An Integrated View of Convection from MC3E

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With thanks to Alyssa Matthews, Brody Fuchs, Elizabeth Thompson, Merhala Thurai (CSU), Angela Rowe (UW), Toshi Matsui, Taka Iguchi, W.-K. Tao (NASA)

Thrust

- Using state of the art Doppler and polarimetric radar analysis techniques to help validate cloud models—both microphysics and kinematics
- Illustrate only a few examples here
- Study both warm and cold season precipitation

MC3E-SGP: Affording a Comprehensive View of Convection April-May 2011

X-SAPR, courtesy DOE

XSAPRs (SE, SW, NW)

X-band (3 cm wavelength)
Network = dual-Doppler retrievals of 3D wind
22 tilts reaching 50 degrees in 6 minutes
Range: **40 km**
Nyquist Velocity: 16.8, 17.2 m/s

NPOL

S-band (10.6 cm)
Variable scanning; aircraft support, RHIs, sector scans
Range: **150 km**

C-SAPR, courtesy DOE

CSAPR

C-band (5 cm wavelength)
17 tilts in 6 minutes
Range: **120 km**
Nyquist Velocity: 16.5 m/s

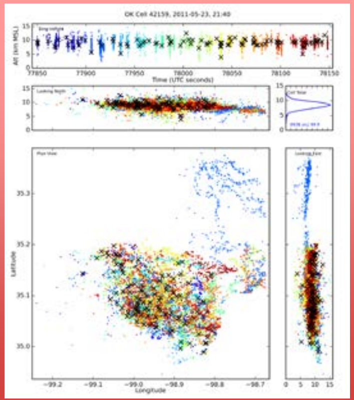
KCYS, courtesy crh.noaa.gov

KVNX (NEXRAD)

S-band (11 cm wavelength)
4.5 min scans
Range: 150 km
Nyquist Velocity: 26.75 m/s

Radar Retrievals:

-3D wind via dual-Doppler techniques
-Bulk microphysics from hydrometeor identification algorithms
-Drop size distributions, rain rate and LWC from distrometers



Lightning Mapping Array

-11 Stations providing time-of-arrival 3D mapping of lightning sources via VHF source data

Disdrometers

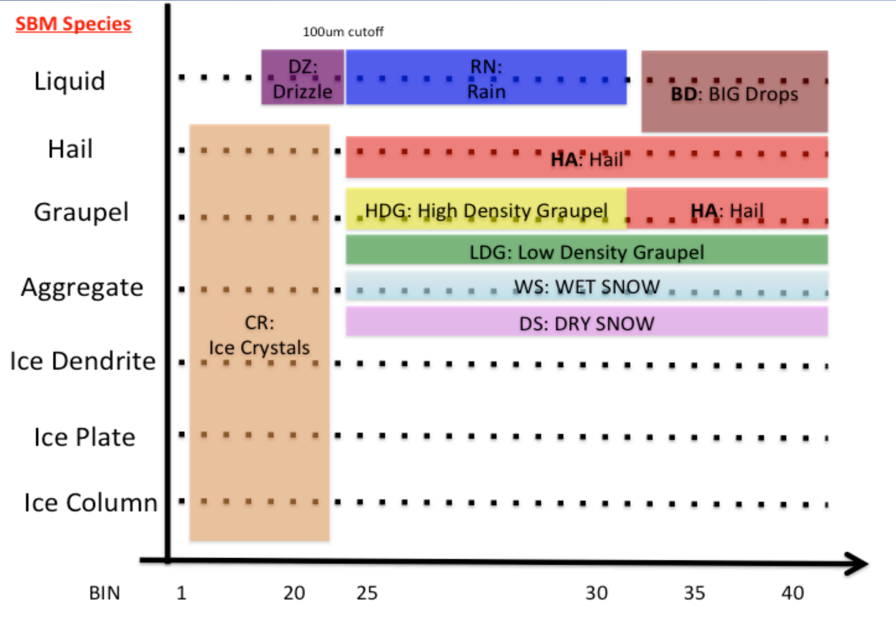
- 5 2DVD
  - Measures drops to 10 mm; 50 0.2 mm bins
- 16 Autonomous Parsivel Units
  - Measures particles up to 25 mm in 32 bins

Image courtesy of http://wallops-prf.gsfc.nasa.gov/Disdrometer/

NASA/WRF Spectral Bin Model

Toshi Matsui, W. K. Tao

- 43 mass bins covering sizes from small cloud particles to hailstones, uses so-called 4 ice scheme (hail, graupel, aggregates and pristine ice) plus 4 water categories
- Riming fractions for aggregates are computed—allowing transition to graupel, melt fraction computed as well allowing transition to wet snow, similar for graupel and hail
- As a first attempt at model / radar microphysical comparisons, the NASA WRF hydrometeor fields are subdivided into HID-consistent categories with respect to size, density and phase. HID algorithm developed by Dolan and Rutledge (2009) and Dolan et al. (2013) is used. For example for rain, specific size bins define drizzle, light rain and big drops (> 5 mm diameter). Aggregates are defined as graupel when riming fraction exceeds 30%. The "matrix" below is therefore realized.

