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Combining Advanced DWR and Surface Observations and Bin Microphysical Modeling to Enhance Frozen Phase Precipitation Process Understanding

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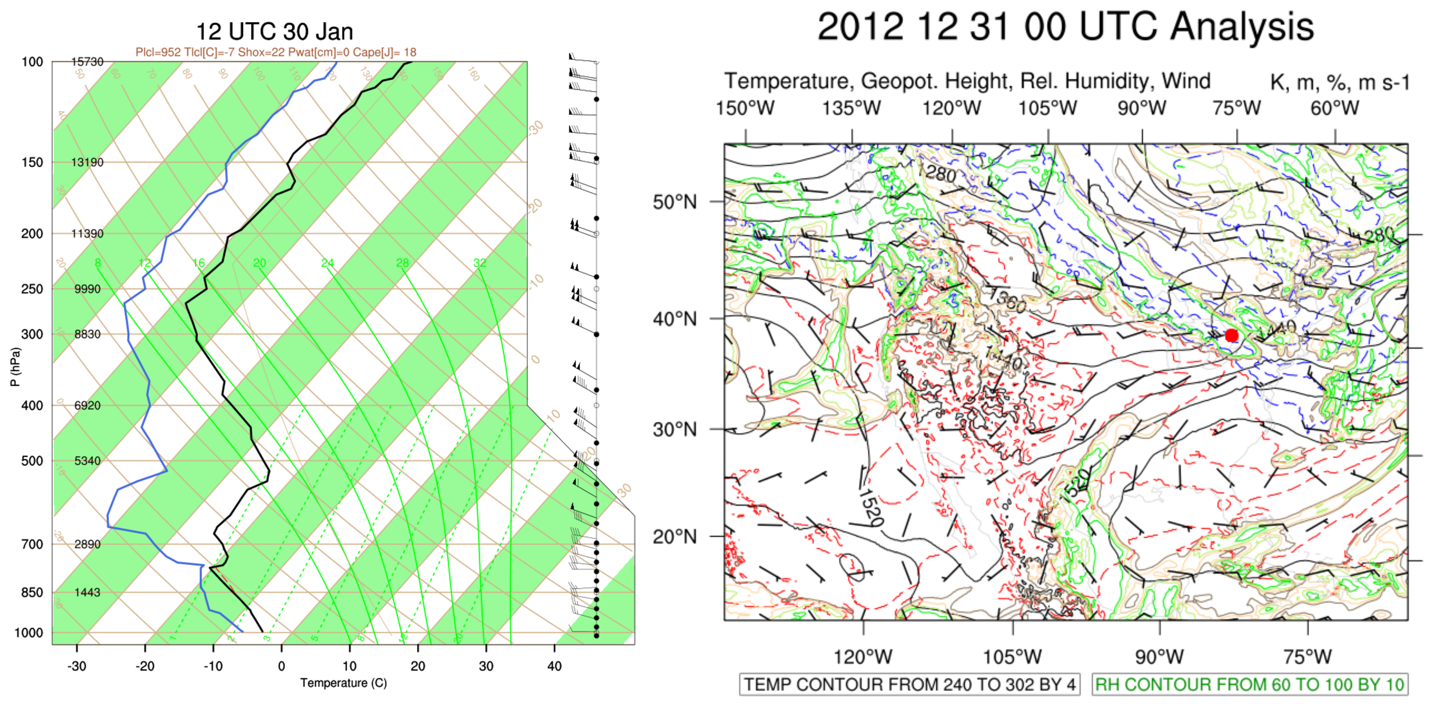
Introduction

- GCPEx had many advanced *in situ* and remote sensing observations for ground validation and microphysical studies
- We focus on the 30-31 January 2012 time period
- We enhance the methods of Huang et al. (2015) to estimate Radar Z_e-SR for snowfall QPE to include the dual-wavelength reflectivity ratio (DWR), and **propose a SR(Zh, DWR) relationship**

- WRF simulations with bin microphysics (UPNB scheme) also performed
- Initial comparisons with traditional observations discussed here

