A Specific Attenuation Based Radar QPE for Operations

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Precipitation and Flash Flood Prediction from Minutes to Days
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Background

- US weather radar network was upgraded with polarimetric capabilities during 2010-2013
- How should this upgrade improve operational radar QPE?
- Several polarimetric radar QPE techniques were evaluated (2012-2014)
- A specific attenuation (A) based synthetic QPE was developed (2015-2017).
- Extensive evaluations and refinements were performed in a pseudo operational environment across the continental US (2017-2019)
- Transitioning into operations Oct. 2020
- Advantages and challenges are documented

R(A) Methodology

At S-band: $R = 4120A^{1.03}$

A: specific attenuation

$$A(r) = \frac{Z_a^b(r)C(b,PIA)}{I(r_1,r_2) + C(b,PIA)I(r,r_2)}$$

Z_a: attenuated reflectivity

r_1 & r_2: beginning and ending ranges of rain segments in a given radial

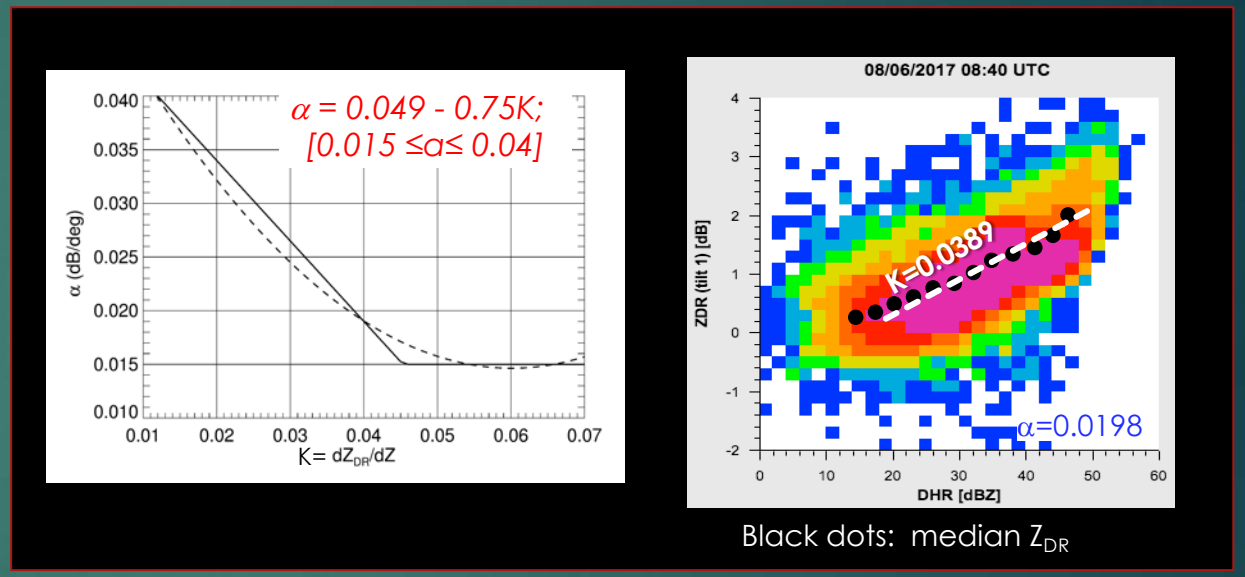
$$I(r_1,r_2) = 0.46b\int_{r_1}^{r_2} Z_a^b(s)ds$$

$$I(r,r_2) = 0.46b\int_{r}^{r_2} Z_a^b(s)ds$$

$$C(b,PIA) = \exp(0.23bPIA) - 1$$

$$PIA(r_1,r_2) = \alpha\left[\phi_{DP}(r_2) - \phi_{DP}(r_1)\right]$$

b: ≈ 0.62



Wang et al. 2019: A Prototype Quantitative Precipitation Estimation Algorithm for Operational S-Band Polarimetric Radar Utilizing Specific Attenuation and Specific Differential Phase. Part I: Algorithm Description. *J. Hydromet.* **20**, 985-997.

Estimating α using Z_{DR}-slope minimizes R(A)'s sensitivity to Z_{DR} biases.

Ryzhkov et al. 2014: Potential utilization of specific attenuation for rainfall estimation, mitigation of partial beam blockage, and radar networking. *JTECH*, **31**, 599-619.

How is R(A) applied in operations?

Inputs: Z, Z_{DR}, ρ_{HV}, Φ_{DP}, environmental data

Dual-pol radar Quality Control

Φ_{DP} processing

A & K_{DP} estimation (below the ML)

$R(A)$:	$Z \leq 45$dBZ
$R(A)$&$R(K_{DP})$:	$45 < Z < 50$dBZ
$R(K_{DP})$:	$Z \geq 50$dBZ

$R(A) = 4120\ A^{1.03}$

$R_1(K_{DP}) = 29\,|K_{DP}^{0.77}|$; $\rho_{HV} < 0.97$

$R_2(K_{DP}) = 44\,|K_{DP}^{0.822}|$; $\rho_{HV} \geq 0.97$

Single radar processes

Multi-radar processes

Multiple $R(Z)$ with VPR correction ("Q3RAD")

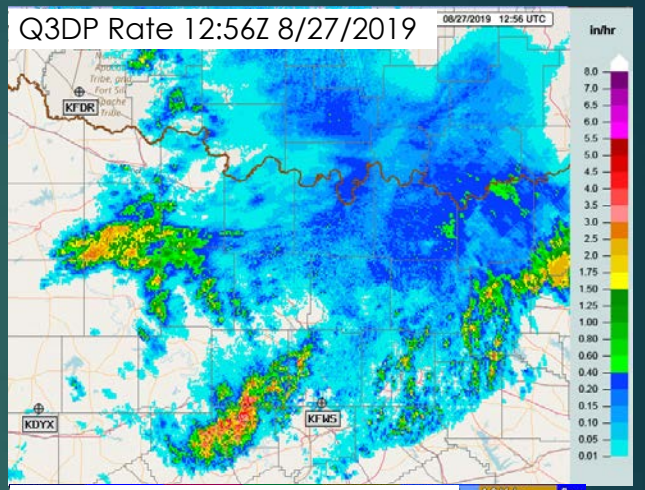
Stratiform: $R_{stra} = \max(0.0365\ Z^{0.625}, 0.1155\ Z^{0.5})$

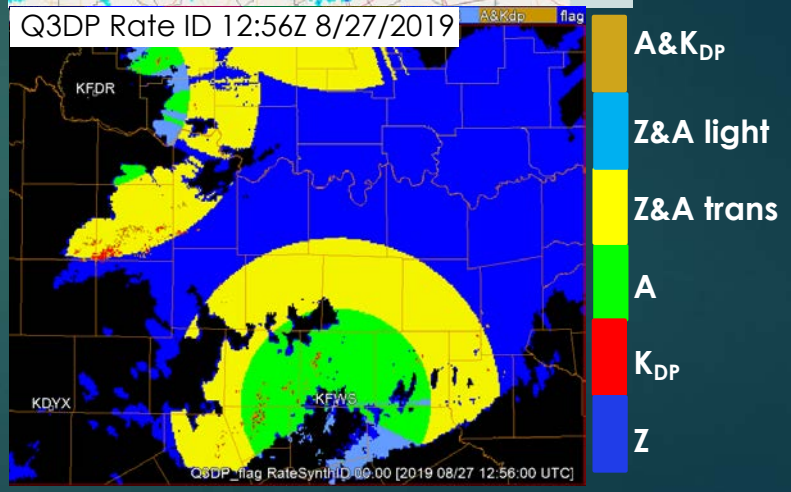
Convective: $R_{conv} = 0.017\ Z^{0.714}$

Tropical: $R_{trop} = \beta\ 0.010\ Z^{0.833}$; $\beta = 1.0 \sim 1.5$

$R(A,K_{DP})$ Mosaic (below the ML)

$R(A, K_{DP}, Z)$ Synthetic ("Q3DP")





ML: Melting Layer

VPR: vertical profile of reflectivity

Zhang et al. 2020: A dual-polarization radar synthetic QPE for operations. *J. Hydromet*. https://doi.org/10.1175/JHM-D-19-0194.1.