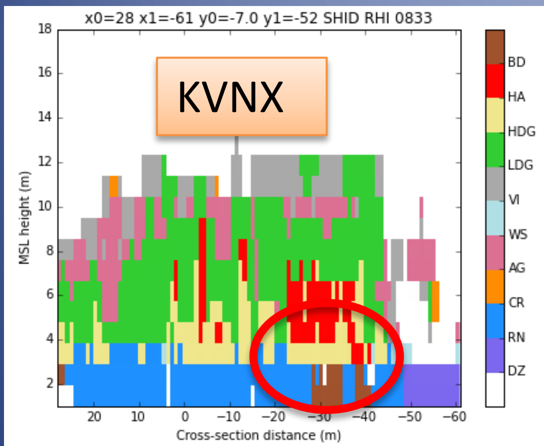


- At each model grid point the hydrometeor type that dominates the radar reflectivity is identified and assigned to that grid point (hail, rain, etc.)

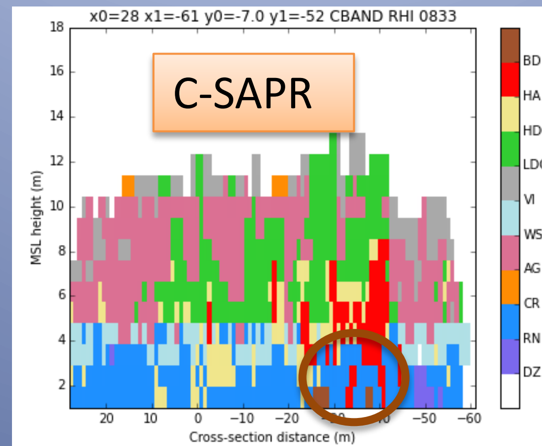
- **Big drops were an interesting observation from MC3E, D > 5 mm.**

Multi-wavelength HID (MWHID)

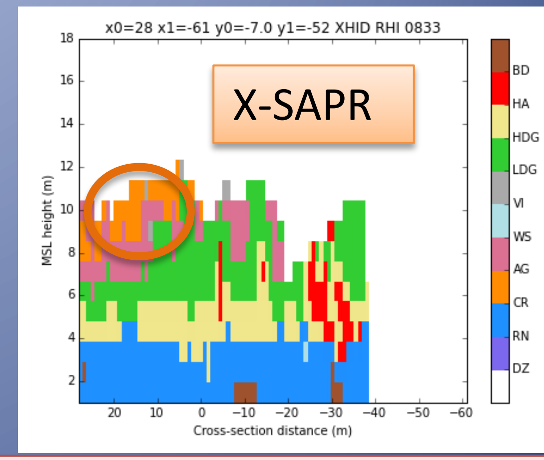
- Combine the available cm radars (KVNX, C-SAPR, X-SAPR) into a single classification to leverage the strengths of each wavelength



S-band: Insignificant attenuation and Mie scattering



C-band: Resonance effects (big drop detection)

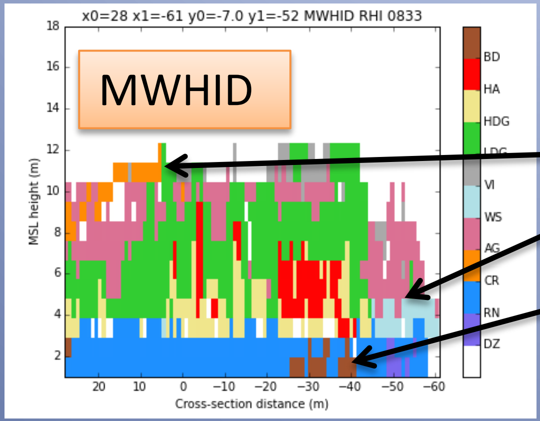


X-band: Greater sensitivity in light precipitation and ice region (K_{dp} proportional to wavelength^{-1})

- Fuzzy logic classifications for each hydrometeor type is a function of radar wavelength
  - For example, hail and graupel weighted heavily at S-band, big drops more at C-band, pristine ice species weighted at X-band
- Combine HID from each wavelength using a ‘weighted mode scheme’ at each grid point—weights based on scattering simulations and empirical data

$$MWHID=Mode[W_S*HID_S,W_C*HID_C,W_X*HID_X]$$

Multi-wavelength HID (MWHID)