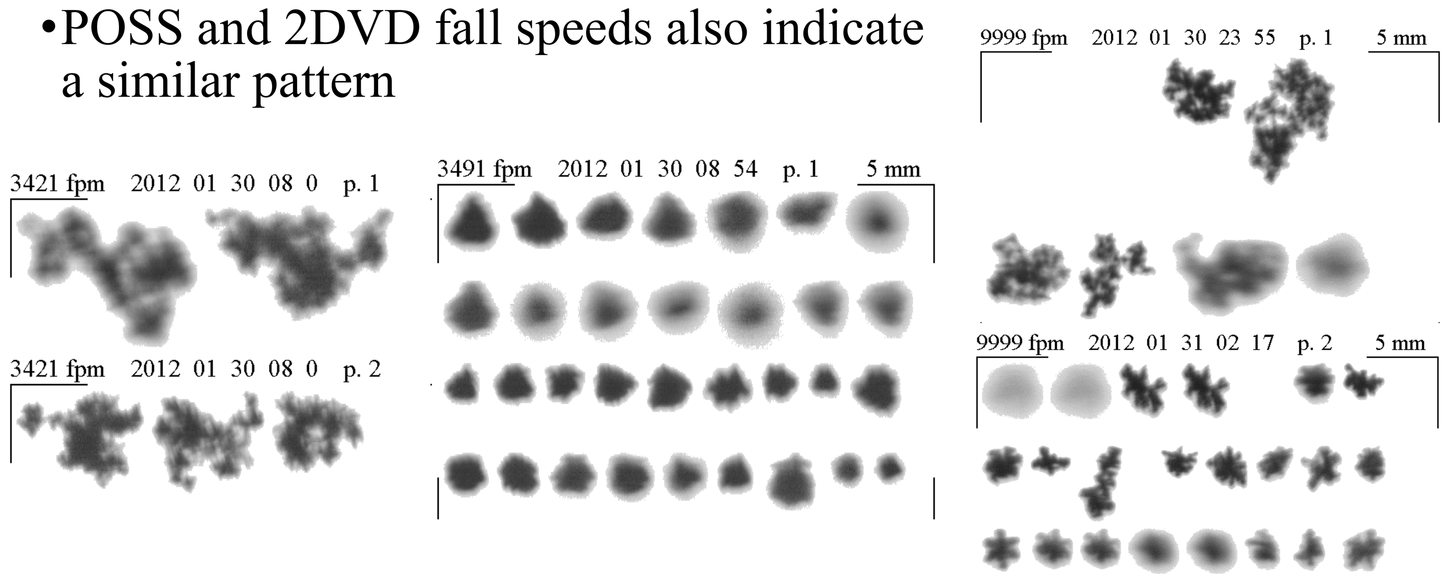
Synoptic Overview



- (left) Lake effect snow, *(right)* followed by shortwave trough
- Shallow, intense convective bands during lake effect event
- Synoptic snow from warm air advection and frontal overrunning
- Both events had high relative humidity with temperatures -10 to -15°C
- Efficient crystal growth and aggregation in both events, and riming in lake effect event only

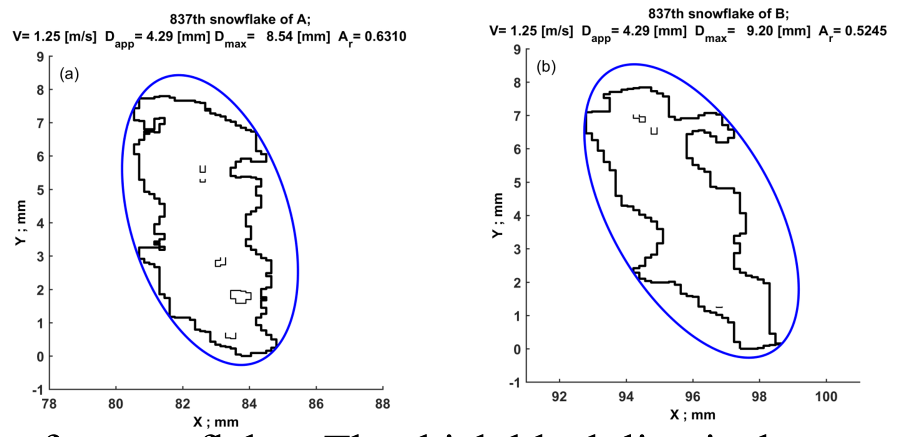
Snowflake Observations

- Surface images from PIP and U of Manitoba photographs indicate aggregate flakes with minimal riming for synoptic and alternating for lake effect
  - POSS and 2DVD fall speeds also indicate a similar pattern

