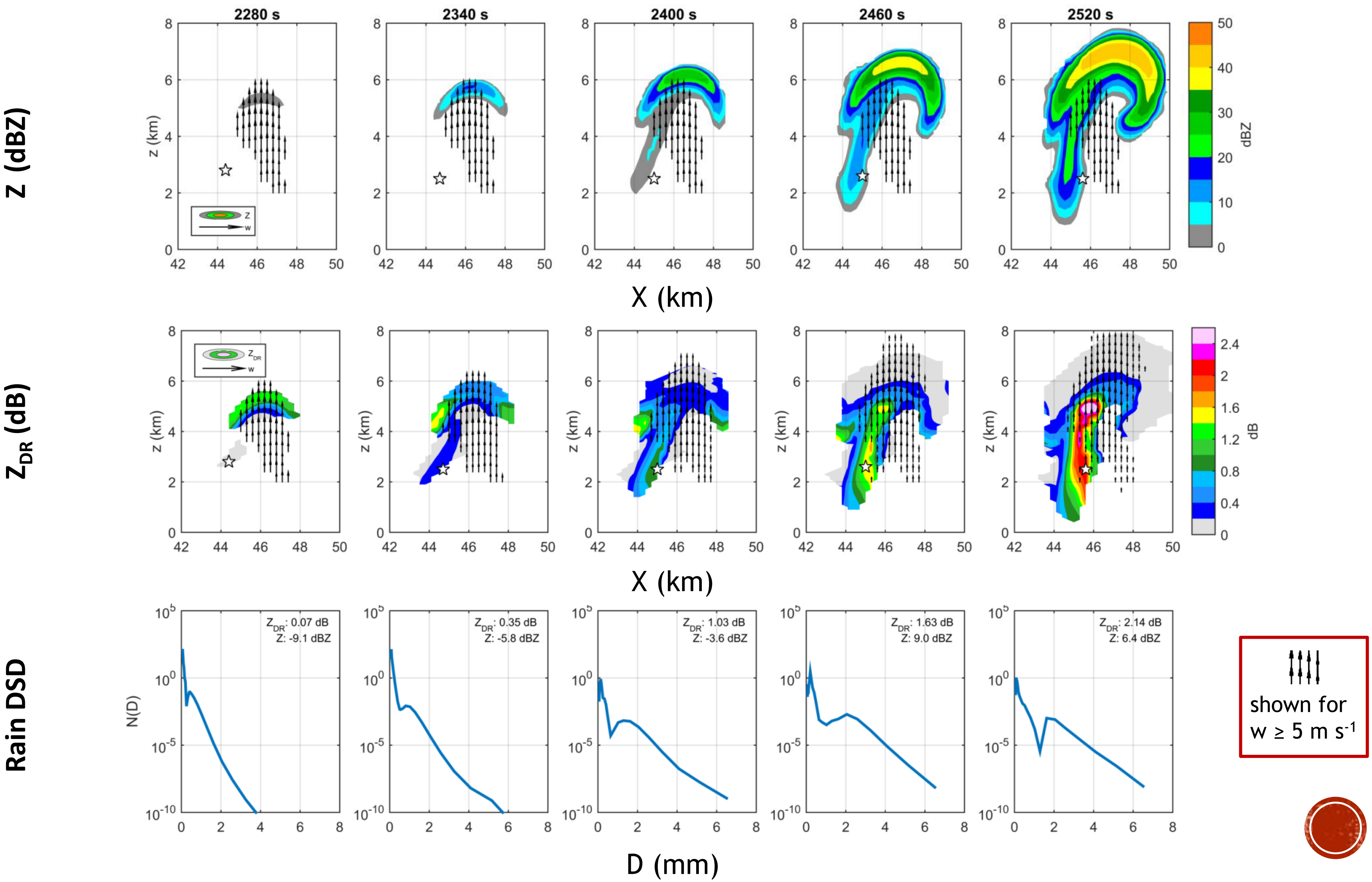
95th percentile of Z vs. time

"Clean" "Polluted"