Fairly coherent picture and less noisy than individual radars

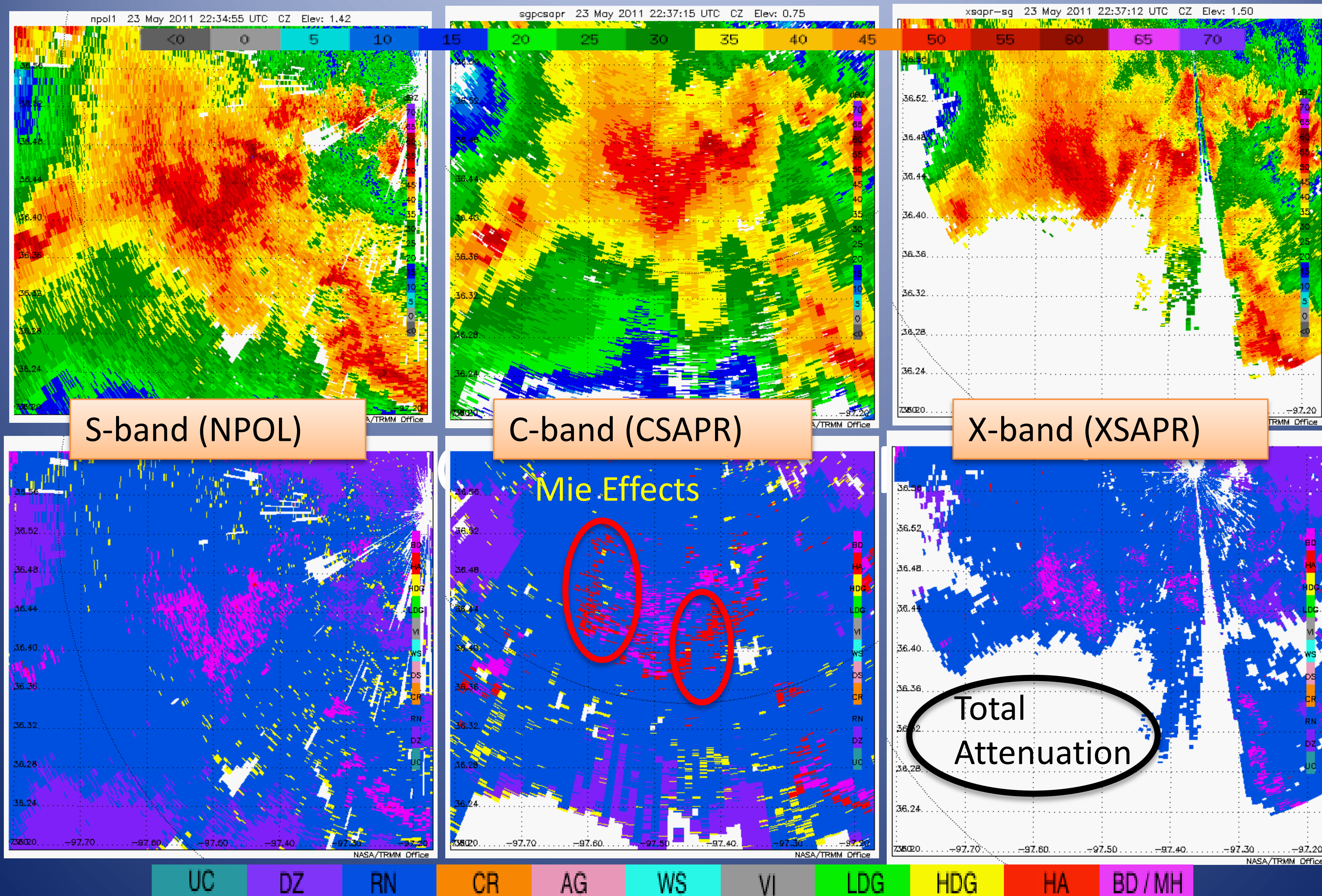
- Ice in the upper levels
- Layer of wet snow in the stratiform with aggregates above and rain/drizzle below
- Hail core and big drops below

Conducted sensitivity tests by removing wavelengths and comparing to the 3-wavelength MWHID

- X-band best at resolving pristine ice particles and vertically aligned ice
- C-band best at resolving “big drops”, drizzle, wet snow and vertically aligned ice
- S-band best at resolving graupel and hail, and heavy rain

- But ambiguities exist…..the picture is not always crystal clear……

A particular example…….



