Estimating the Concentration of Large Raindrops from Polarimetric Radar and Disdrometer Observations

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Our D_{max} problem

- In radar meteorology, we wish to estimate various (n) moments (p_n) of the rain drop size distribution (DSD), N(D)

$$p_n = \int_0^{D_{\max}} D^n N(D) dD$$

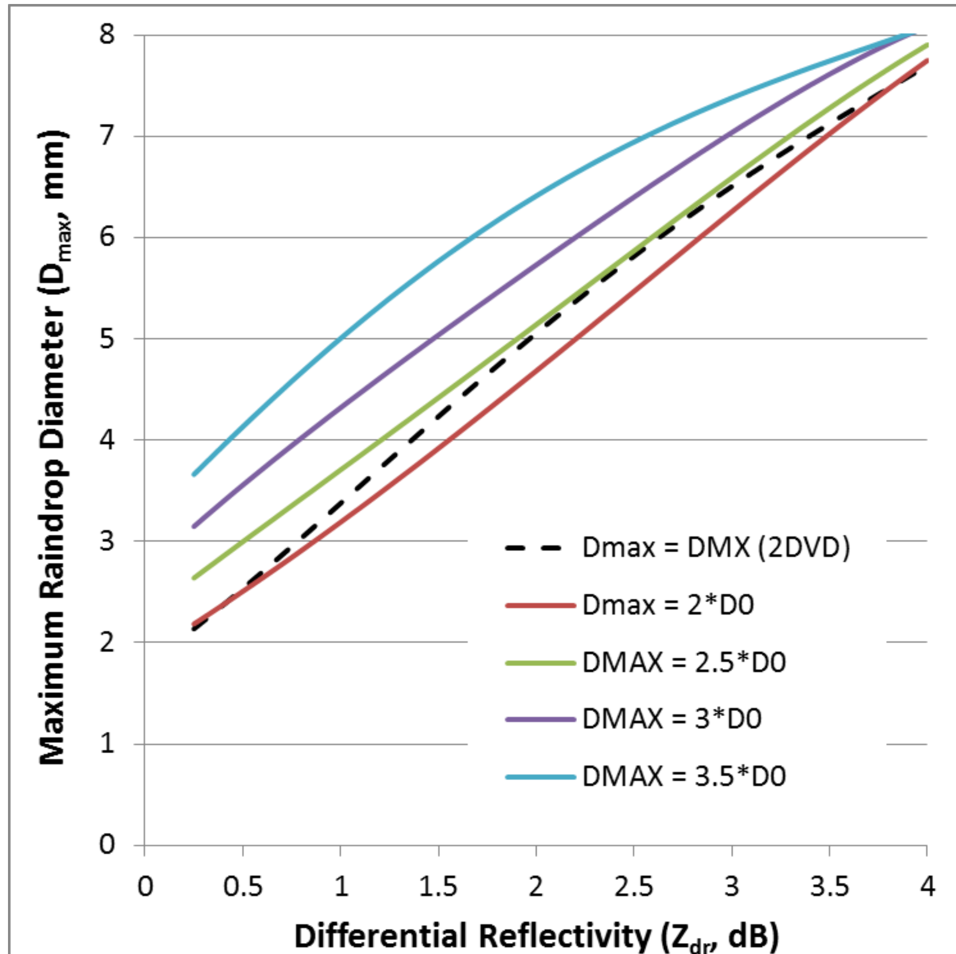
n^{th} moment of the DSD

  - D = drop diameter; **D_{max} = maximum drop diameter**
  - E.g., p_6 = Z, Rayleigh Reflectivity (6^{th} moment of the DSD)
- Disdrometers are used to measure N(D), calculate various moments of DSD and make relations between them (E.g. Z-R relations, R: rainfall rate)
- Past studies have shown p_n is sensitive to choice of D_{max} (~ 10% bias error not uncommon) (Ulbrich and Atlas 1984; Ulbrich 1985; Ulbrich 1992)
- At resonant frequencies (e.g., C-band), D_{max} effect is greatly exacerbated
- D_{max} sampling issues documented in disdrometers (Ulbrich 1992; Smith et al. 1993)
- **D_{max} is under-constrained; a "tunable parameter" in our radar methods**
  - **Observed D_{max} (DMX); constant (D_{max} = 5-8 mm); Dmax=X*D0 where D0 is the median volume diameter and X=2.0 – 3.5**

D_{max} from radar?