- Precipitation formation is <u>delayed</u> approx. 5 – 8 min in "polluted" cases relative to "clean" cases
- In general, as CCN ↑:
  $Z_{max}$ ↑ $dZ_{max}/dt$ ↑ Height of $Z_{max}$ ↑

# HUCM REPRODUCES "EARLY ECHO" HIGH $Z_{DR}$
# … for *high CCN* cases



# CONCLUSIONS

- Polarimetric radar has added considerably to our ability to observe convective storms, allowing us to infer microphysical processes and compositions not previously possible
- The forward operator is being ported to WRF and is under continued development
- There remains much work to do in the interaction between polarimetric radar and numerical modeling that will further allow for improved data assimilation, studies on other complications (e.g., role of CCN in polarimetric fields)

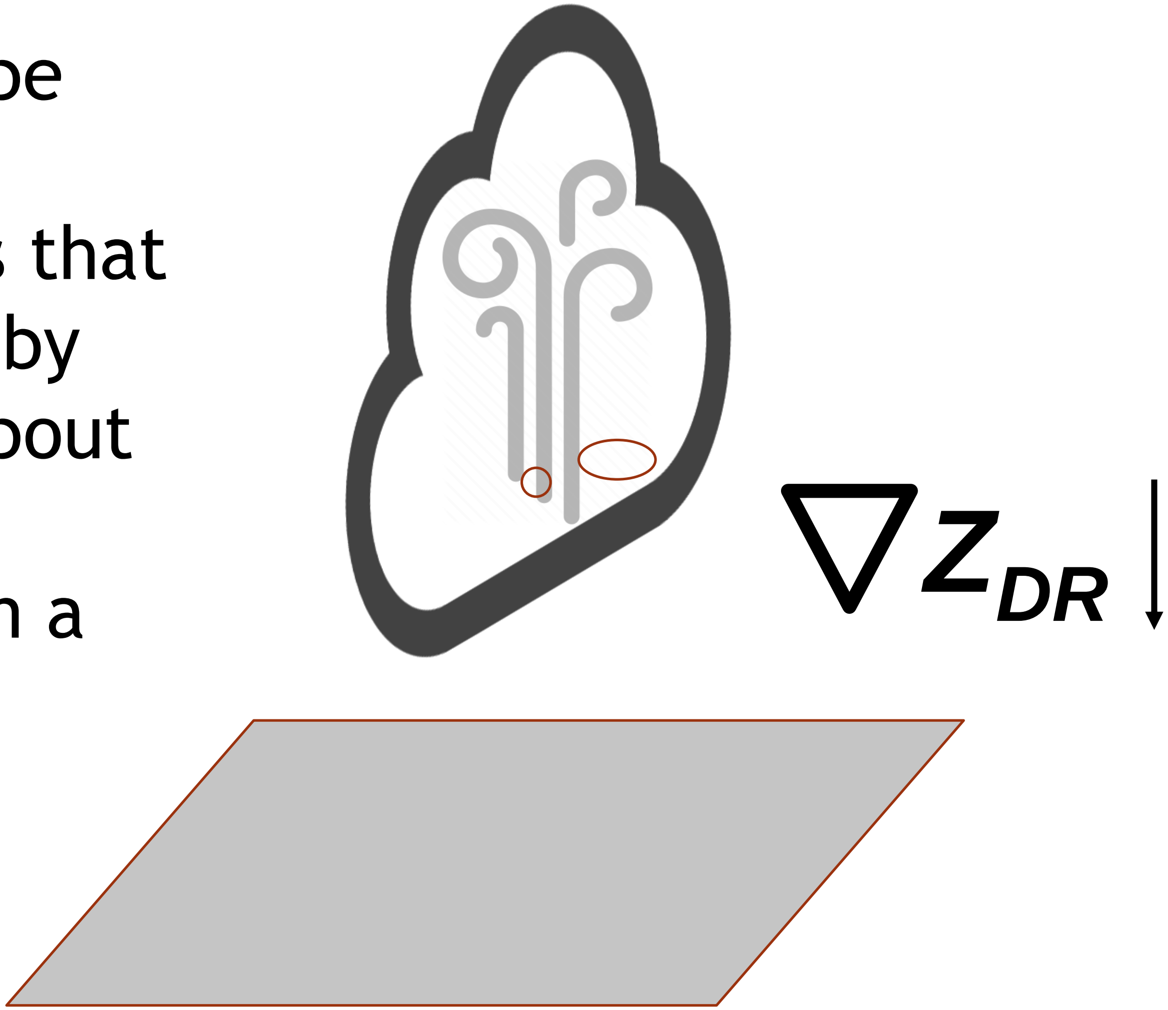
Questions?