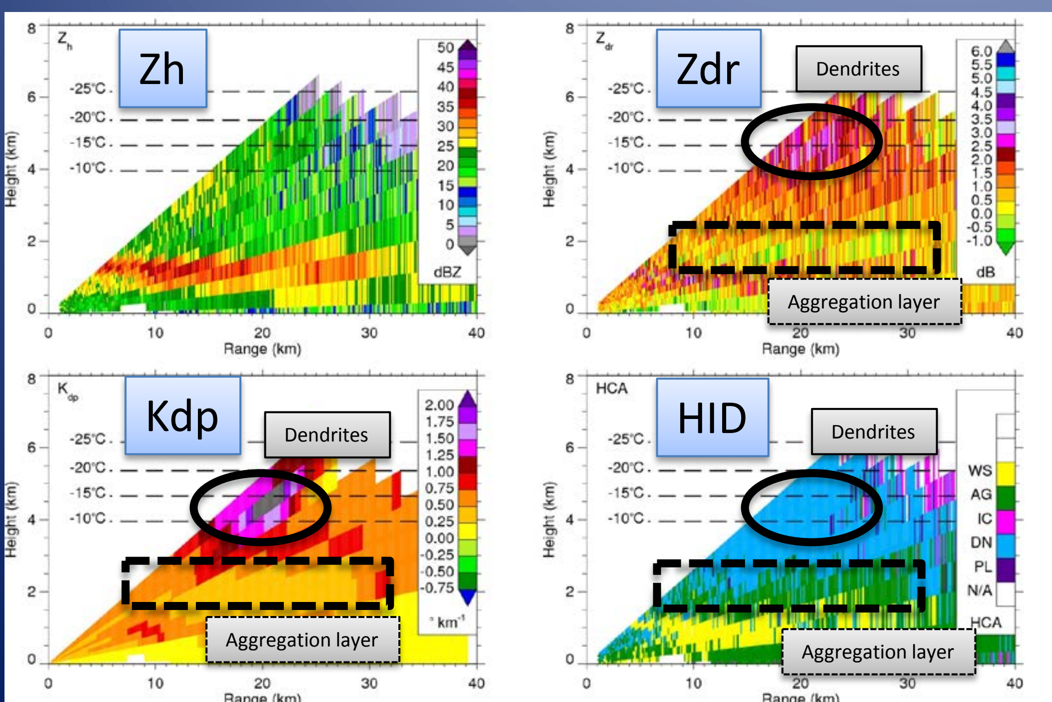
- Large region of big drops; no hail
- Ambiguity between hail and big drops
- Regions of big drops, but totally attenuated behind core

MWHID----Cold Season

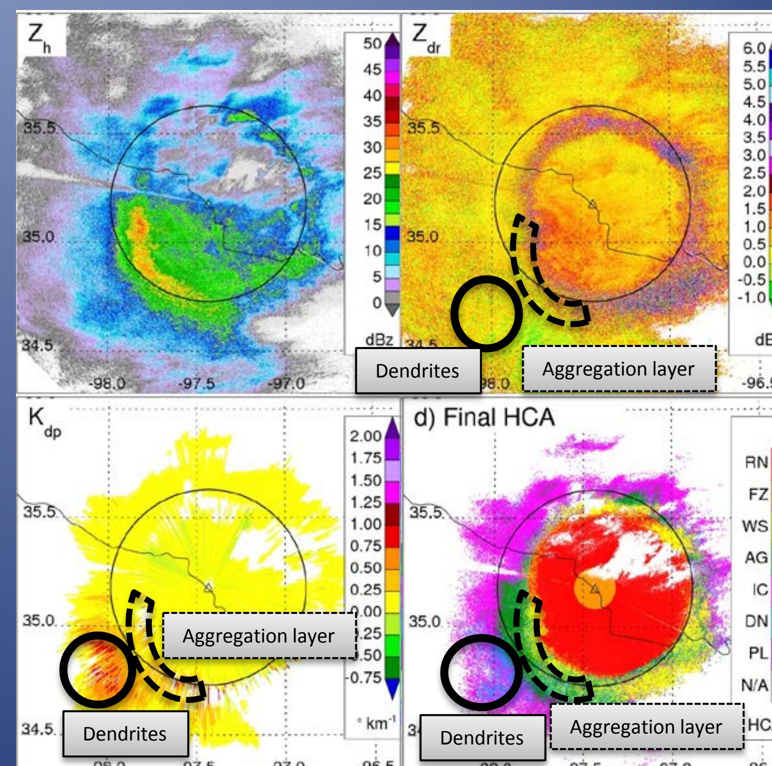
- Shorter wavelengths (X- and C-band) valuable for discriminating ice species in winter, S-band adds little additional information for cold season precipitation
  - Due to increased phase shifts, K_{dp} (scales with $1/\lambda$)
  - Less attenuation in cold-season storms