- How can we constrain D_{max}?
- Radar has large samples…
- Can we use polarimetric radar observations of horizontal reflectivity (Z_h) or differential reflectivity (Z_{dr}) to estimate D_{max}?
- $D_{max}=F(Z_h)$, $D_{max}=F(Z_{dr})$
  - E.g., 4th order polynomial (Brandes et al. 2003)
- RMSE: 0.6 to 0.8 mm
- **Very large potential bias error associated with D_{max} assumption**
- Brandes et al. (2003) used an arbitrary "D′ adjustment" to account for likely 2DVD large drop under-sample

D_{max} at S-band



Large Drop Concentration

- **Can we estimate the concentration of large rain drops using 2DVD and radar?**
  - If yes, could help assess 2DVD large drop sampling issues
  - Then, radar and networks of disdrometers combined might constrain D_{max}
- What do we mean by "large" rain drop? How about D > 5 mm ?
  - Also, where strong resonance starts at C-band

Large Drop Concentration (D > 5 mm)

$$NT5(D) = \int_{5mm}^{D_{max}} N(D)dD \quad [m^{-3}] \quad [1]$$

- Estimate NT5 directly from 2DVD observations of drop size distribution, N(D)
  - Strict N(D) bin count; Gamma model fit to N(D)
- How well do 2DVD disdrometers estimate NT5?
- Can we check with polarimetric radar?

NASA Two-dimensional Video Disdrometer (2DVD)

Empirical Estimate of NT5 from Polarimetric Radar

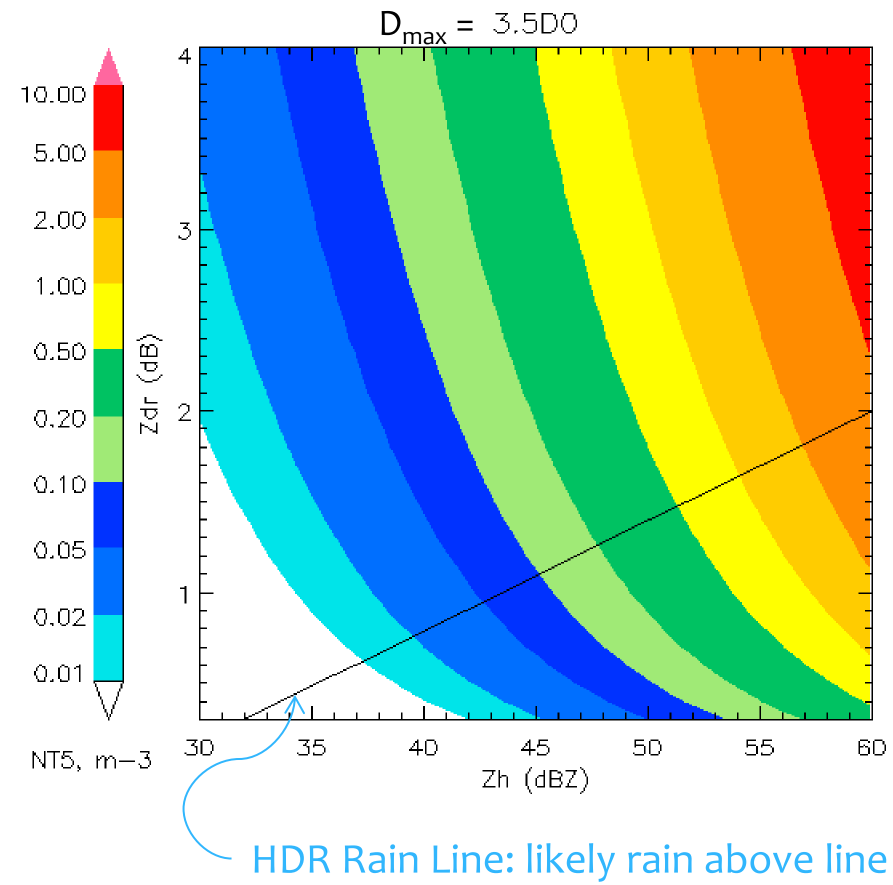
$NT5(z_h, Z_{dr}) = A * (z_h)^b * (Z_{dr})^c$ $[m^{-3}]$ [2]