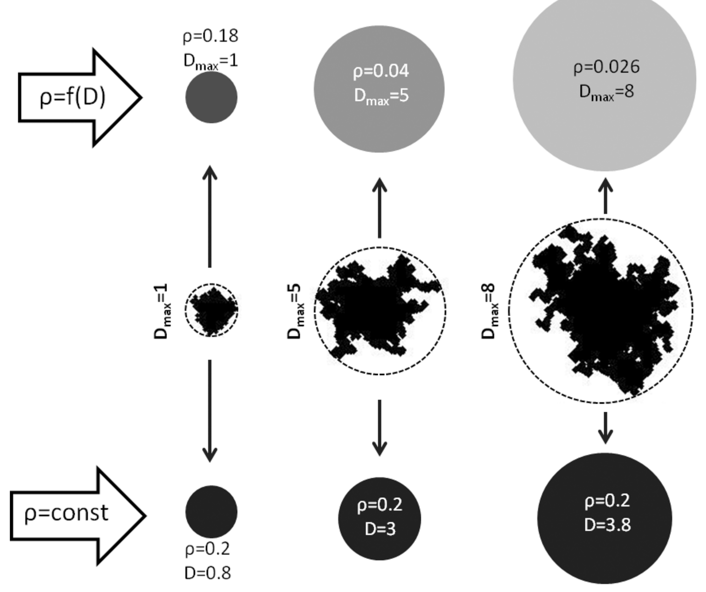


New SR(Z,DWR) Method

- Two snowflake mass estimation methods: **(1)** Böhm (1989) or **(2)** Heymsfield and Westbrook (2010)
- Particle fall speed : **(1)** Using Huang et al. (2015), or **(2)** from manufacturer (Joanneum Research)
- Particle cross sectional area: **(1)** single camera maximum dimension and total area, or **(2)** minimum circumscribed ellipse

