Dual-Polarimetric Radar Data Assimilation and Information Content Analysis Study

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Dual-Polarimetric Radar

Horizontal and vertical signals: more info about the type, shape, and size of the hydrometeors – more accurate estimates of precipitation and cloud particles.

Standard Variables from ARMOR (C-band):

ZH: Horizontal reflectivity

VR: Radial velocity

ZDR: Differential reflectivity ZDR = 10 log10(ZH/ZV)

KDP: Specific differential phase, range derivative of ΦDP

ρHV: Correlation coefficient, the coefficient between the horizontal and vertical power returns.

ΦDP: Differential phase, the measured phase shift between horizontal and vertical pulses

Advanced Radar for Meteorological and Operational Research (ARMOR) located at Huntsville International Airport

Motivation and Goals

• *Only a few* studies have been done assimilating real dual polarimetric data in storm scale forecasting.

• NWS upgrades current NEXRAD radar network to include dual-polarization capabilities (2012-2014). Migrate to use of S-band data.

• Project goal is to assimilate dual-pol Doppler radar observations for real cases and seek better performance in radar data assimilation.

• Examine how and by how much the dual-pol variables influence the initial fields, the sensitivity of radar data assimilation to operator.

• Investigate information content for dual-pol radar variables

Model & Radar Data Assimilation Package

- WRF ARW v3.0
- WRF 3DVAR system
- Warm-rain forward operator
- Cycled assimilation of ARMOR data

Radar Forward Operators

VR:

$$VR = u\frac{x - x_i}{r_i} + v\frac{y - y_i}{r_i} + (w - v_T)\frac{z - z_i}{r_i}$$

ZH On

$$Z_H = 2.04 \times 10^4 q_r^{1.75}$$

ZH and ZDR:

$$q_r = 0.6 \times 10^{-3} \times Z_H^{0.85} \times \Im_{DR}^{-2.36}$$

$\Im_{DR}$: non-dimensional differential reflectivity in linear scale

Comparison of KDP and ZDR assimilation:

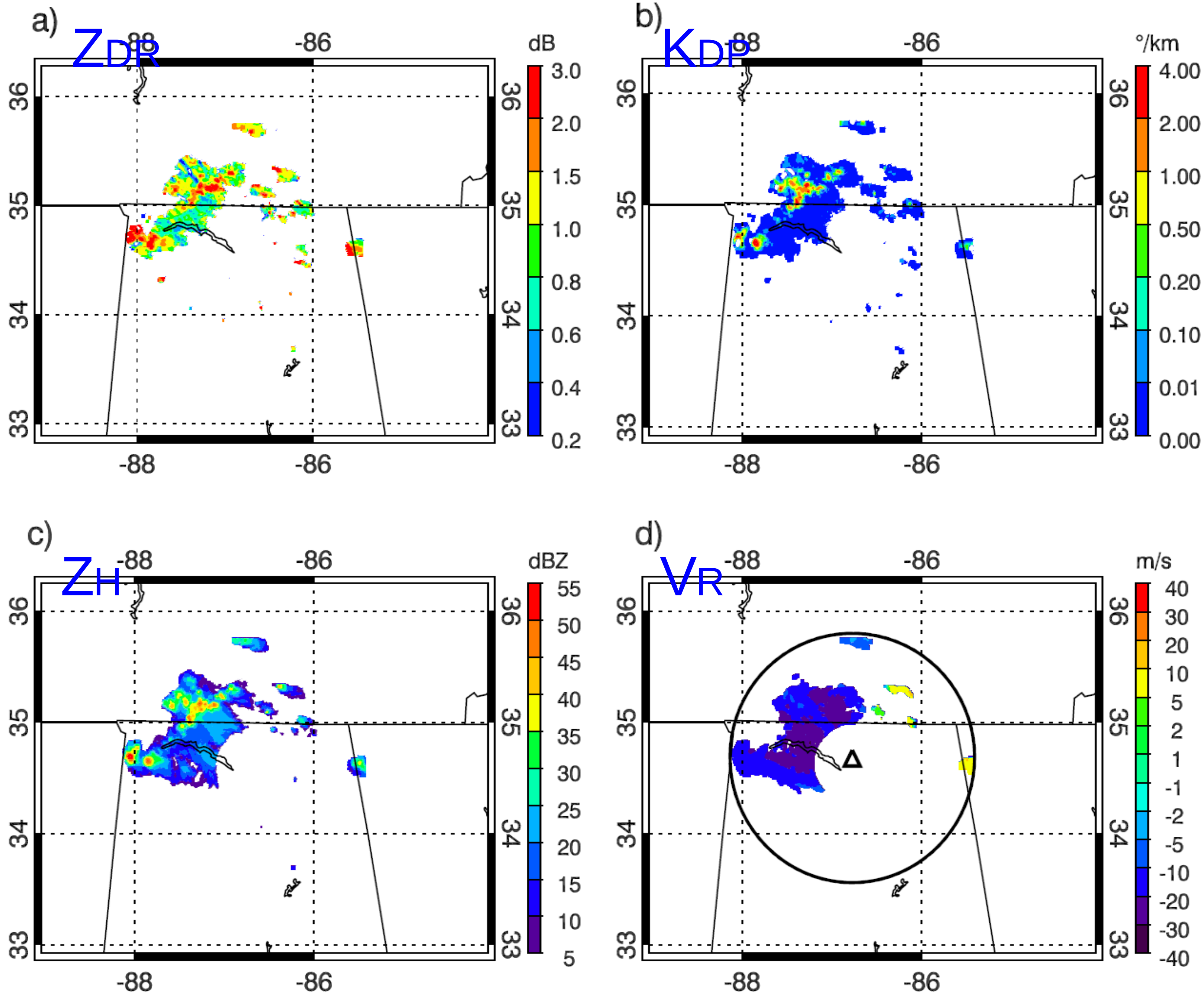
Ryzhkov and Zrnić (1995):