- z_h: $mm^6\ m^{-3}$, Z_{dr}: dB

- Large (N=7678) training dataset of 2DVD disdrometer observations
- Truncated Method of Moments (TMoM) used to fit 1-minute N(D) observations to Gamma DSD model
- Gamma DSD fits and T-matrix model used to calculate NT5, Z_h, Z_{dr}
- Non-linear least square regression to derive power law relations $NT5(z_h, Z_{dr})$
- **Obvious question: What is sensitivity to D_{max} assumption?**
- **Vary D_{max} = Actual 2DVD (DMX), 2*D0, 2.5*D0, 3*D0, 3.5*D0**

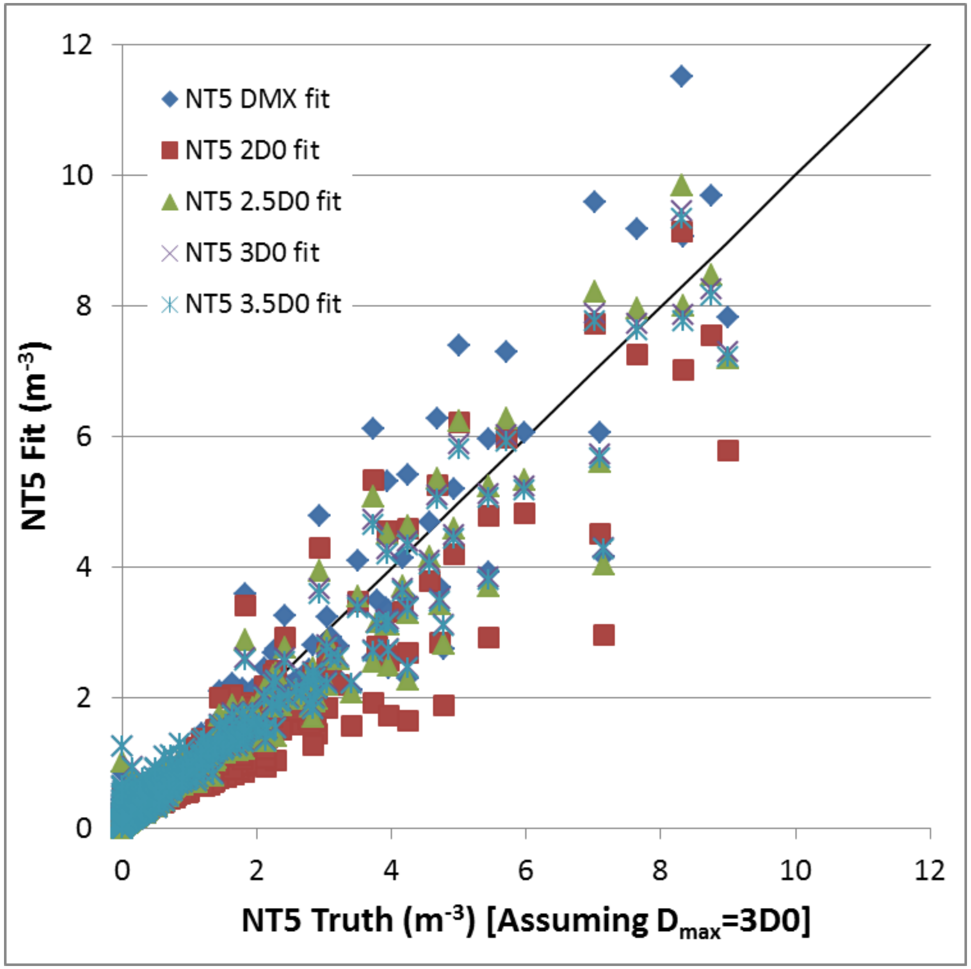
$NT5(z_h, Z_{dr})$ at S-band

Sensitivity to D_{max}



NT5 sensitivity to D_{max}

- Postulate a truth for D_{max} (e.g., 3*Do)
- Calculate true NT5 from Gamma fit N(D) assuming D_{max}=3*Do using [1]
- Use T-matrix to calculate (Z_h,Z_{dr}) from Gamma fit N(D) for varying D_{max} assumptions
- Use power-law fit equations, [2], to estimate NT5(z_h,Z_{dr}) for varying D_{max} assumptions
- Compare NT5 truth to empirical fit estimates
- **NT5(z_h,Z_{dr}) relatively insensitive to D_{max}; less bias error**
- RMSE = 0.30 – 0.36 m^{-3}