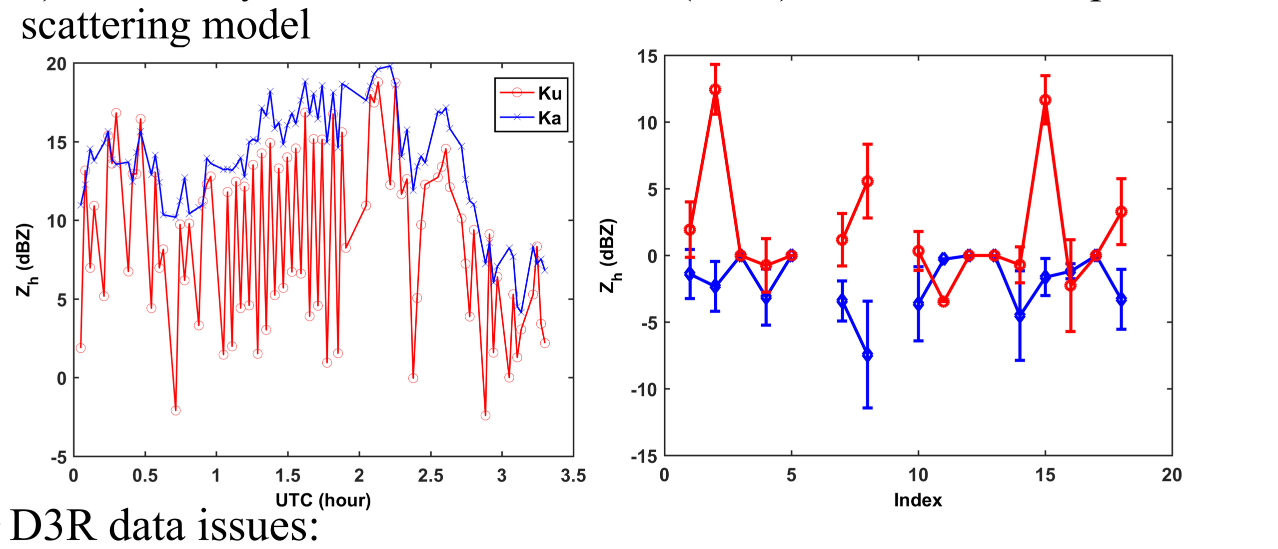


2DVD views of a snowflake. The thick black line is the outer contour and the thin black lines show interior holes. The effective area is the area enclosed by the thick black curve minus the area enclosed by thin lines. The blue line represents the minimum circumscribed ellipse



- Two scattering models: **(1)** T-matrix using soft spheroids with fixed axis ratios and quasi-random orientations; **(2)** Liao et al. (2013) (left) effective fixed density (0.2 g cm^{-3}) and oblate spheroids

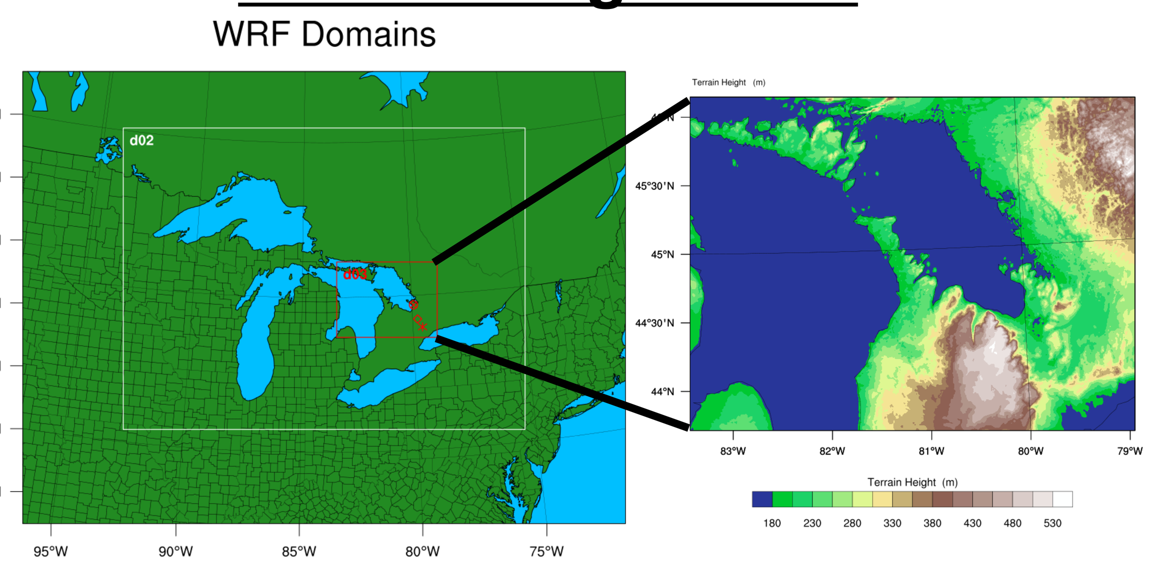
- Combine above choices into three SR(Z,DWR) approaches:
- 1) **HB** – Bohm (1989), Huang et al (2015) fall speed and scattering model
- 2) **LM** – Bohm (1989), Joanneum fall speed, Liao et al. (2013) scattering model
- 3) **HW** – Heymsfield and Westbrook (2010), Joanneum fall speed, Liao scattering model



- D3R data issues:
  - *(left panel)* **1)** Ku-band Z_h is less than Ka and **2)** Ku-band Z_h has systematic large bias at high scan angles
  - *(right panel)* Determine Ku/Ka Z_h offset for **(1)**, average over several scan angles just below bias point for **(2)**