From Thompson et al. 2014

CASA X-band data from 24 Dec. 2009

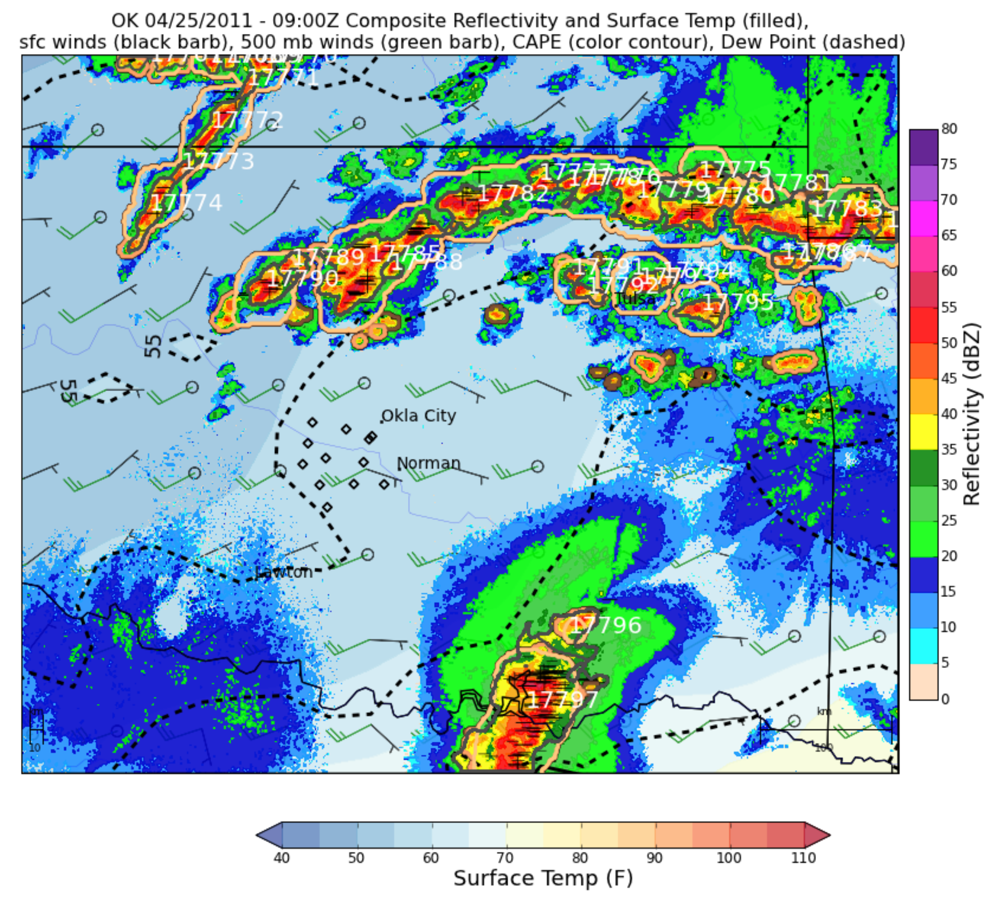


OU-Prime C-band data from 28 Jan. 2010



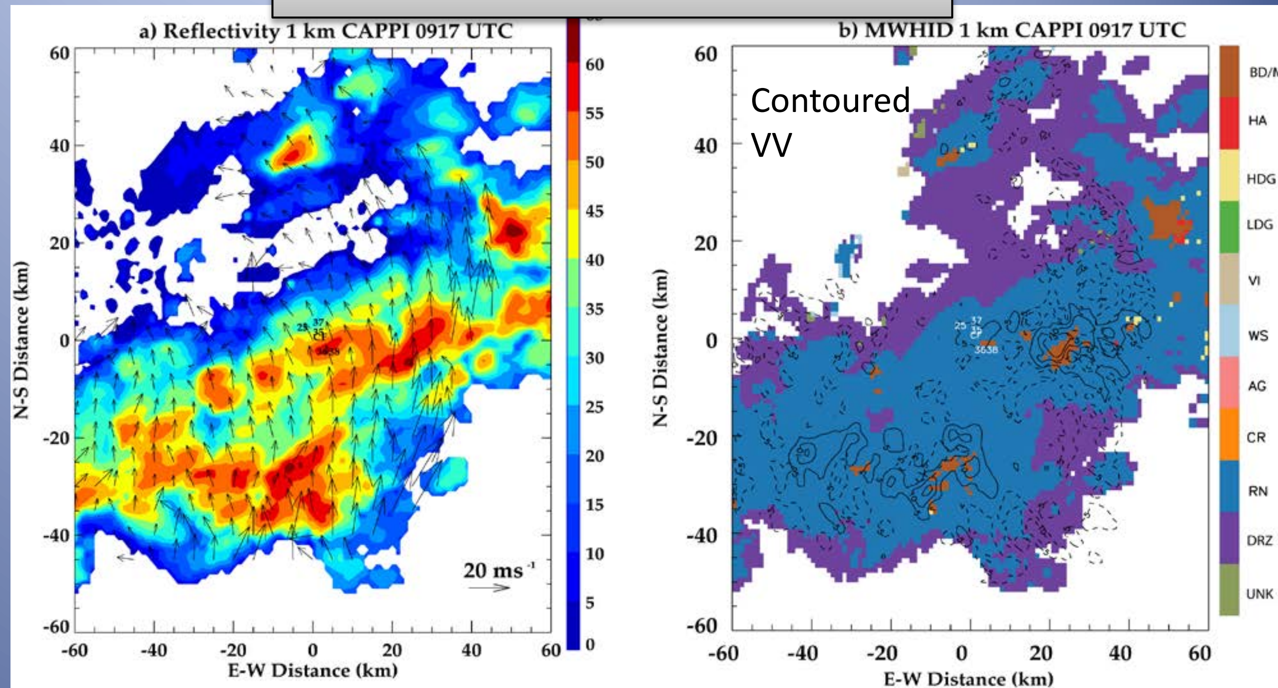
25 April 2011

- Elevated nocturnal convection
  - East-west MCS
  - Moved toward NE
  - 2DVDs observed numerous drops > 5 mm
- 08-1130 UTC
- Frequent lightning activity (up to 60 flashes/min)