S-band

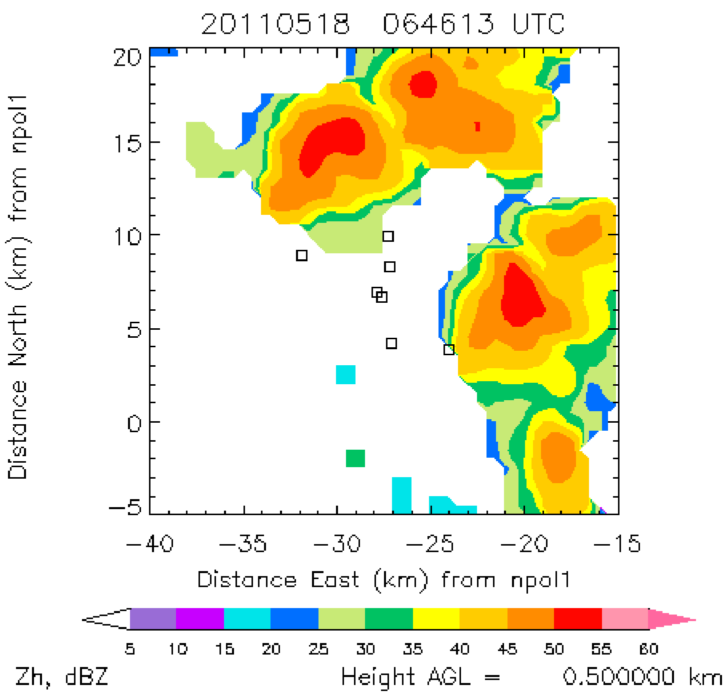
S-band Example

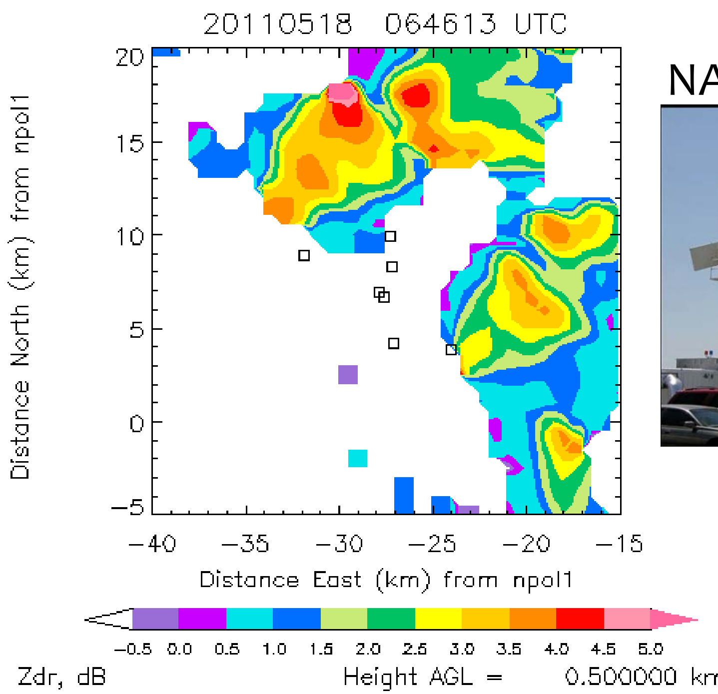
Height = 0.5 km

NPOL Z_h

□ 2DVD

NPOL Z_{dr}





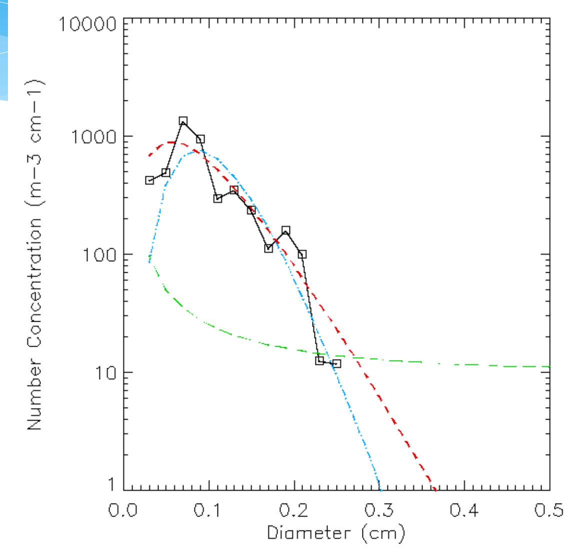
NASA NPOL

MC3E

May 18, 2011: 0632- 0646 UTC (≈ 40 second PPI update rate)