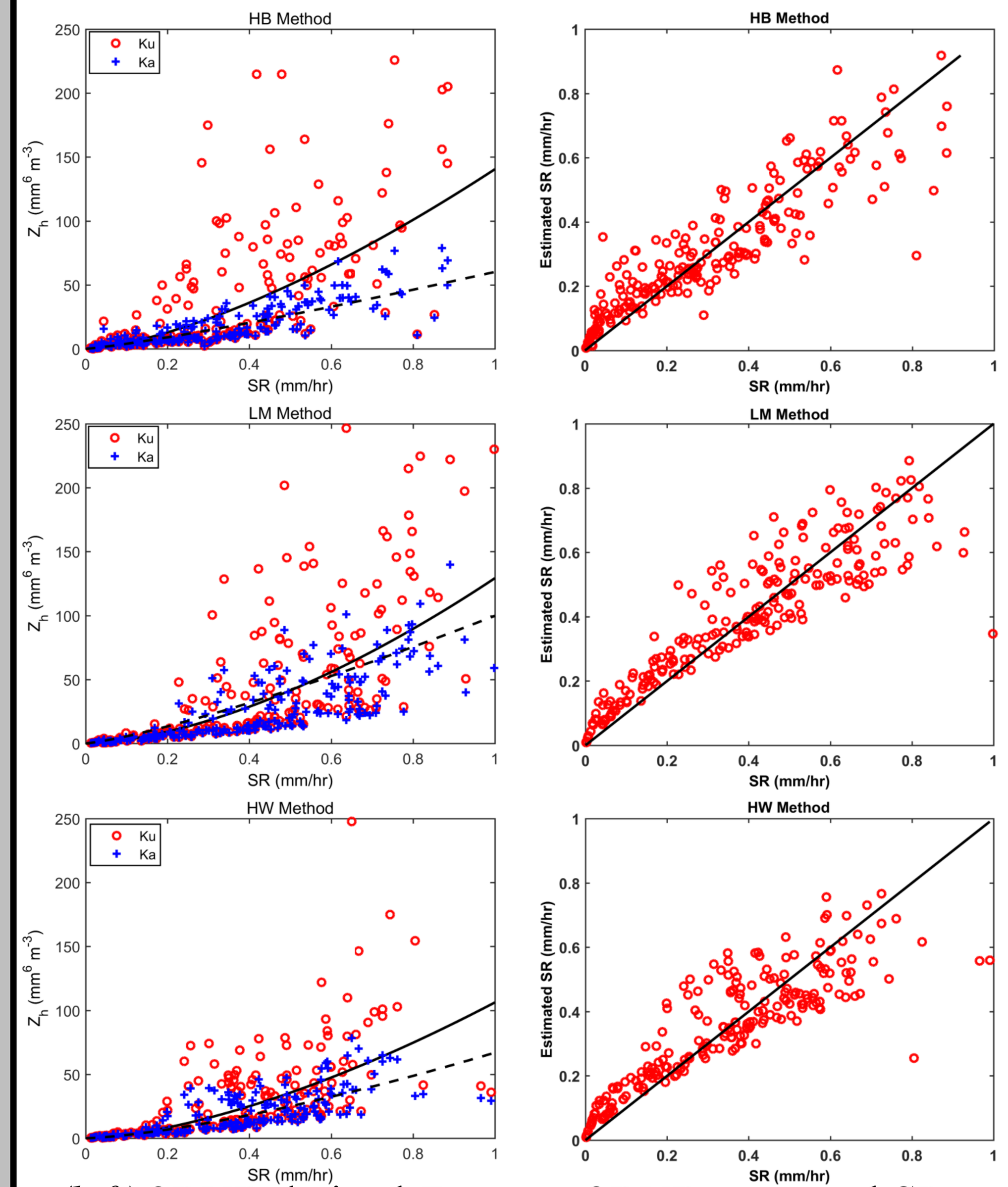
WRF Configuration

WRF Domains



- Nested configuration: 4.5, 1.5, 0.5 km
- 500 m domain - bin microphysics and 1-way nesting
- Using high-resolution NASA MUR SST product for lake temperature