$$q_r = 3.11 \times K_{DP}^{0.918} \times Z_{DR}^{-0.764}$$

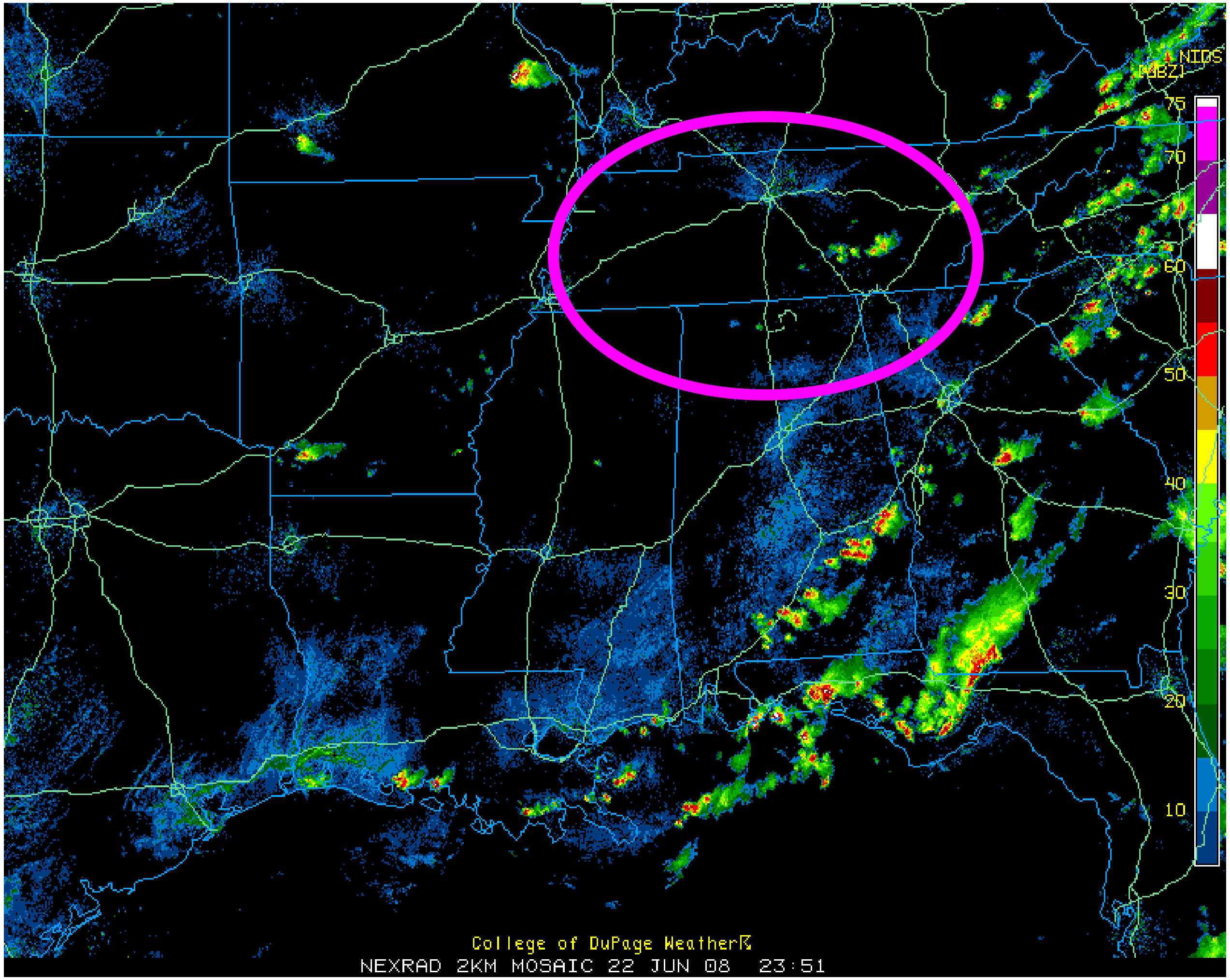
Bringi and Chandrasekar (2001):