Oklahoma during the Midlatitude Continental Convective Clouds Experiment (MC3E)

SN38: 0646 – 0647 UTC

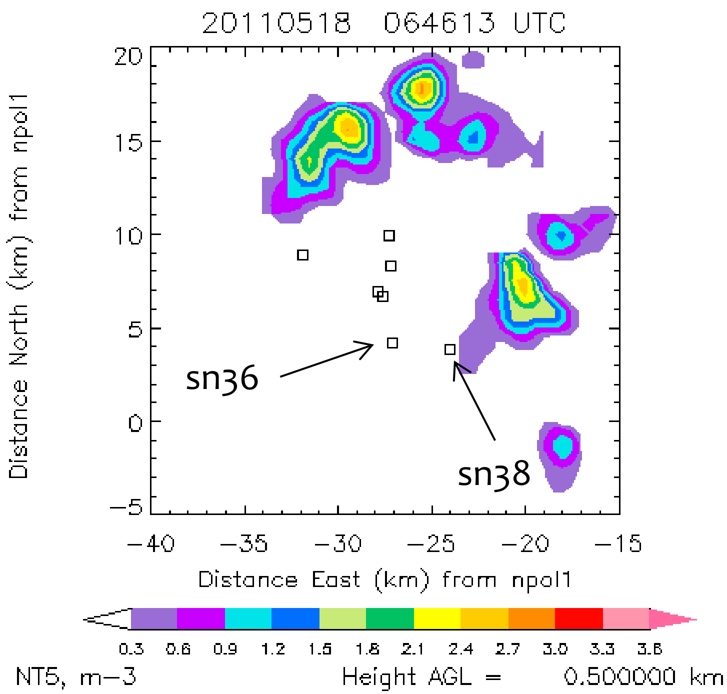


NPOL

NT5=A*(z$_h$)^b*(Z$_{dr}$)^c

(D$_{max}$ = 2DVD DMX)