- Origin of big drops (> 5 mm)?
  - Almost exclusively associated with strongest reflectivity and beneath main updraft cores
  - Melting hail rather than collision-coalescence produces big drops

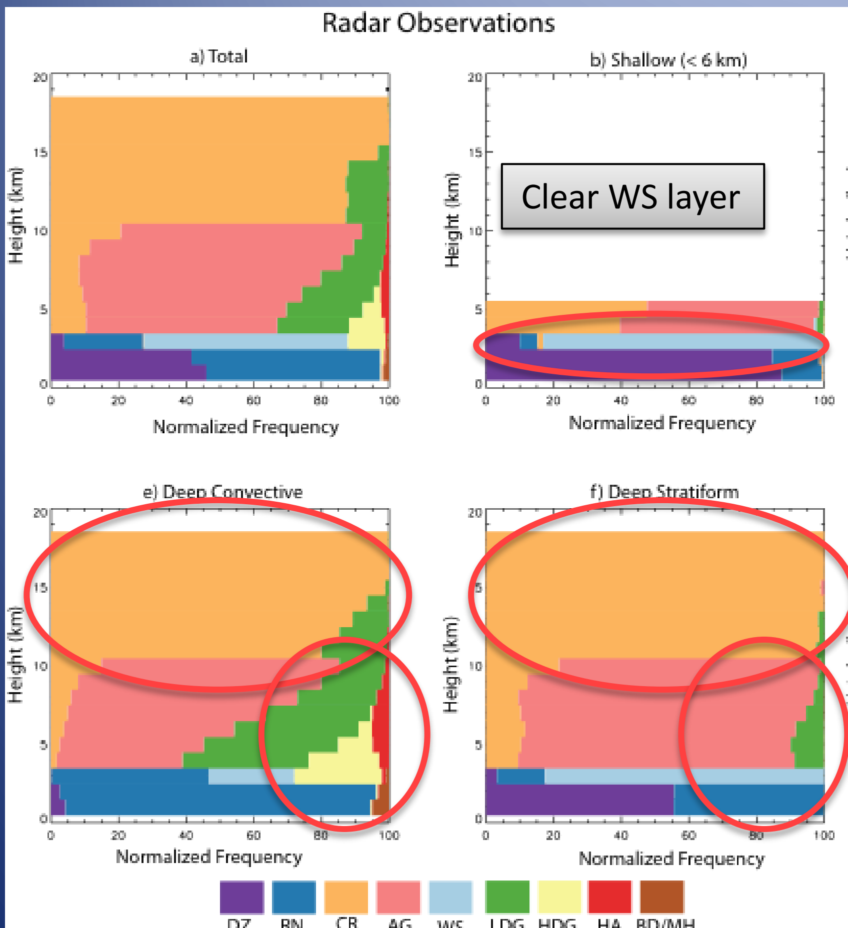
Horizontal cross-section at 0917 UTC

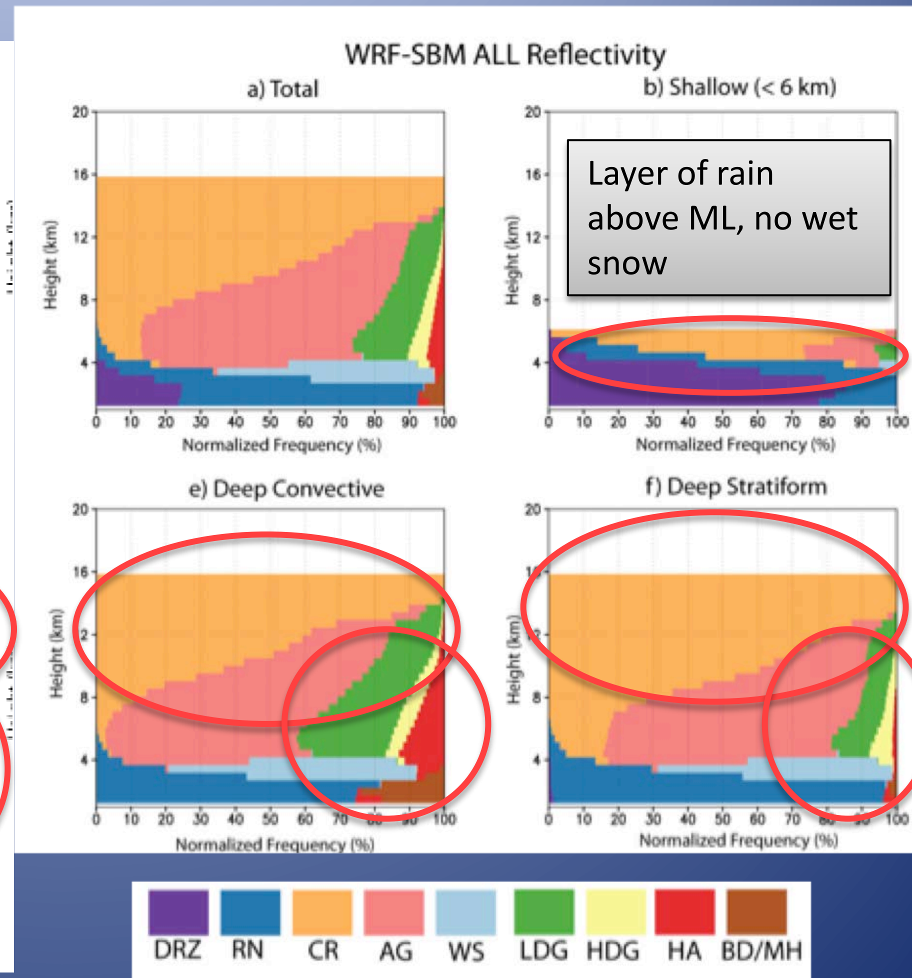


Column Maxima integrated over 08-1130 UTC