Evaluation: 1 year categorical hit/miss

CONUS, May 2017 – Apr 2018. QPE/gauge pairs: ~122K

	Gauge	VL	L	M	H	E
Multi-R(Z) based	VL	0.804	0.134	0.002	0	0
	L	0.194	0.790	0.353	0.017	0.004
	M	0.002	0.076	0.628	0.592	0.142
	H	0	0	0.015	0.324	0.344
	E	0	0	0.002	0.067	0.510
R(A) based	VL	0.849	0.156	0.009	0	0
	L	0.149	0.752	0.286	0.010	0.002
	M	0.002	0.092	0.671	0.369	0.039
	H	0	0	0.031	0.488	0.208
	E	0	0	0.002	0.133	0.751

24hr Accumulation Categories:

*Very Light.(**VL**):* $G < 12.7$mm
*Light (**L**):* $12.7 \le G < 38.1$mm
*Moderate (**M**):* $38.1 \le G < 101.6$mm
*Heavy (**H**):* $101.6 \le G < 152.4$mm
*Extreme (**E**):* $G \ge 152.4$mm

A large scale analysis indicated significant improvement of R(A) over R(Z), especially for warm season heavy rainfall. This has important implications for flash flood warnings.

Detailed analysis event-by-event was done to understand R(A) performance on local scales.

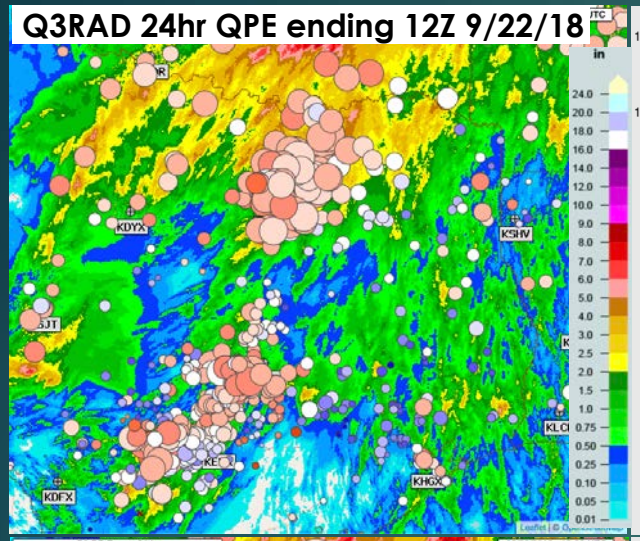
A few examples follow…

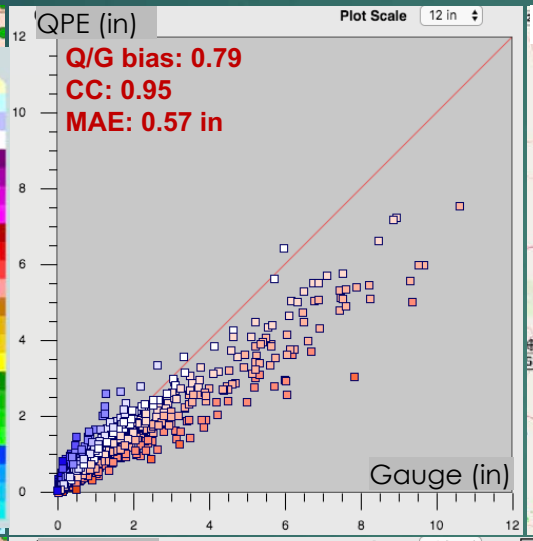
Statistic scores are based on 24hr QPE vs. manual gauges:

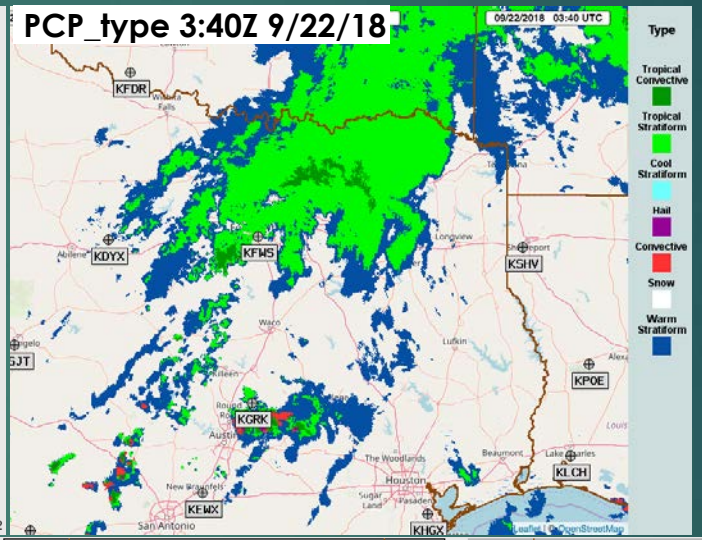
- Q/G bias = (QPE mean)/(Gauge mean)
- CC: correlation coefficient
- MAE: mean absolute error

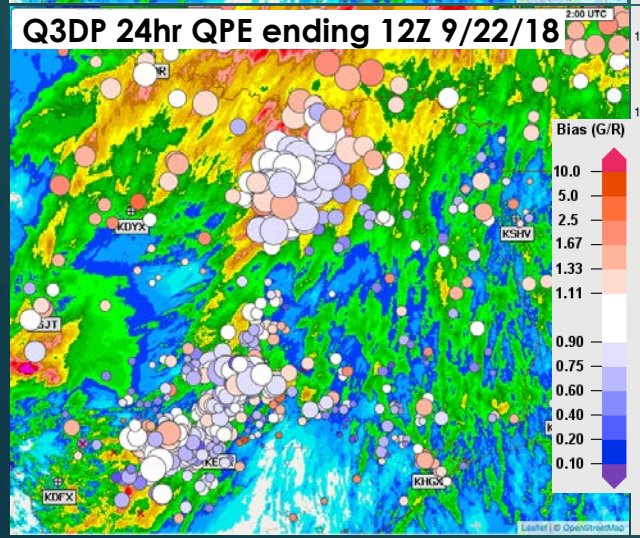
R(A) performance in heavy warm rain

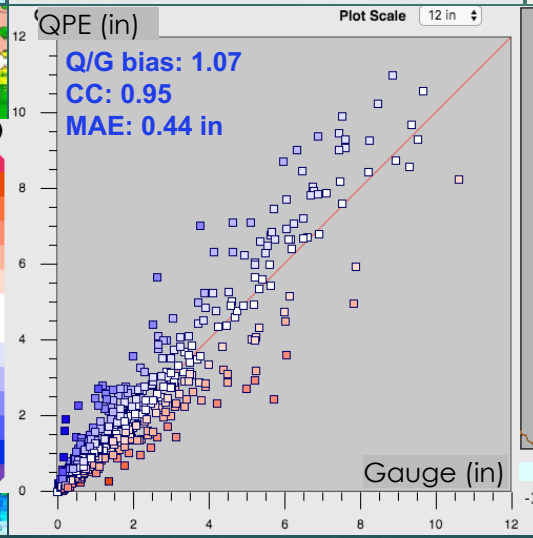
R(A) had less bias and random errors than R(Z) in heavy warm rain.