Height = 0.5 km



SN38 BIN DATA

R = 1.2 mm h^{-1}

TND = 151 drops

Z = 27.6 dBZ

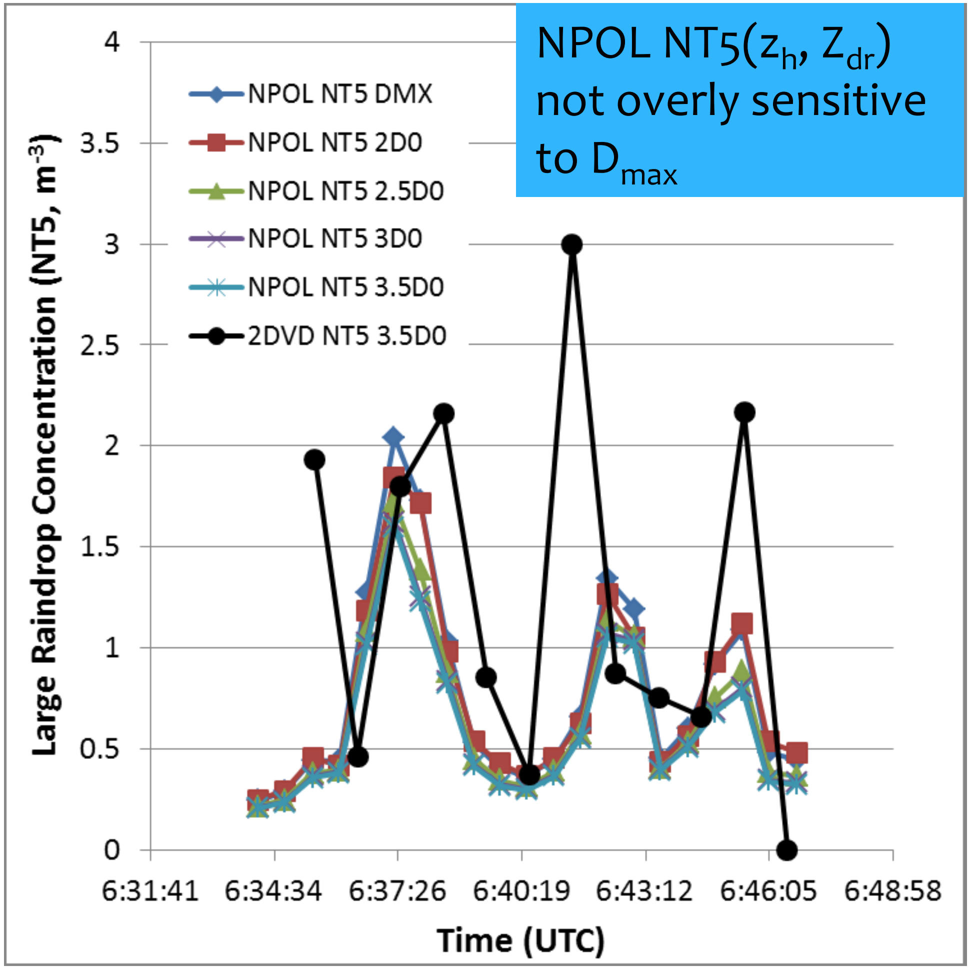
M = 0.06 g m^{-3}

D$_m$ = 1.5 mm

D$_{max}$ = 2.5 mm

NT5 = 0.0 m^{-3}

NT5 at SN38
NPOL vs. SN38 2DVD



NPOL NT5(z_h, Z_{dr}) not overly sensitive to D_{max}

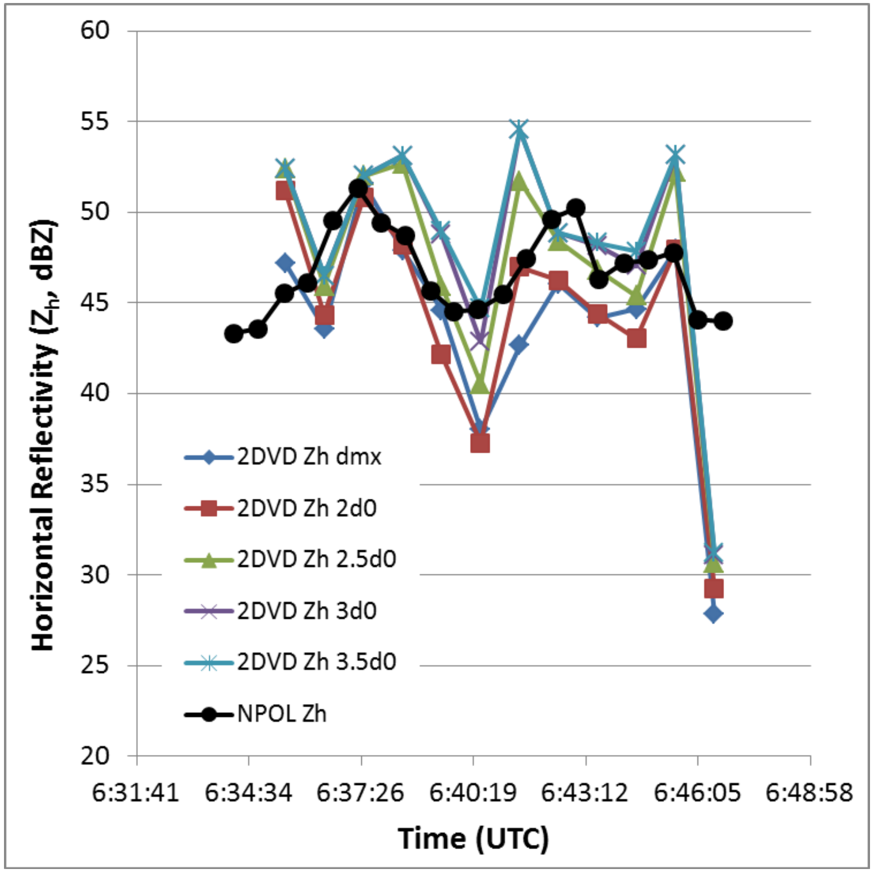
SN36+SN38 Mean/Median NT5

Dmax Assumption	2DVD Eqn. [1]	NPOL Eqn. [2]
Actual 2DVD (DMX)	0.42 / 0.27	0.73 / 0.52
2*D0	0.56 / 0.45	0.71 / 0.54
2.5*D0	0.97 / 0.72	0.62 / 0.45
3*D0	1.10 / 0.86	0.58 / 0.42
3.5*D0	1.11 / 0.87	0.57 / 0.42