$$q_r = 2.32 \times K_{DP}^{0.83} \times \Im_{DR}^{-1.11}$$

Sample ARMOR Data: 1930 UTC 23 June 2008



Case Study
23 June 2008

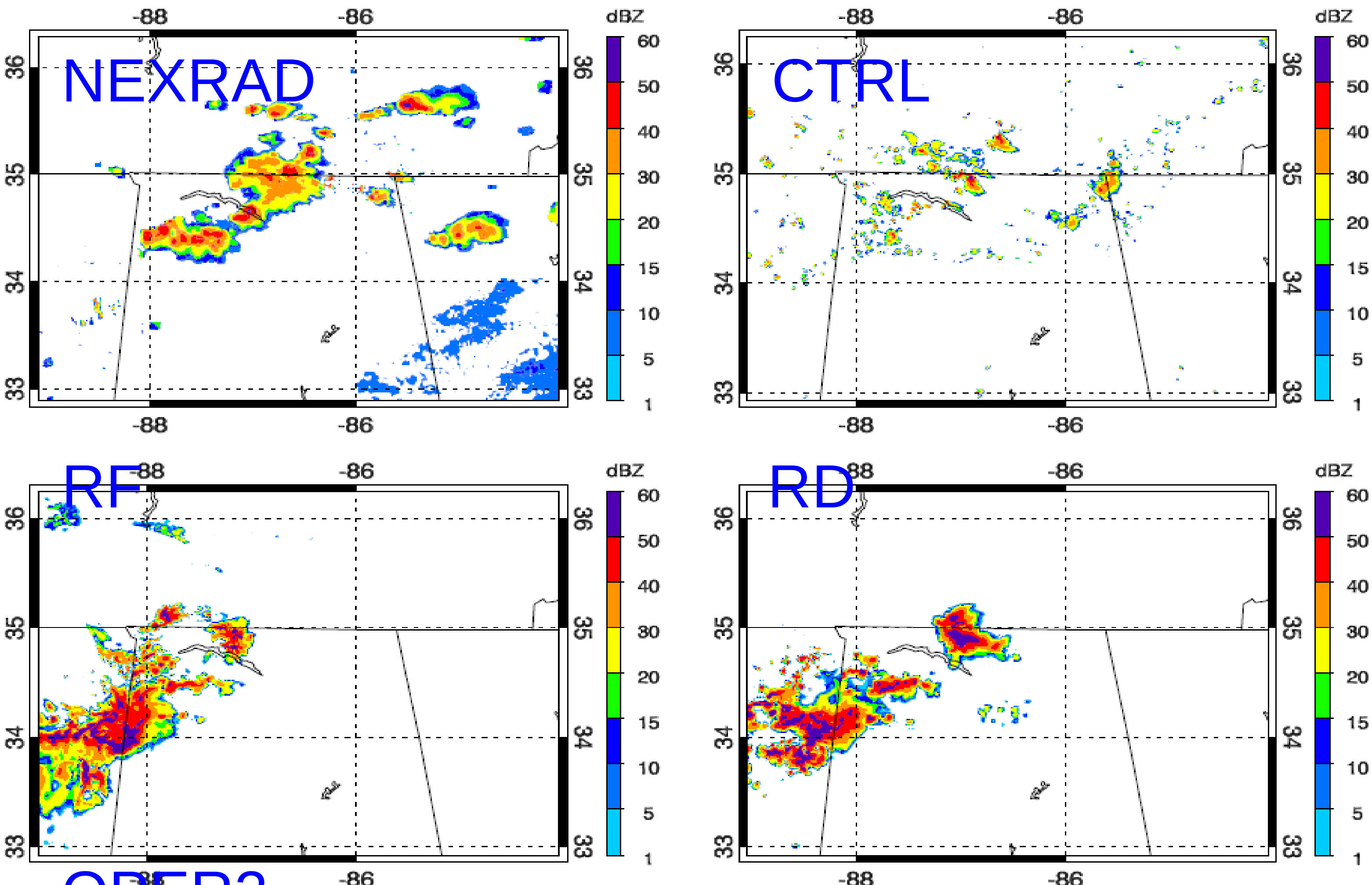


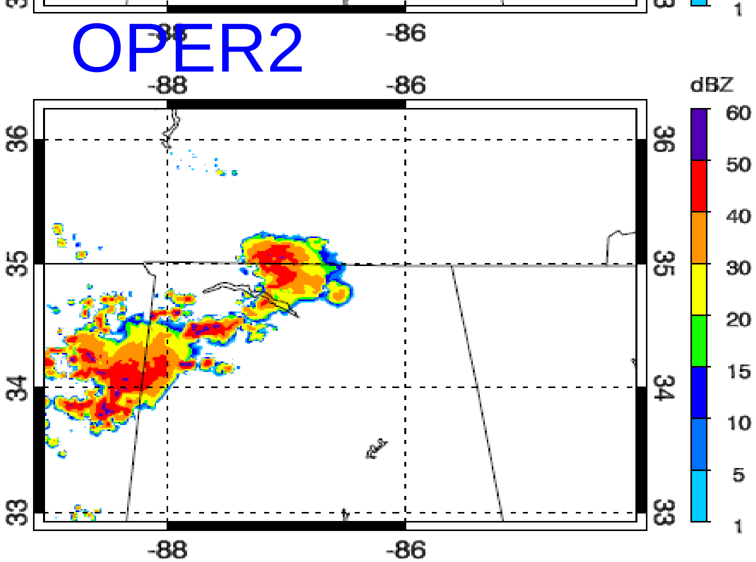
Thunderstorm in the afternoon over southern Tennessee and northern Alabama.

Storm was within ARMOR radar coverage for much of its lifetime, making it ideal for analysis in a data assimilation framework.