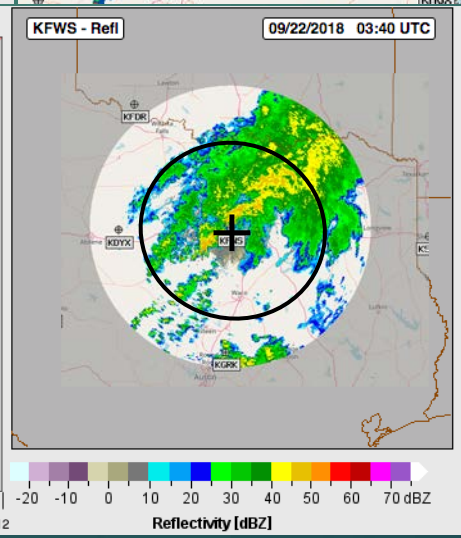


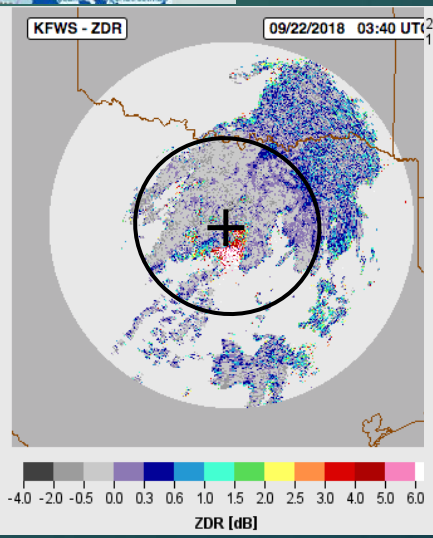


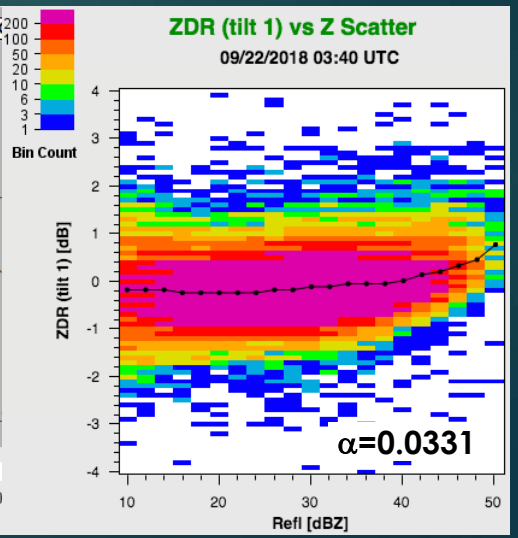












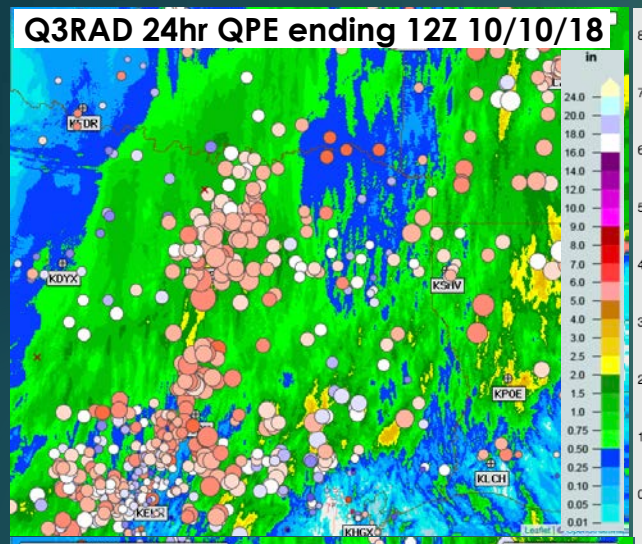
Enhanced ($\beta \approx 1.25$) tropical R(Z) underestimated heavy rain above 2 in and resulted in a **21%** underestimation overall.

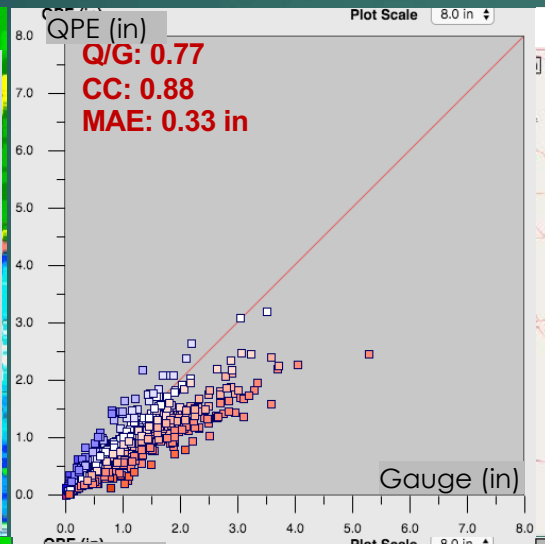
R(A) QPE eliminated the dry bias and reduced the MAE by **30%**.

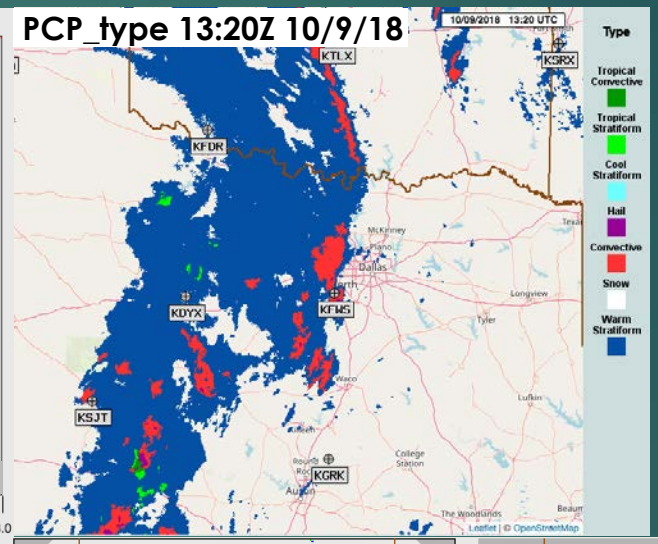
α ranged from **0.022 to 0.034** indicating a mixed to tropical rain.

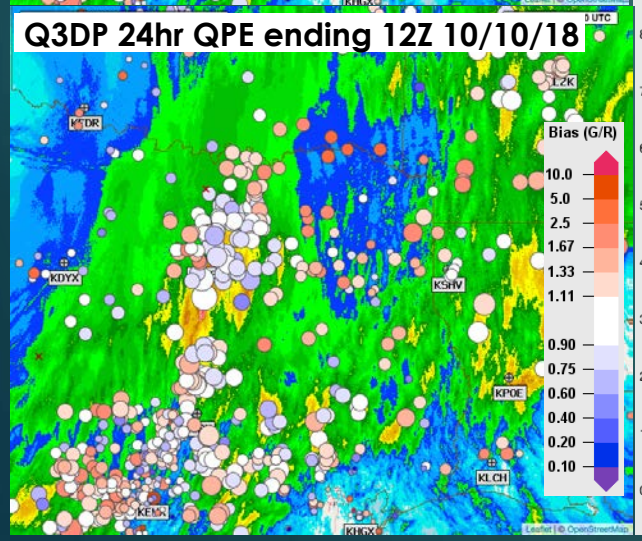
R(A) performance in convective rain

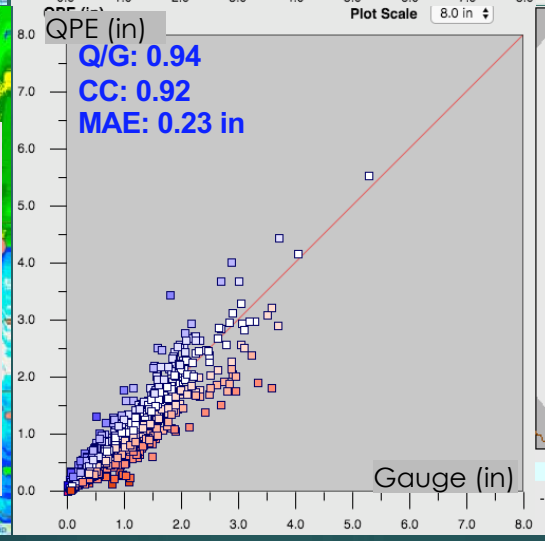
R(A) had less bias and random errors than R(Z) in strong convective rain.