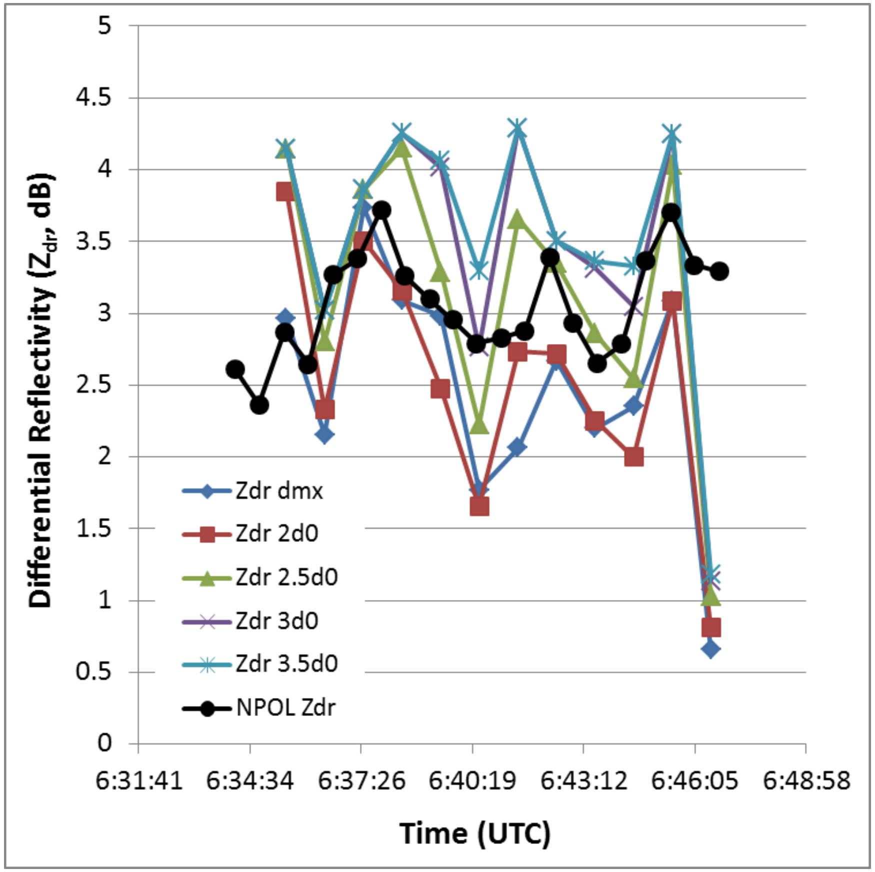
D_{max} = 2*D0 provides better consistency between NPOL + 2DVD NT5