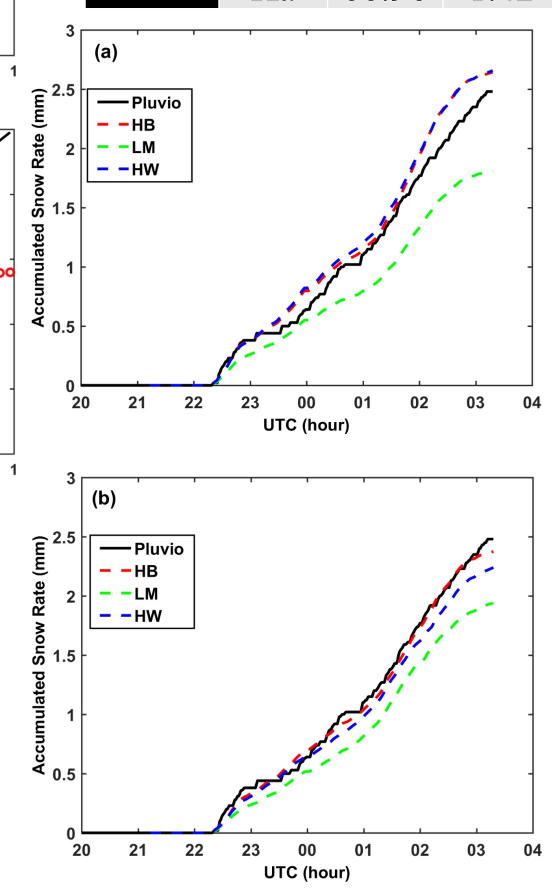
SR(Z,DWR) Results



- *(left)* 2DVD derived Z_h versus 2DVD measured *SR*, with *Z-SR* power-law fits, for Ku- and Ka-bands for **HB, LM**, and **HW**
  - Z_{Ku}-SR has much more scatter than Z_{Ka}-SR - **Use Z_{Ka}-SR for single band retrievals**
- *(right)* Estimated *SR* using Z_e and DWR of the 2DVD versus 2DVD *SR* for **HB, LM**, and **HW**
  - **LM** has smallest NSTD, all biased high when SR<0.2 mm – **No information in DWR for low SR & DWR ≈ 1**

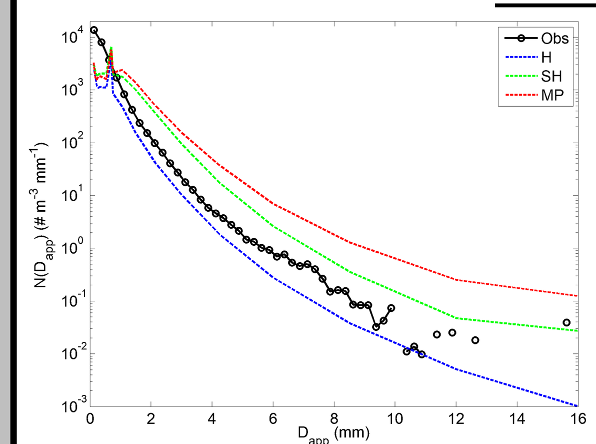
- Coefficients and exponents of the *Z-SR* relationship for **HB**, **LM**, and **HW** methods and Ku- and Ka-bands

Method	Band	a	b	STD (mm/hr)	NSTD (%)
HB	Ku	140.52	1.48	0.2156	70.99
	Ka	60.17	1.18	0.1366	44.97
LM	Ku	129.27	1.64	0.2235	55.89
	Ka	99.85	1.25	0.1614	**40.35**
HW	Ku	106.25	1.58	0.1889	55.30
	Ka	66.96	1.42	0.1473	43.11