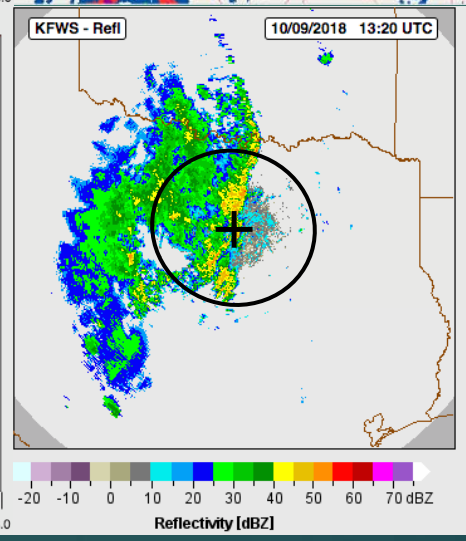


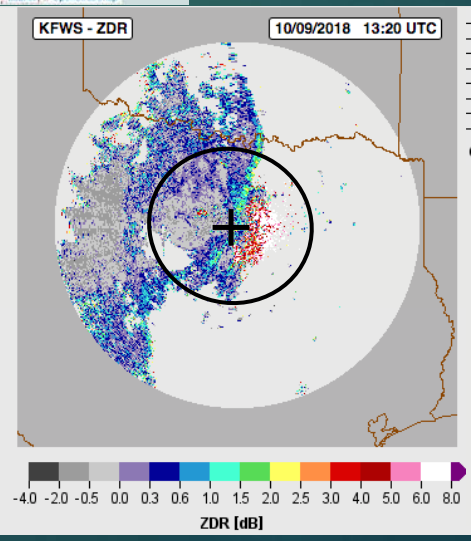


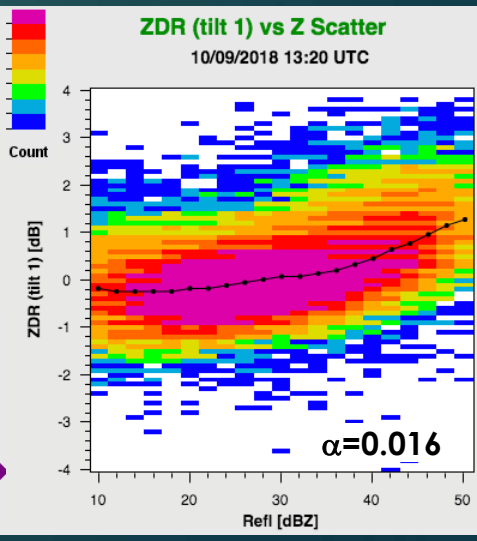












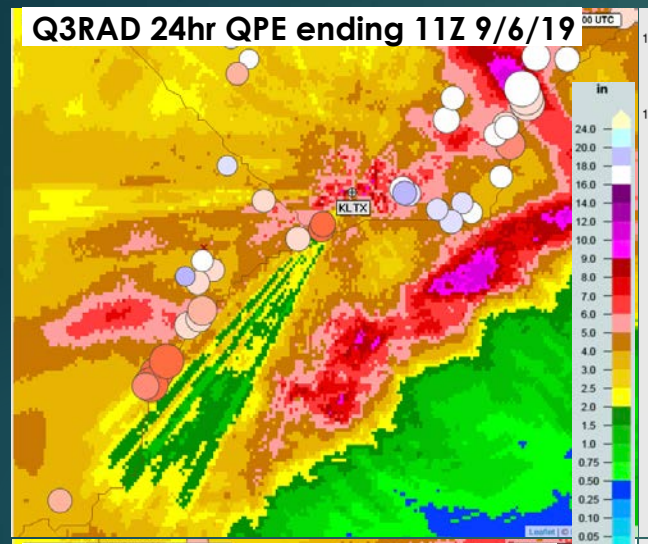
Convective/stratiform R(Z) resulted in a **23%** underestimation overall.

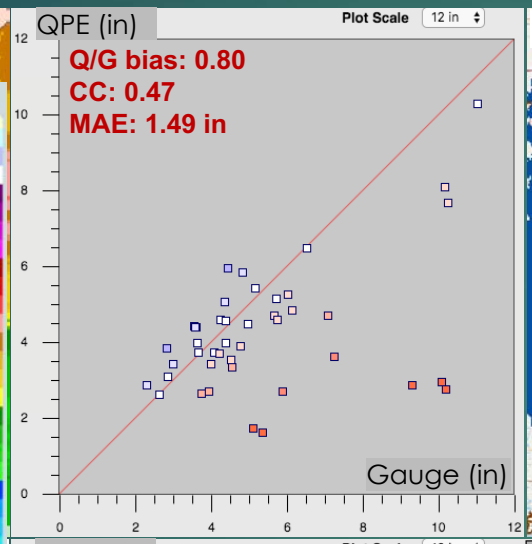
R(A) QPE reduced the bias by **17%** and reduced the MAE by **30%**.

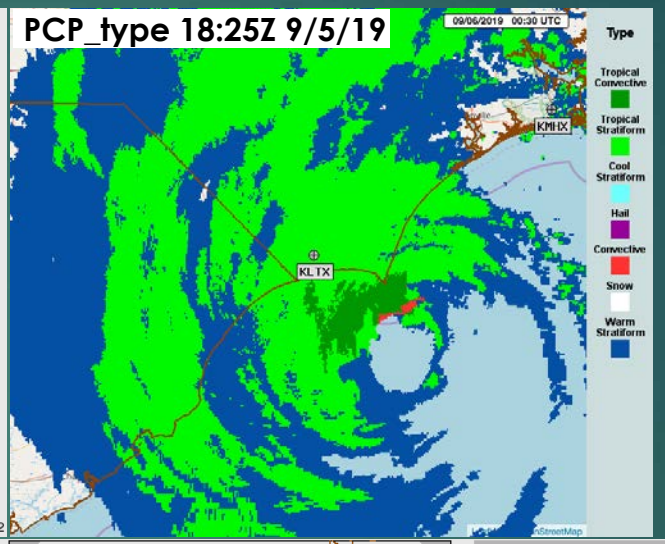
α ranged from **0.016 to 0.031** indicating convective to mixed rain regimes.

R(A) performance in partial blockage

R(A) is insensitive to partial beam blockage. The Z_{DR}-slope is insensitive to small areas of "bad" Z and Z_{DR} data.