# EXTRA SLIDES

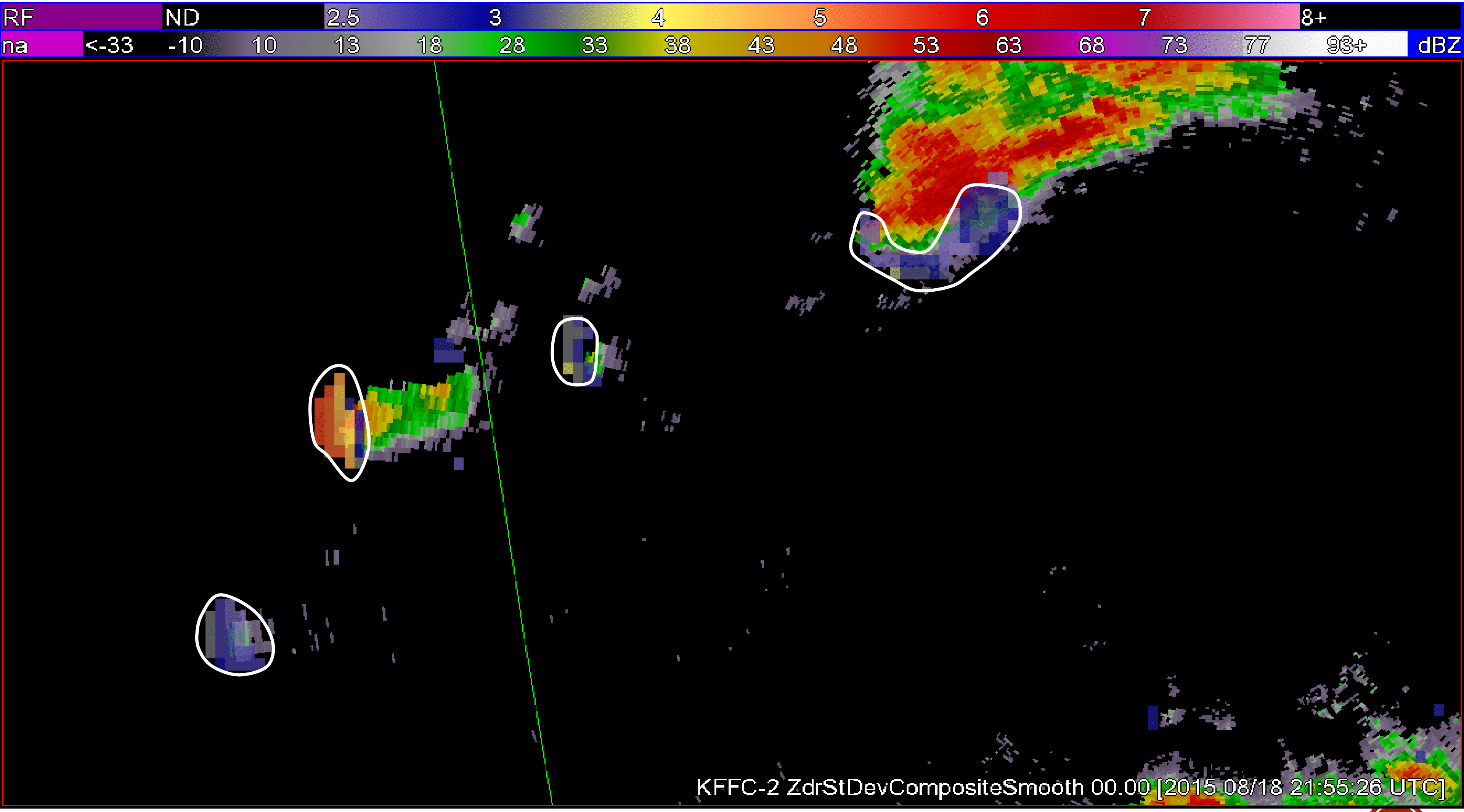
# NEARER THE GROUND…

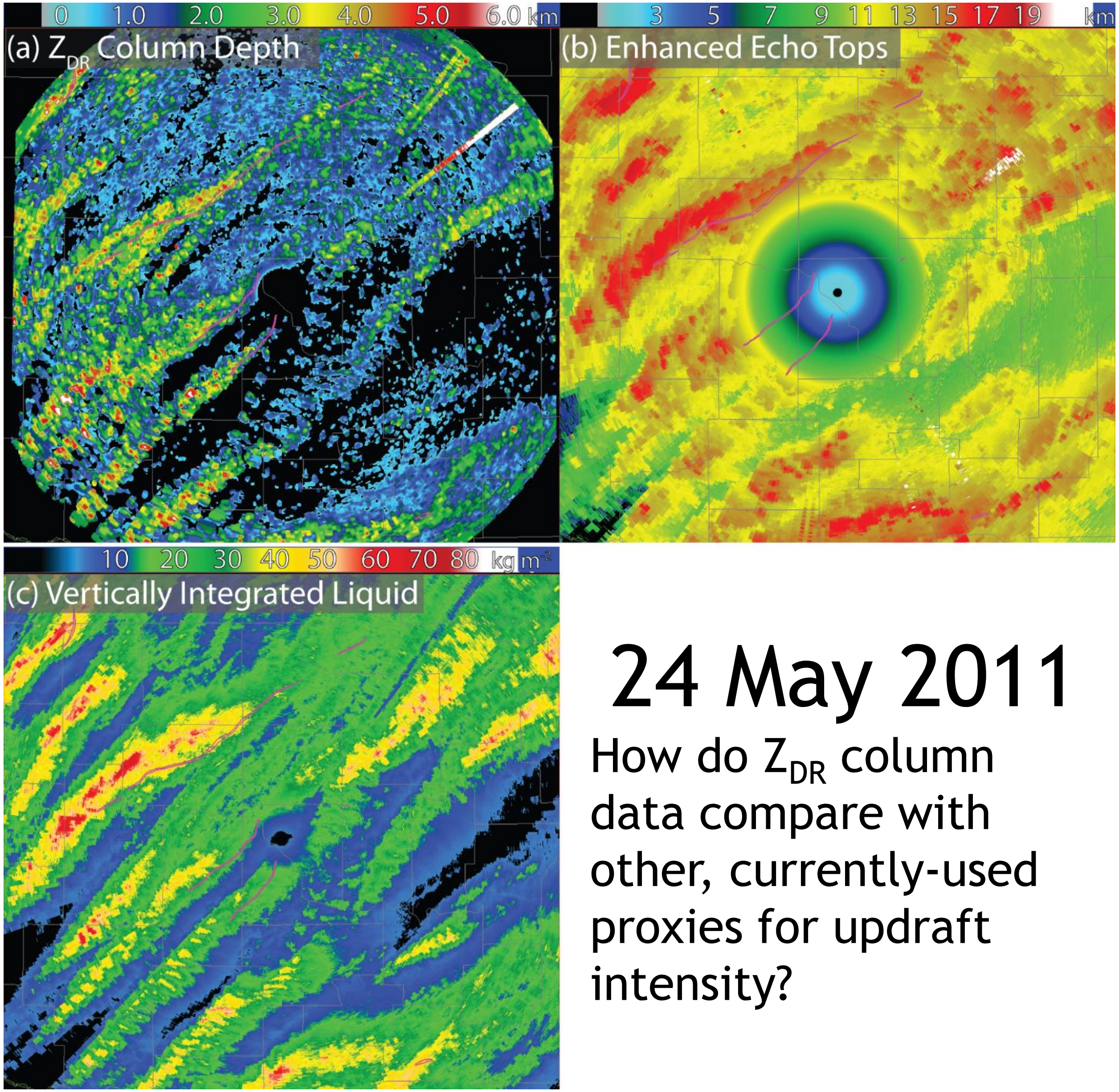
$Z_{DR}$ columns may be useful in deep convective storms that are well-sampled by radar, but what about weaker storms or those farther from a radar?