Data Assimilation Experiments

Experiment	ARMOR Data Assimilation	Variables
CTRL	N/A	N/A
RF	1930, 2000, 2030 UTC 23 June 2008	Z_H
RD	1930, 2000, 2030 UTC 23 June 2008	Z_H and Z_{DR}
OPER1	1930, 2000, 2030 UTC 23 June 2008	K_{DP} and Z_{DR} (Ryzhkov and Zrnic 1995)
OPER2	1930, 2000, 2030 UTC 23 June 2008	K_{DP} and Z_{DR} (Bringi and Chandrasekar 2001)



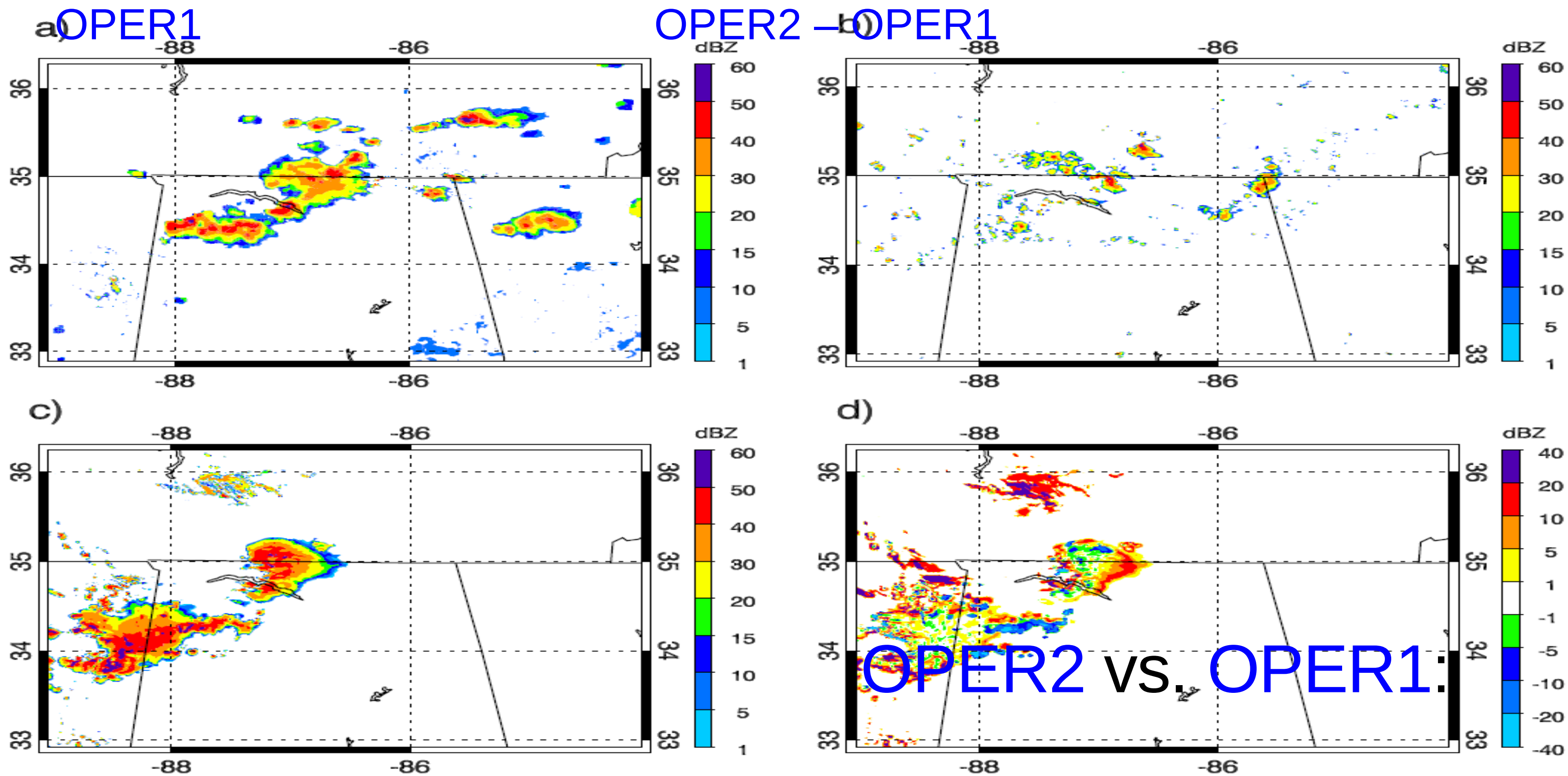


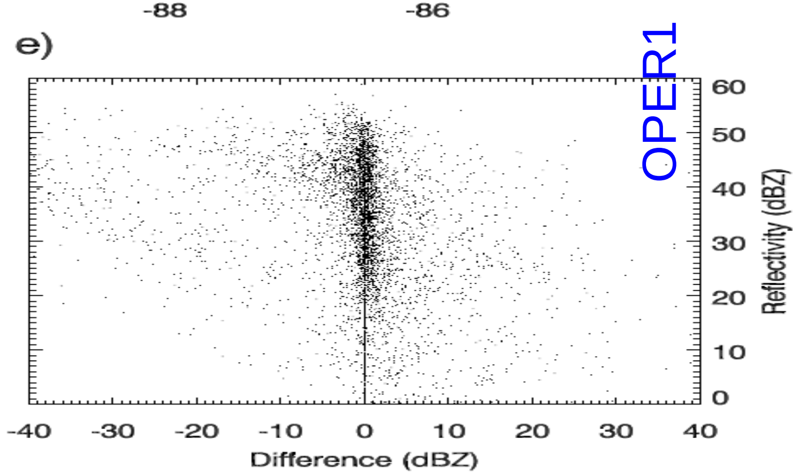
Reflectivity 2030 UTC 23 June 2008:

KDP and ZDR data assimilation (OPER2) produces better initialization than ZH and ZDR assimilation (RD) and ZH-only assimilation (RF).