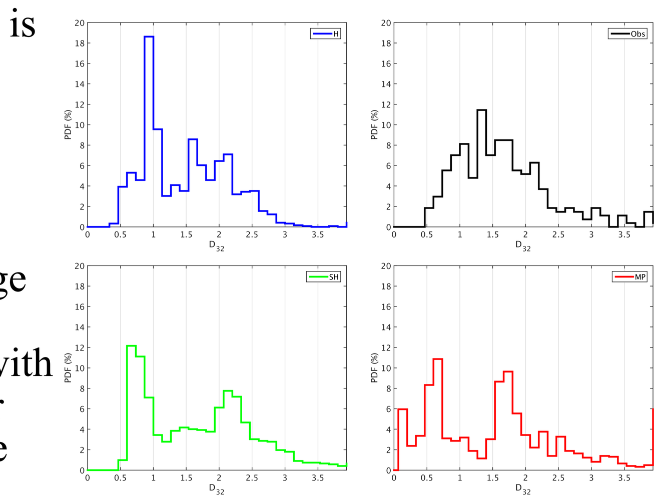


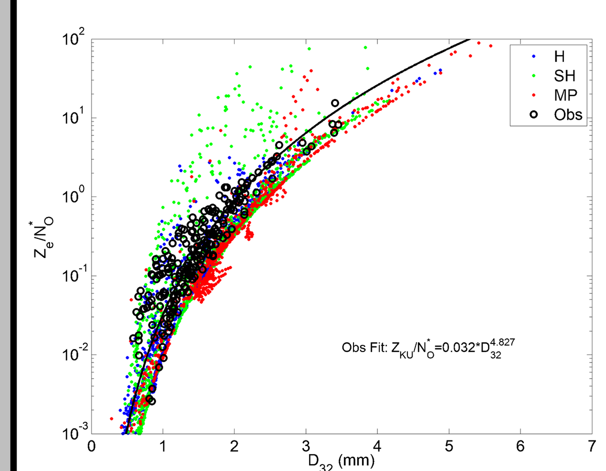
- *(top)* Radar *SR* using Z_{Ka}-*SR* only
- Overestimation by **HB** and **HW**, underestimation by **LM**
- *(bottom)* Radar SR using *SR(Z_{Ku}, DWR)* and Z_{Ka}-*SR* when DWR ≈ 1
- Performance improved for **HB** and **LM** methods when using DWR where appropriate; slight degradation for **HW**, **HB** is best in this case

WRF Bin Microphysics Results



- 2DVD storm averaged PSD (left) - Shape is non-exponential; gamma with negative μ
- Bin scheme reproduces PSD shape and number well for D>1mm
- 2DVD not accurate for smaller sizes
- Storm D_{32} histograms (left)
- Obs has peak frequency near 1.5 mm, large spectral width with tail of large D_{32}
- Model also has large spectral width, but with bimodal distribution - aggregates at larger D_{32}, graupel and/or ice at small D_{32}? Issue with species conversion?





- Scattering simulations of Z_e/N_0^* vs D_{32}, where observed Z_e is at Ku-band assuming oblate spheroid with an axis ratio=0.8. Model Z_e is based on Rayleigh scattering, spherical shape and fixed density
  - $N_0^* = (M_2)^4 / (M_3)^3 = (M_2) / (D_{32})^3$
  - Both observations and model data agree qualitatively with the theoretical relationship ($Z_e/N_0^* \sim D_{32}^5$)
- Agreement with obs is reasonable at the SH and MP locations for D_{32}<2mm. At larger D_{32}, Rayleigh Z_e from the model is larger than T-matrix at Ku-band
- Goal is to use dual-wavelength ratio from D3R radar (DWR=Z_{Ku}/Z_{Ka}) to estimate D_{32}, then use Z_{Ku} and D_{32} to estimate N_0^*

Conclusions

- Initial development of SR(Z,DWR) algorithm using GCPEx data (2DVD, D3R, Pluvio)
- **HB** method is least biased for DWR simulation and subsequent accumulation
- Discrepancies between modeled and observed data can be attributed to the fixed mass-size and terminal velocity relationships in the UPNB.
- Z_e/N_0^* vs. D_{32} appears not dependent on precipitation rate and is a good way to synthesize data

Next Steps

- Add cases from other field campaigns, e.g. ICE-POP
- Use the improved SR and accumulation data in model-observation comparisons
- Finalize UPNB modifications and re-run simulation to test for improvements

Acknowledgments

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