Points identified as BD from 08-1130 UTC

Model and Radar Bulk Microphysics





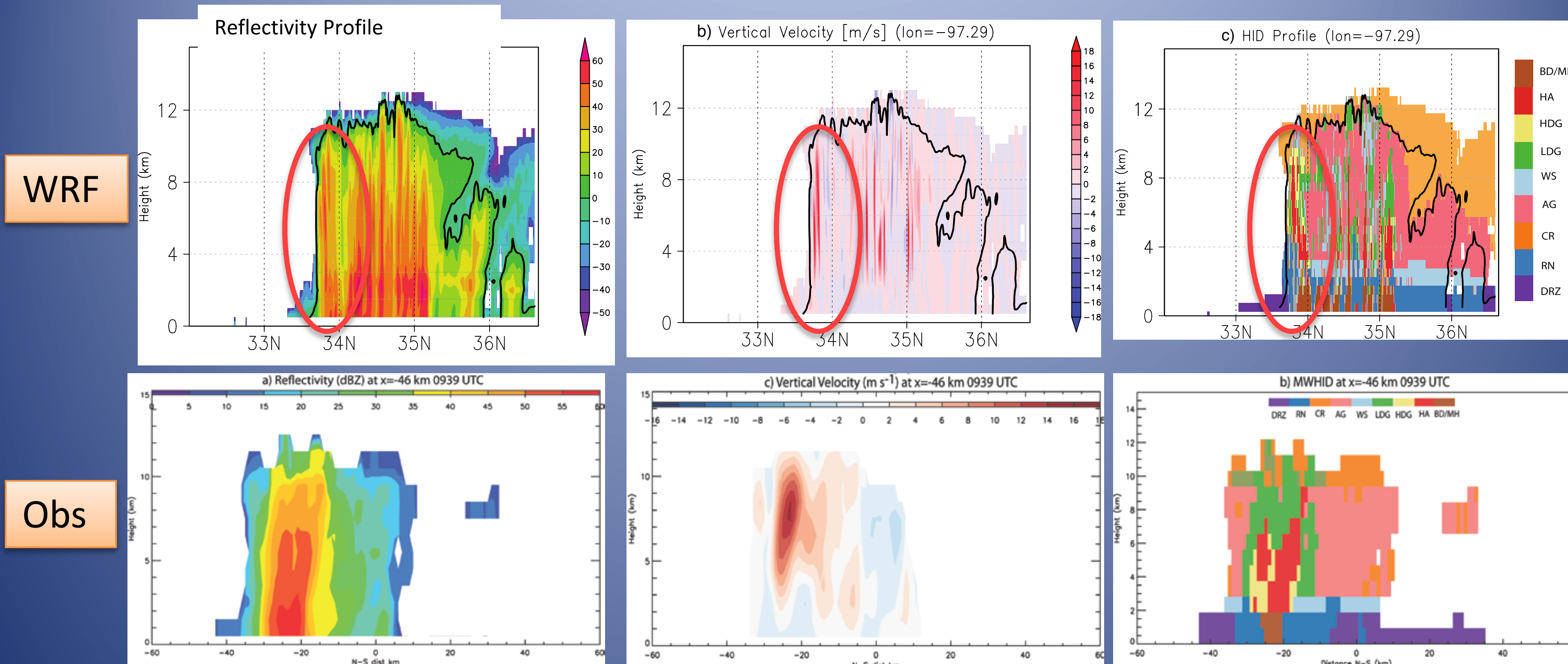
Dee

Mo

Deep Stratiform:

Steiner et al. (1995) Convective / Stratiform used in both model and radar; some aliasing of convection in model space leading to more graupel and a small amount of hail in deep stratiform region