Warm rain processes being better represented.

KDP and ZDR Data Assimilation Comparison:

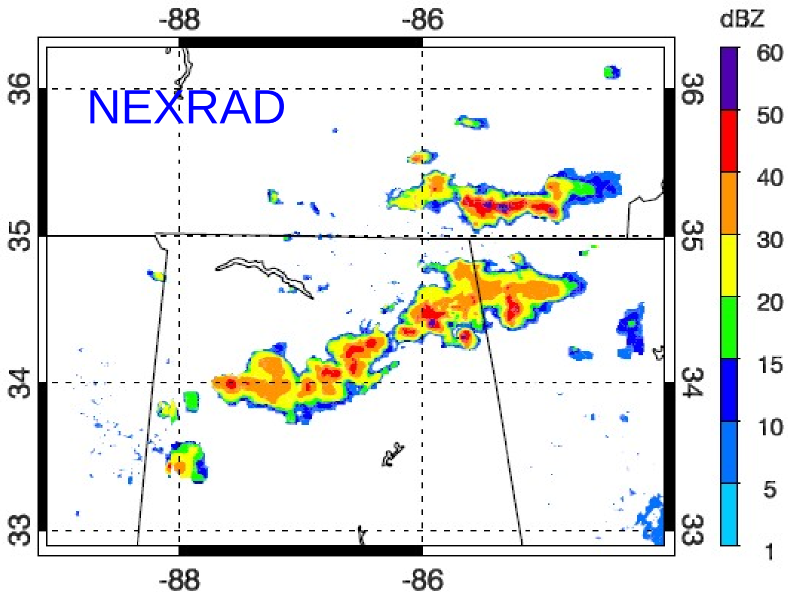


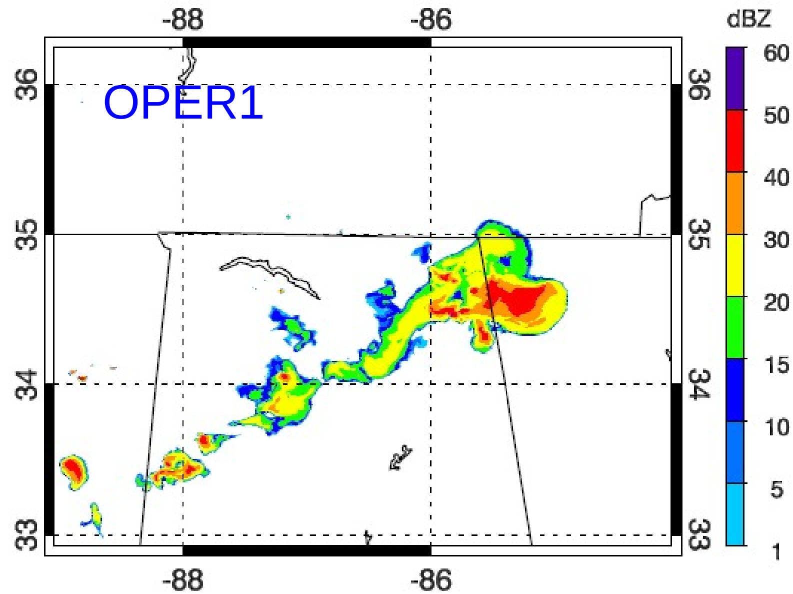


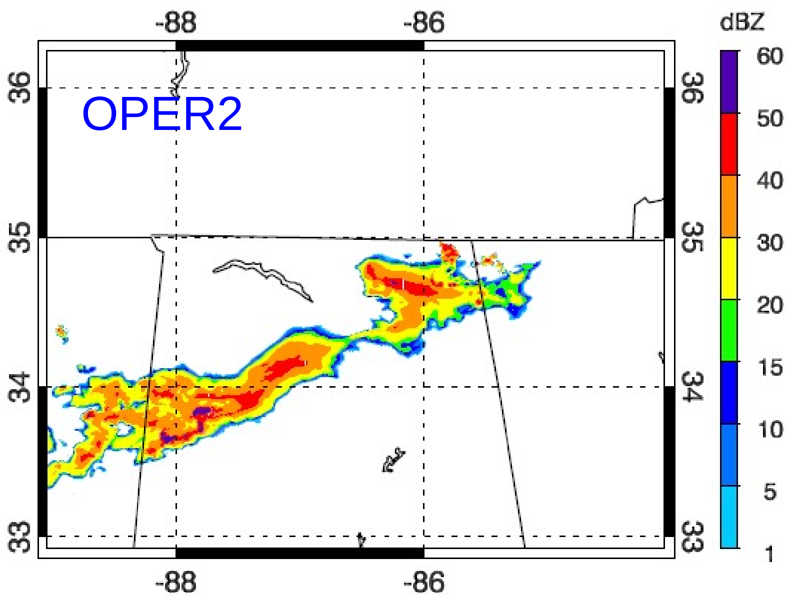
OPER2 - OPER1

Similar storm location and less water (negative values) at high reflectivity region in OPER2 versus in OPER1.