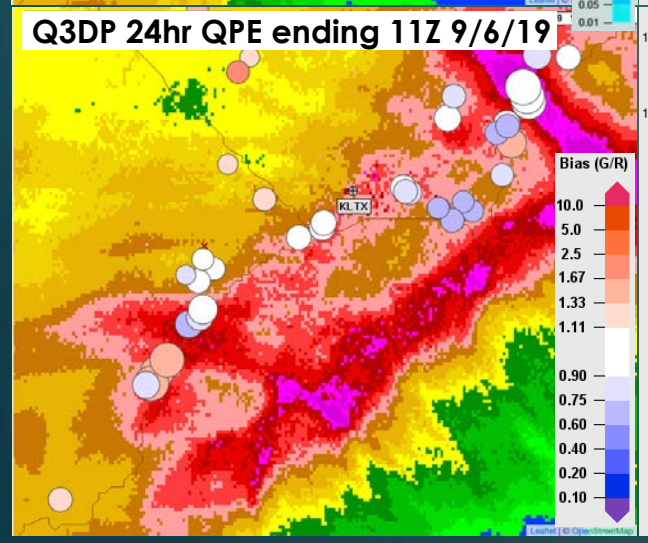


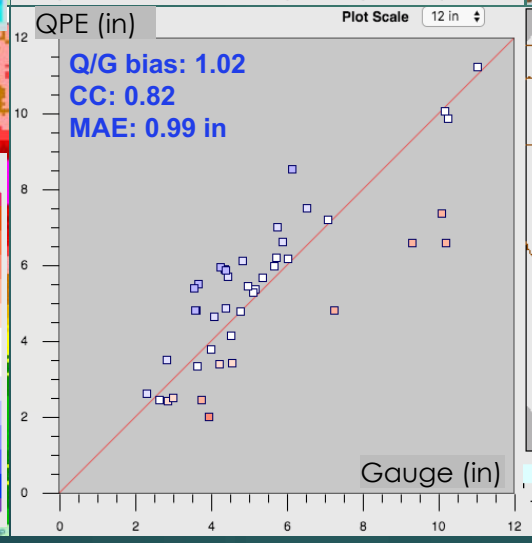
Enhanced ($\beta \approx 1.5$) tropical R(Z) captured the heavy rainfall well but some tree blockage caused a significant underest.

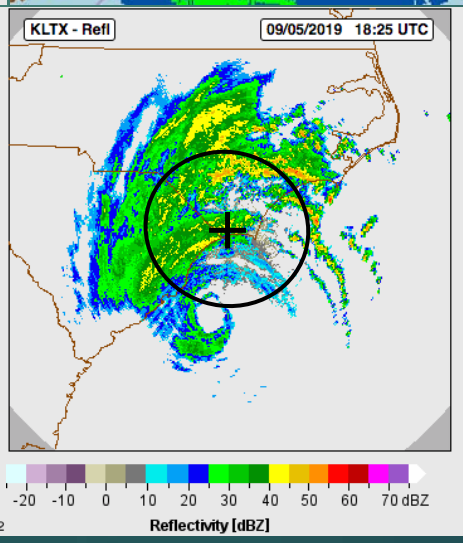
R(A) reduced bias by **20%** and MAE by **33%**.

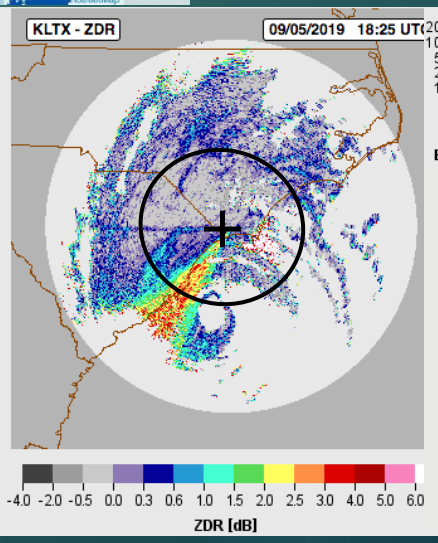
α ranged from 0.024 to 0.037 indicating a super tropical rain.

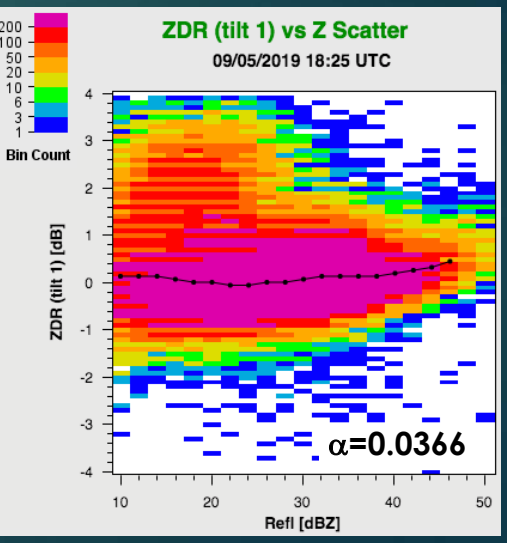
The use of Z_{DR} slope reduced impact of "bad" Z_{DR} data in tree blockage areas.





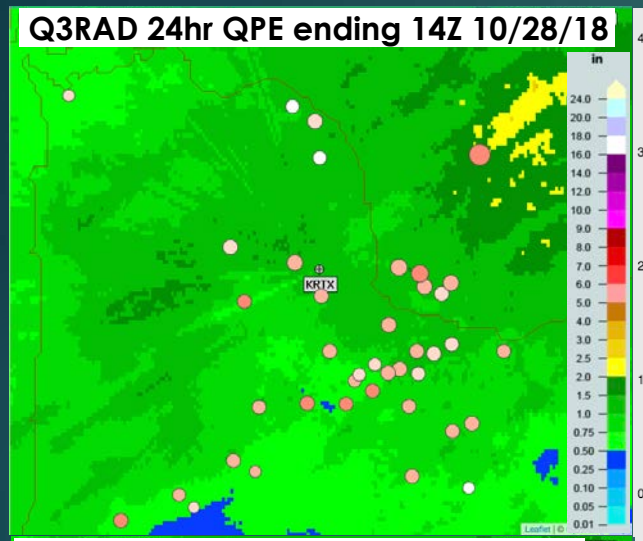


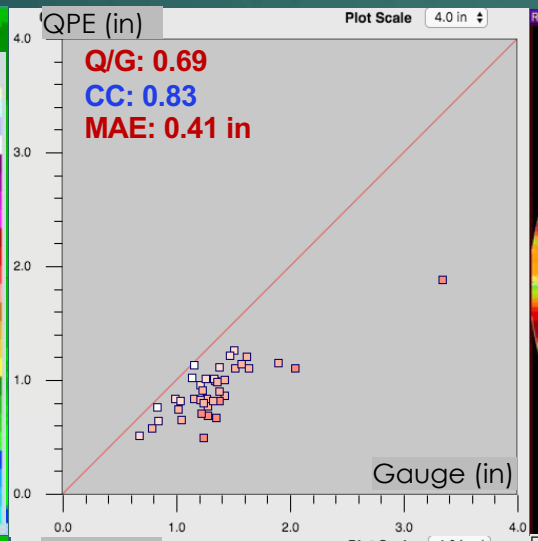


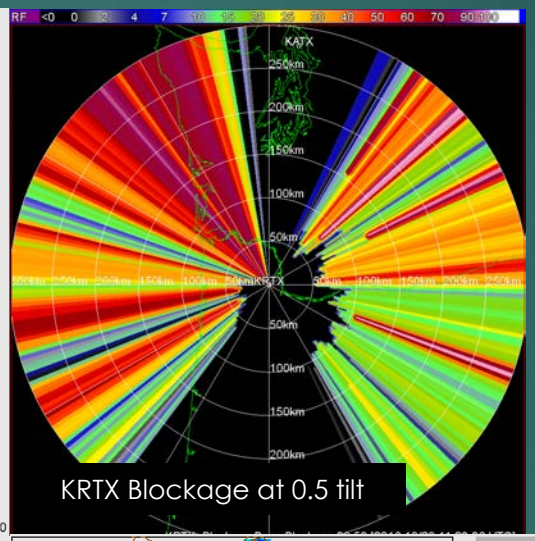


R(A) performance in severe blockage

R(A) had less bias and random errors than R(Z) in severe blockage areas.