**Look for signs of sedimentation!**



# CONVECTIVE STORM EVOLUTION



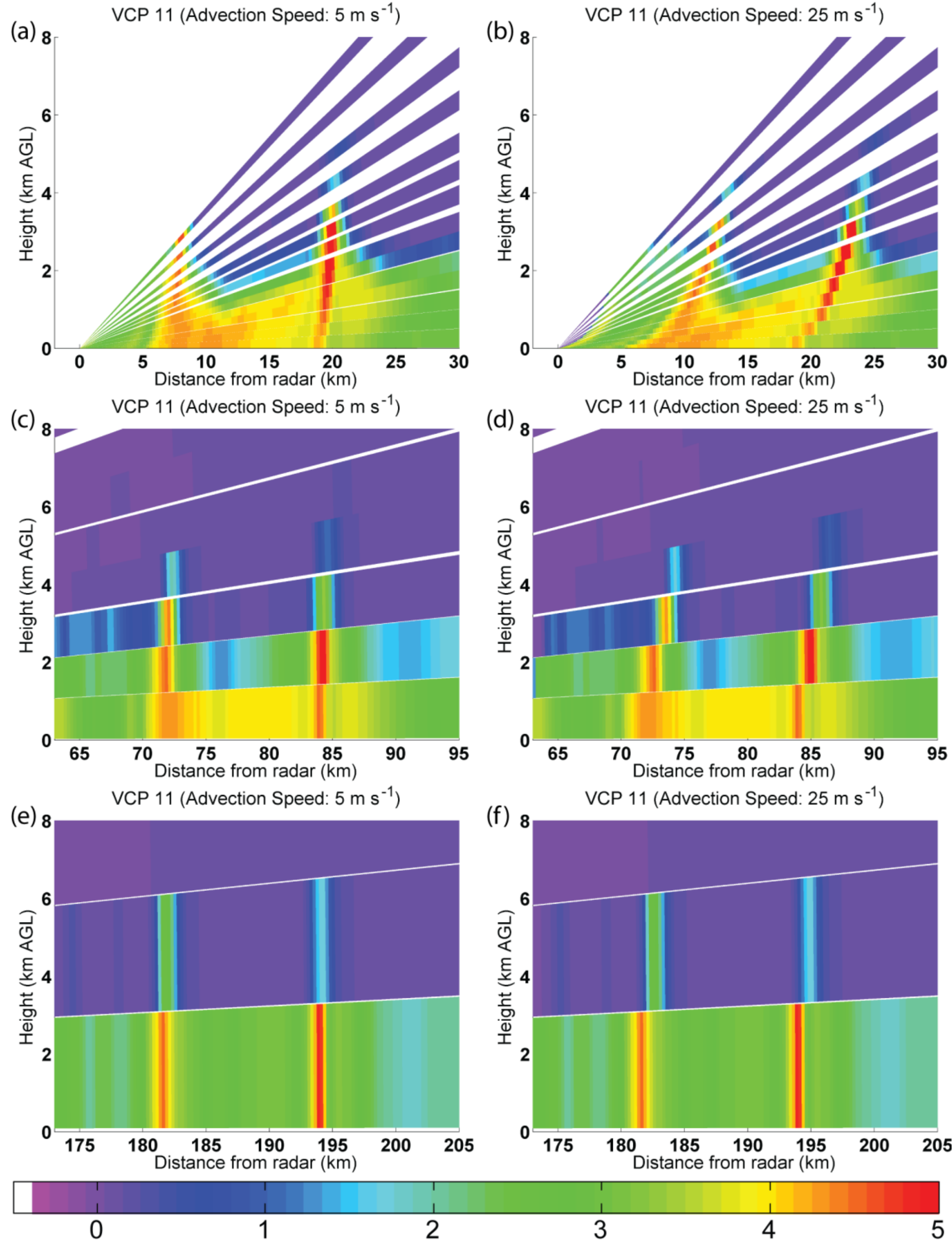



# 24 May 2011

How do $Z_{DR}$ column data compare with other, currently-used proxies for updraft intensity?

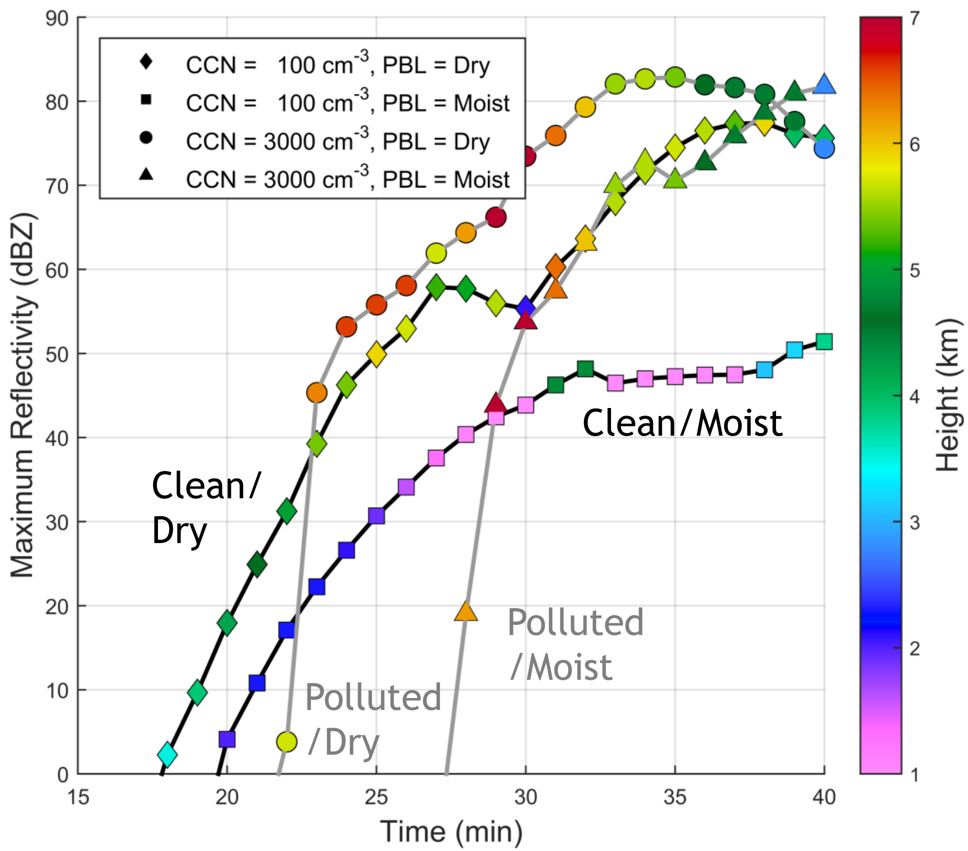
Current version of algorithm looks for vertical continuity without allowing for tilt

Problem: Storm movement during duration of data collection can introduce artificial tilt!



# RESULTS

## An increase in CCN results in more intense storm development

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