Forecast Validation 2200 UTC







Location: similar

Storm Structure: quite different

Quicker dissipation in OPER1

Dual-Pol Radar Data Assimilation Work

- The C-band dual-pol radar variables, ZH, ZDR, KDP and VR data have been successfully assimilated with the WRF 3DVAR system.

- KDP and ZDR data assimilation is superior to ZH and ZDR, and ZH– only data assimilation, in the initialization of the simulated convective storm with warm rain radar operators.

- OPER2 outperforms OPER1 for KDP and ZDR assimilation.

On-going work:

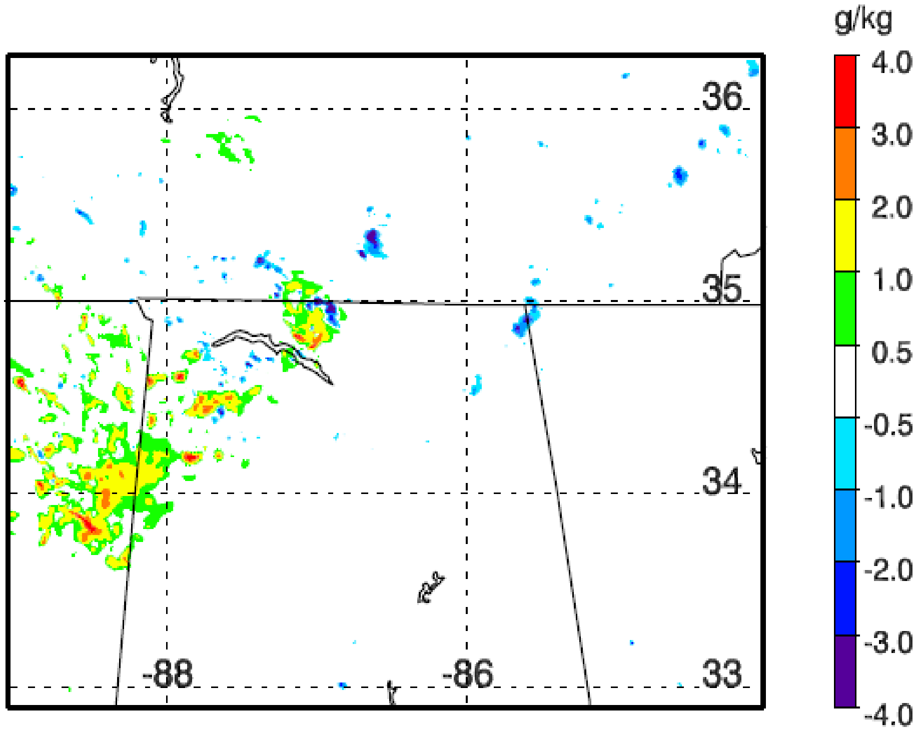
1. Toward S-band dual-pol radar data assimilation;
2. Additional case studies, ice-phased processes in 3DVAR;
3. Complete information content & forward operators (below);
4. Utilization of additional dual-pol variables in the characterization of ice microphysics.

Ongoing dual-pol radar DA with ice microphysics

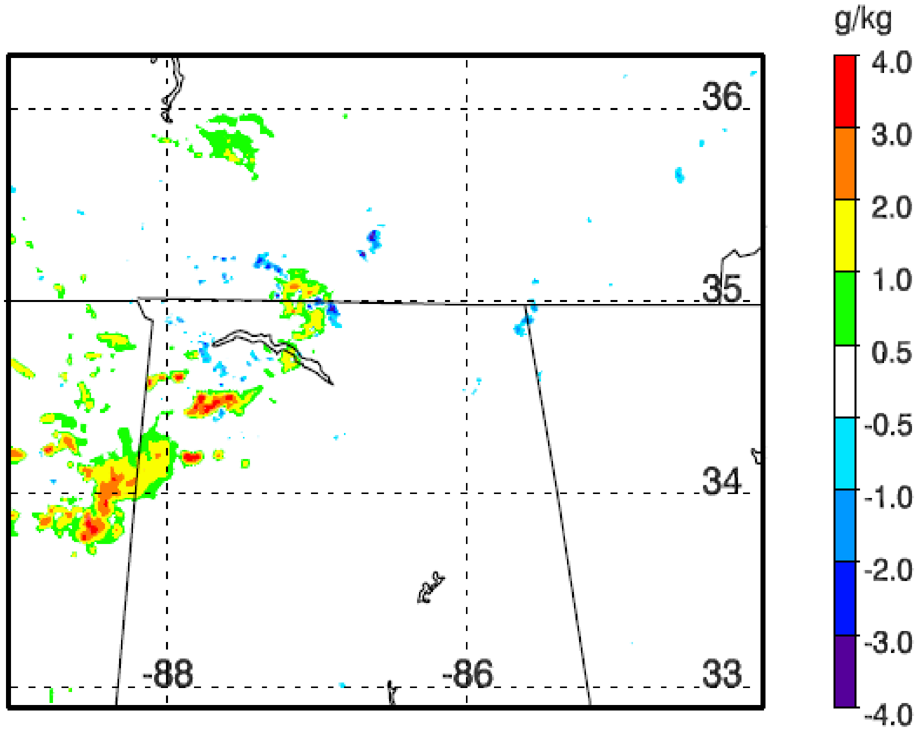
Radar DA control variables: qt = qv+qc+qr+qi+qs