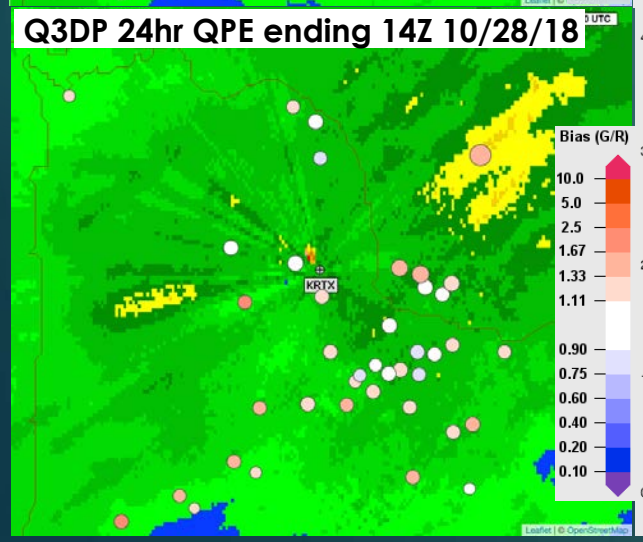


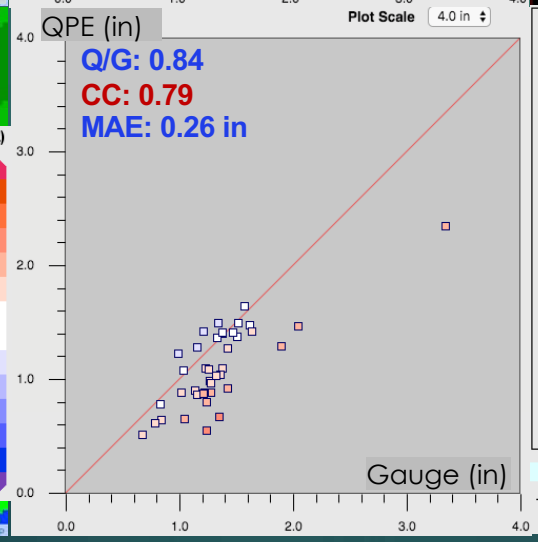
Stratiform R(Z) underestimated rainfall by **31%**. Hybrid scan and azimuthal smoothing were applied in R(Z).

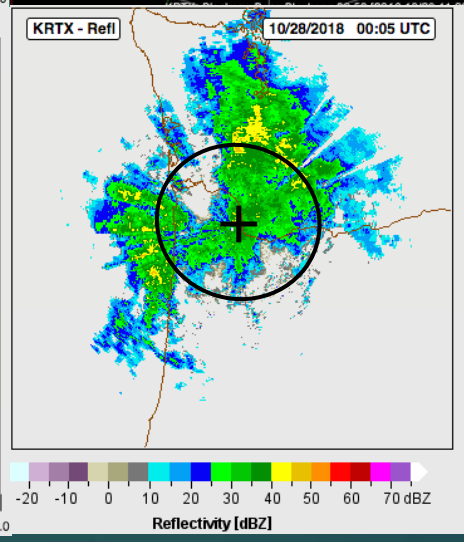
R(A) reduced bias by **15%** and MAE by **36%**.

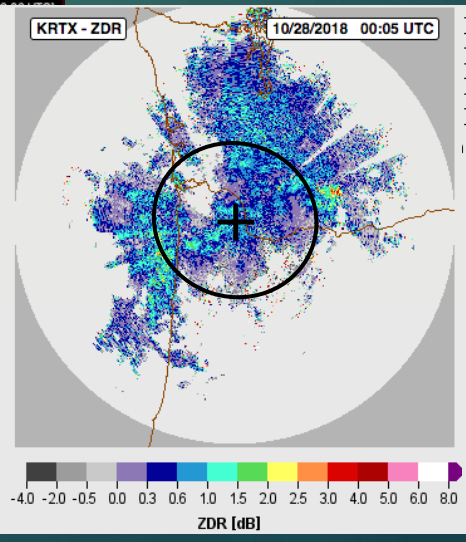
Default stratiform α=0.035 was applied for the whole period.

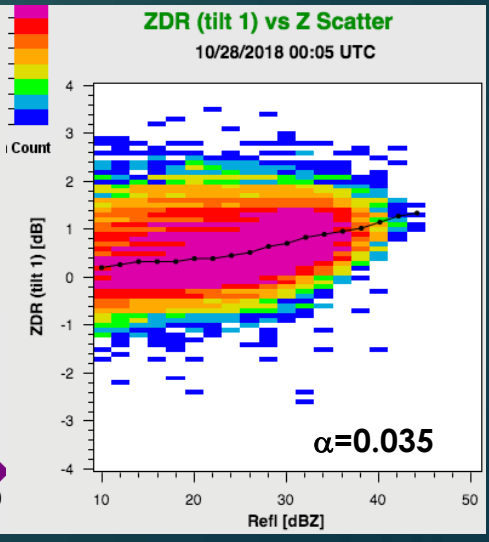
Azimuthal discontinuities were observed in R(A) in severe blockage areas.