Model /Radar: Cross-section Comparison

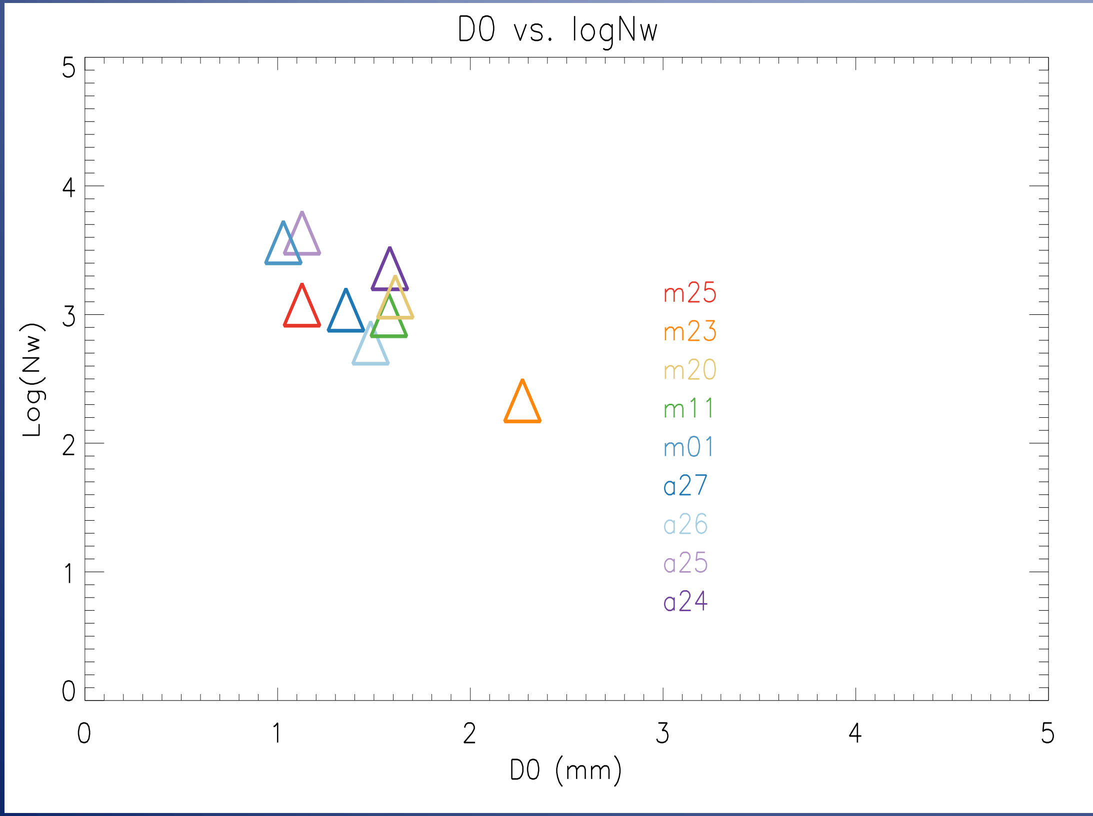


- Kinematics:
  - Updraft cores in model and obs are > 10 ms^{-1}
  - Model has stronger updrafts and weaker downdrafts—this is a common pattern, not just in this model/radar comparison study
  - Model and observations peak around 7-8 km
- Microphysics:
  - Similar vertical structure, although model noisier due to reflectivity-weighted HID mapping
  - Continuity between hail / graupel aloft and big drops at the surface in cores
    - All big drops in model originate from hail

Next steps

- Apply a sophisticated polarimetric radar simulator for model output
  - Simulate polarimetric moments at S, C and X cm-wavelengths from model output, then apply radar-based fuzzy logic HID
  - Provide a more direct comparison between model and radar microphysics
- Process additional cases (MC3E and TWP-ICE)

Is there a relationship between DSD and environmental variables?



- 9 cases from MC3E
- RUC closest point to each 2DVD was selected and ‘matched’ to disdrometer times; parameters taken at surface
- Storm means of each variable were calculated; convection only
- Data were then correlated using Spearman correlations

Correlations with DSD and Environment

Disdrometer data *Simulated	Warm Cloud Depth	Dew Point	Relative Humidity	Sfc Temp.	Cloud Base Height
D_0	0.75	0.6	0.0	0.48	-0.07
$Log_{10}(N_w)$	0.50	-0.37	0.67	-0.6	-0.48
LWC	0.72	0.31	0.45	0.05	-0.27
RR	0.80	0.28	0.45	0.0	-0.38
DBZ*	0.77	0.63	0.07	0.43	-0.18
Zdr*	0.68	0.55	-0.15	0.45	0.02
Kdp*	0.85	0.42	0.25	0.15	-0.33

Warm Cloud Depth
-Deeper warm cloud depth results in larger particle sizes, heavier rain rates, larger liquid water contents

Higher T_d_sfc:
-Larger drops, lower $Log(N_w)$, increased LWC and RR

Higher T_sfc:
-Slightly larger D0, lower Log(Nw)
-No correlation to LWC or RR

Higher Cloud base height:
-Slightly smaller D_0, lower LWC, lower RR

Deeper warm cloud depths (through higher freezing levels, higher surface dew points, and lower cloud base heights) allow hail to melt faster (less evaporative cooling; less exposure to sub-cloud dry air) resulting in large drops exiting the base of cloud

- Large hail in cloud will result in hail at surface
- Small hail can fully melt producing rain at the surface
- **Intermediate hail results in big drops at the surface**
  - 5.75 mm particle with 900 kg m^{-3} will melt into a 5 mm drop