Ice microphysical processes: WSM3

Ice



Warm Rain



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MCMC-Based Analysis

Dual-Pol Radar Ice Information Content

Markov chain Monte Carlo (MCMC)

Objectives:

- Assess information content in observations
- Determine whether ice content and particle size distribution can be uniquely determined

Procedure:

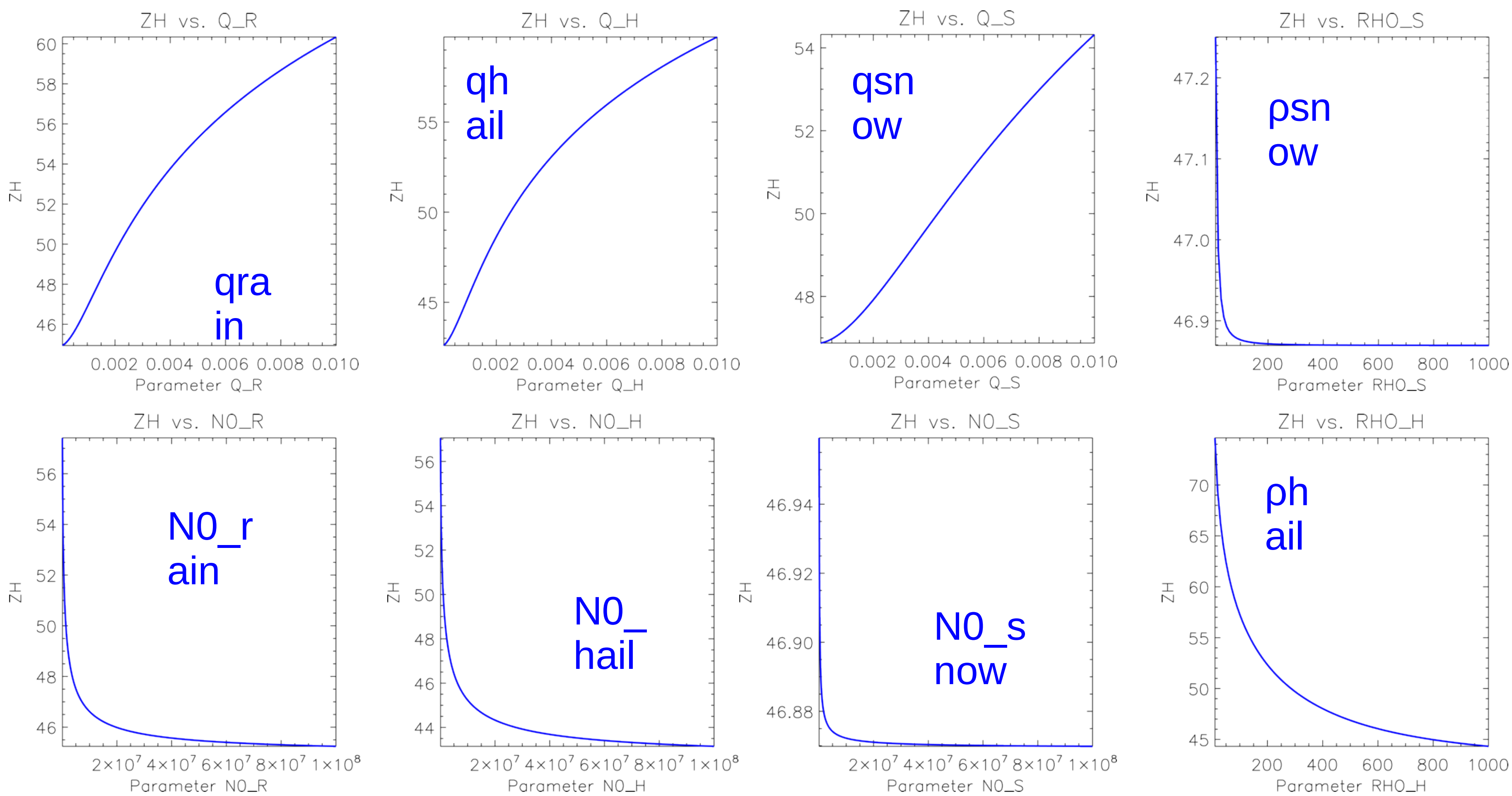
- Map (response) functional relationship between control variables and dual-pol variables
- Use a Bayesian probability sampling algorithm (MCMC) to produce posterior PDFs of control variables given *simulated observations* and assess information content and uniqueness

Data:

- WRF output at 1800 UTC 23 June 2008
- Simulated dual-polarimetric observations from WRF output
- MCMC-based computation of control variables PDFs
- Use selected grid boxes only, that contain significant ice hydrometeors