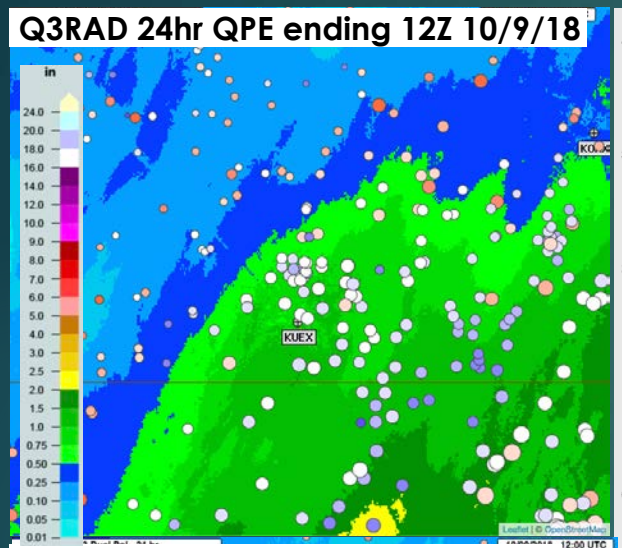


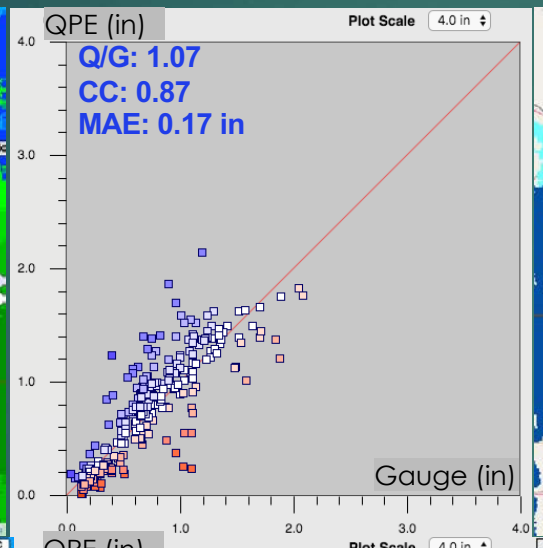


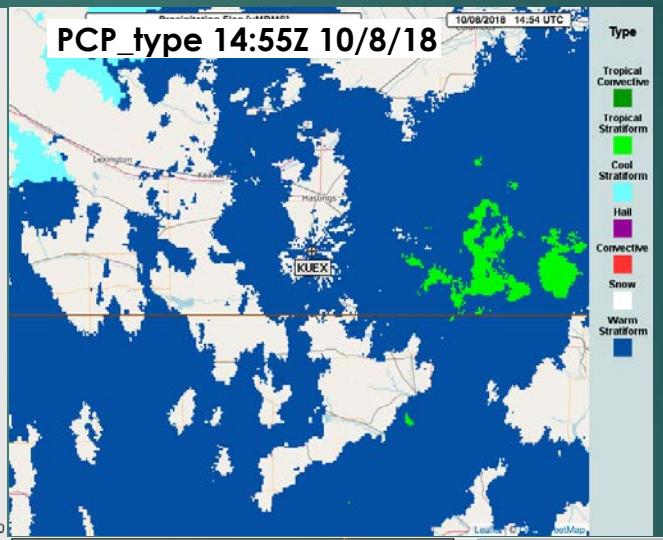


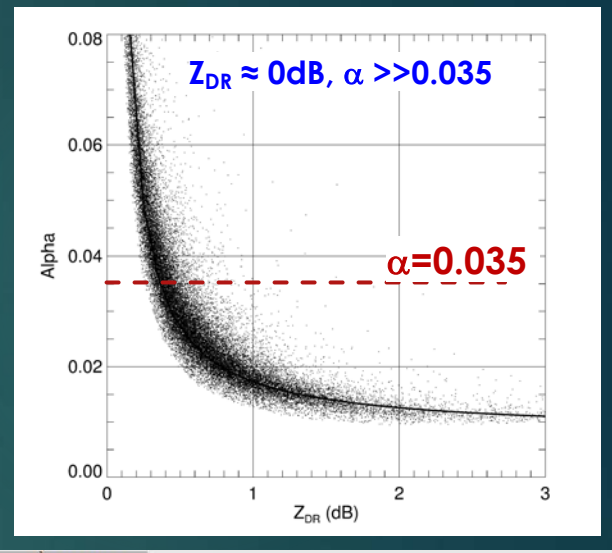
R(A) performance in light stratiform rain

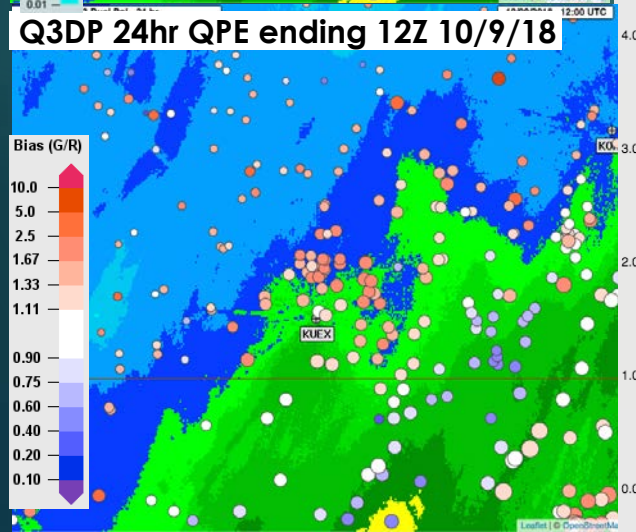
R(A) underestimation due to 1) the default stratiform α (0.035) was too low and 2) the path integrated differential phase was small.