D_{max} impact on Z_h, Z_{dr}

Z_h at SN38
NPOL vs. SN38 2DVD

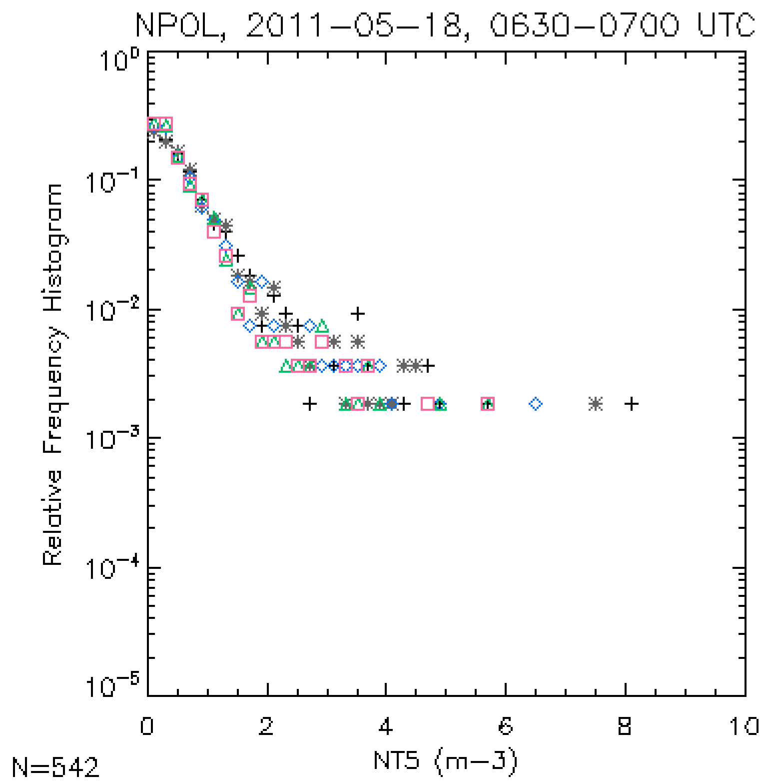


Z_{dr} at SN38
NPOL vs. SN38 2DVD

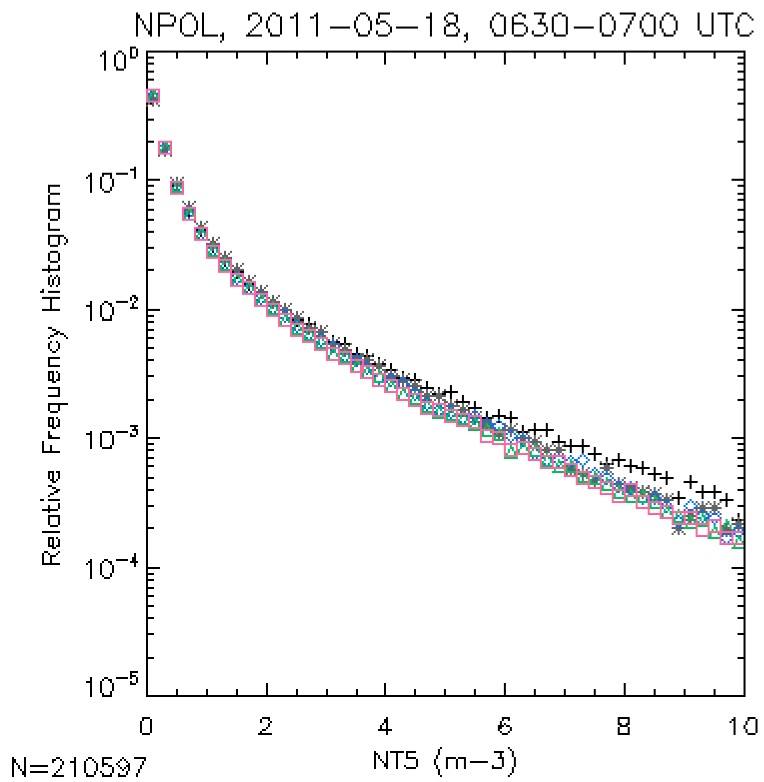


Statistical Characterization of Radar NT5(z_h, Z_{dr})

NPOL GATES OVER 2DVD



ALL NPOL GATES



Different colors = Eqn. [2] with different D_{max} assumption. With large sample (right), little sensitivity of NPOL NT5(z_h,Z_{dr}) relative frequency histogram to D_{max}.

Summary

- D_{max} is difficult to observe with disdrometer or radar
- Large raindrop concentration (NT5) [D > 5 mm] is a little easier
- Radar NT5(z_h, Z_{dr}) shows limited sensitivity to D_{max} assumptions
- Analyzed 1 MC3E OK case at S-band with large drops from melting hail (*Poster 175, Gatlin et al., large sample 2DVD study*)
- Smaller D_{max} assumptions (e.g., 2*D0) provided better consistency between 2DVD and NPOL estimates of NT5
- **Next steps.** More, varied cases. Statistical comparison between 2DVD and radar NT5.
- **Future considerations.** Sensitivity to Gamma model. Optimal 2DVD integration period. Feasibility at C-band. NT5(K_{dp}, Z_{dr}).