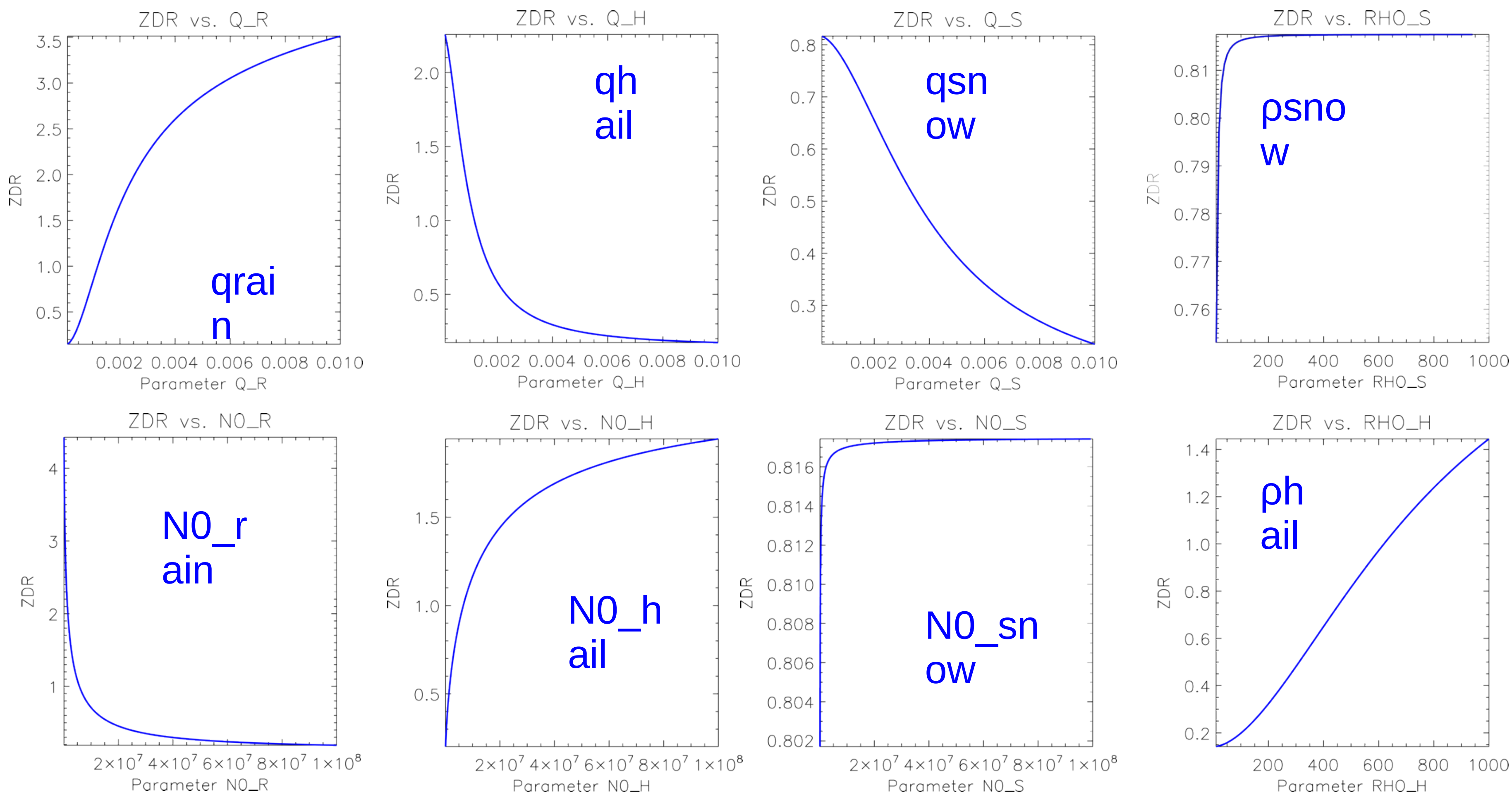
Response Functions

- Vary mixing ratio and particle size distribution slope intercept over a range of values, and compute forward modelled ZH.



Response Functions

- Vary mixing ratio and particle size distribution slope intercept over a range of values, and compute forward modelled ZDR.



Preliminary Conclusions and Future Works

- Dual-pol ZH, ZV, and ZDR can uniquely constrain either mixing ratio or particle size distribution of rain and hail/graupel, *but not both.*

- Clear functional relationship evident between qr/N0r, qh/N0h, and qh/ρh

- Snow not well constrained by dual-pol observations
  - ZDR and ZH response function showed little sensitivity to changes in snow variables
  - Snow amount was 0.1 times qr and qh for the WRF grid box in this experiment

Questions:

- How might response function change with changes in the state, e.g., temperature, water vapor, pressure, and cloud amount; How, in turn, would the posterior PDFs change?
- Would assimilation of Kdp and ρhv serve to produce unique values of both cloud mass and particle size distribution?

Follow-on Work:

Re-run experiments for additional model grid boxes: (1) containing comparable (and small ~ 0.1 g/kg) amounts of snow,graupel, and rain, (2) containing snow and graupel only, (3) containing snow only. Include additional dual polarimetric variables (ρHV).