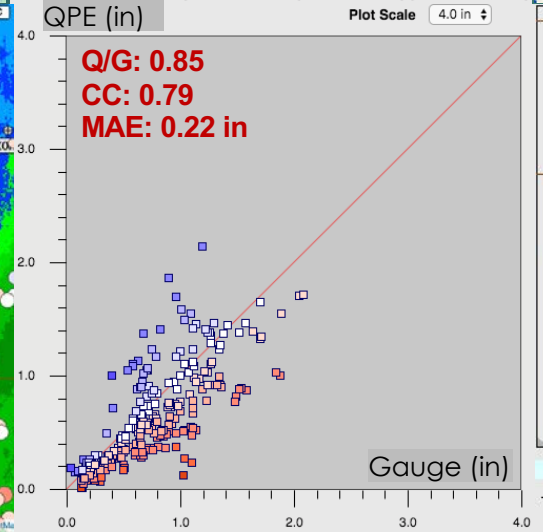


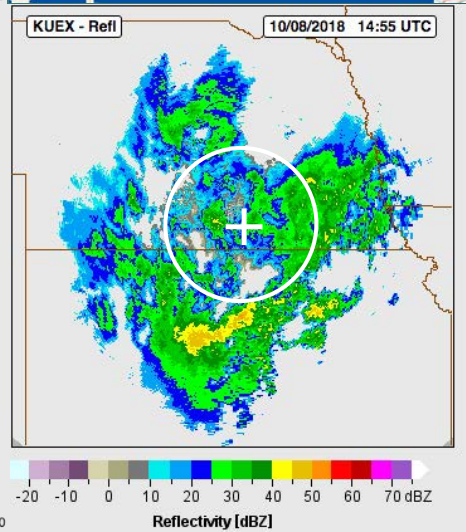


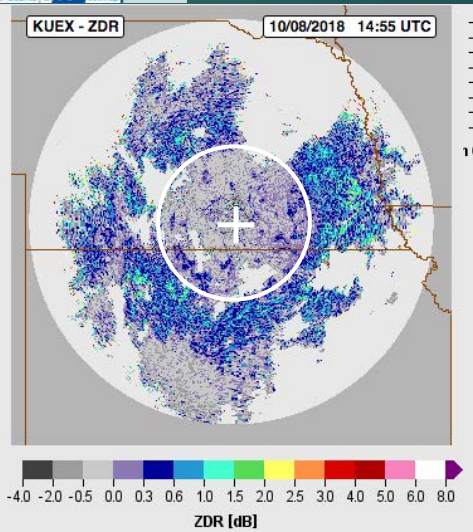


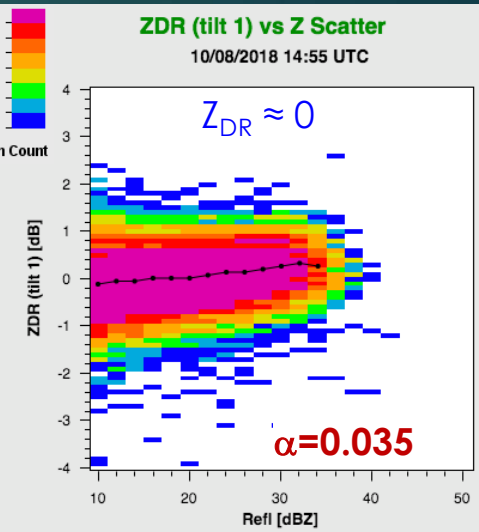






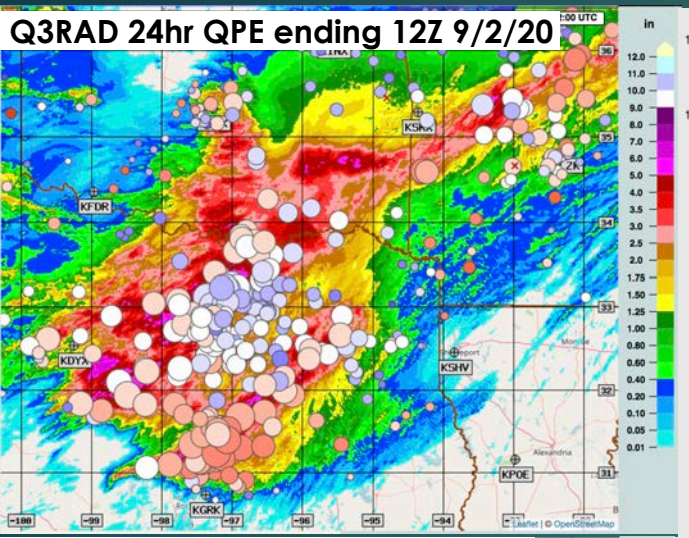


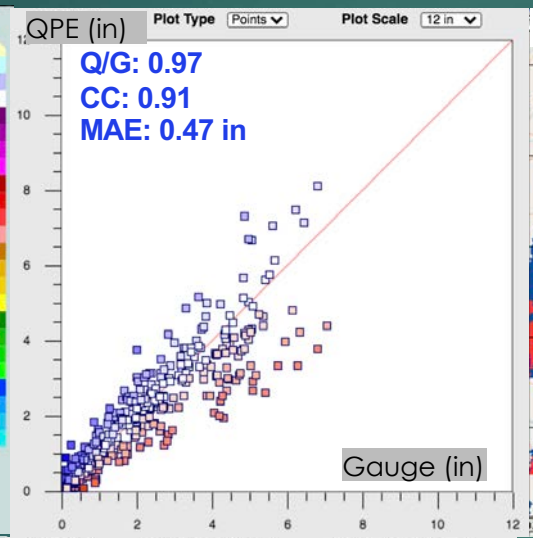


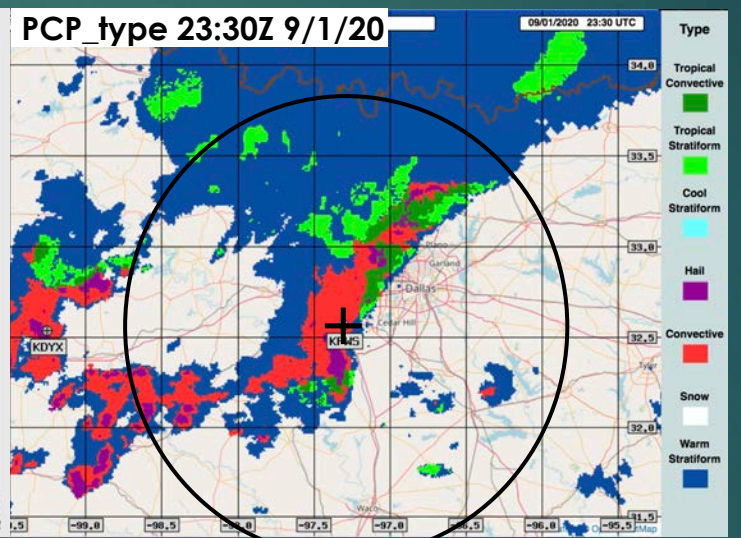


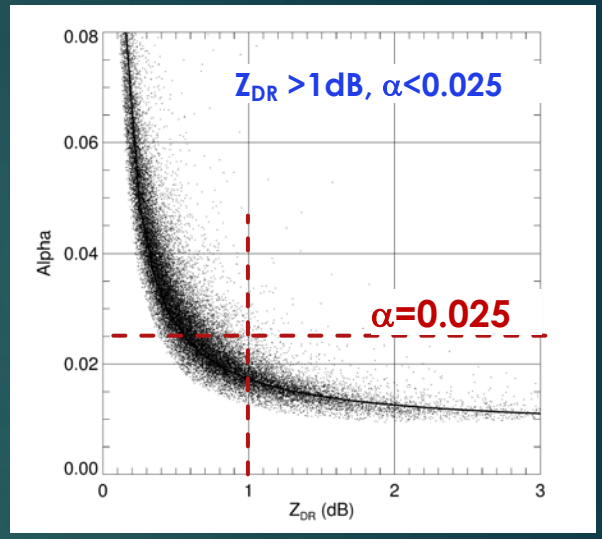
R(A) performance in mixed rain

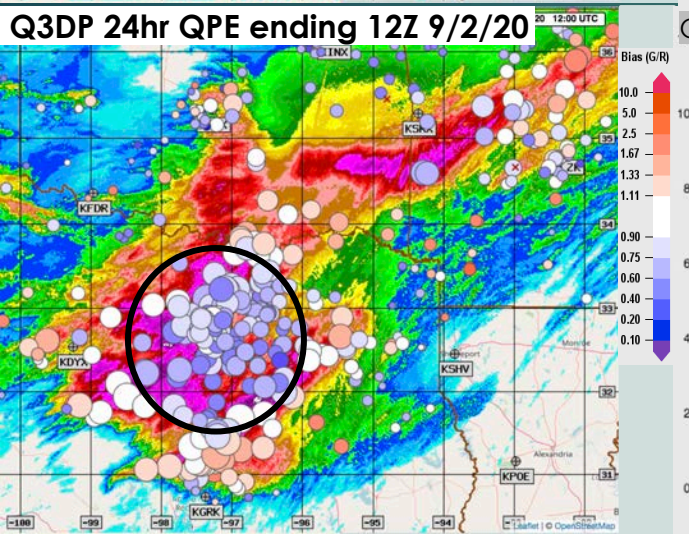
R(A) overestimation in a mixed event with strong convective storms embedded in wide spread stratiform rain

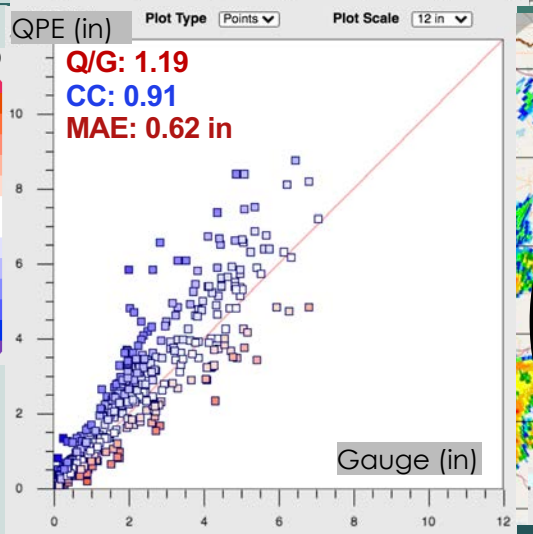


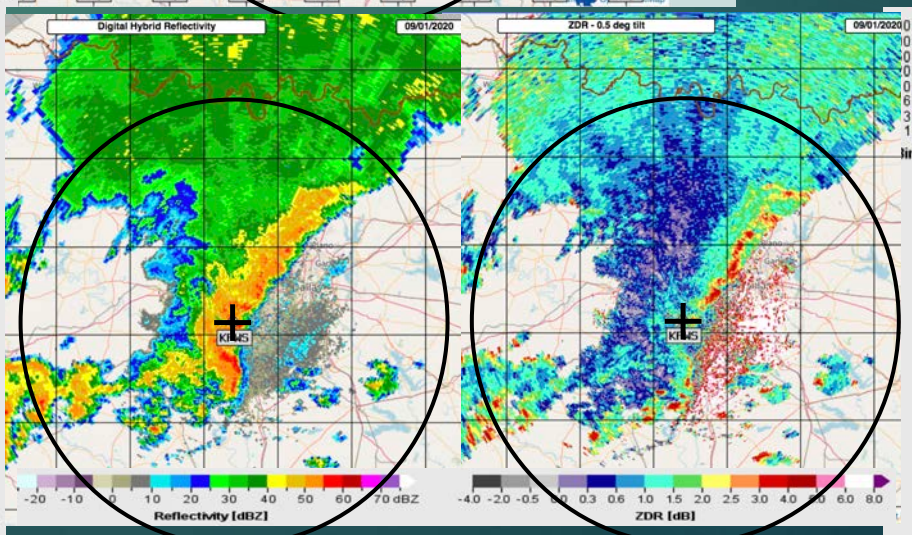


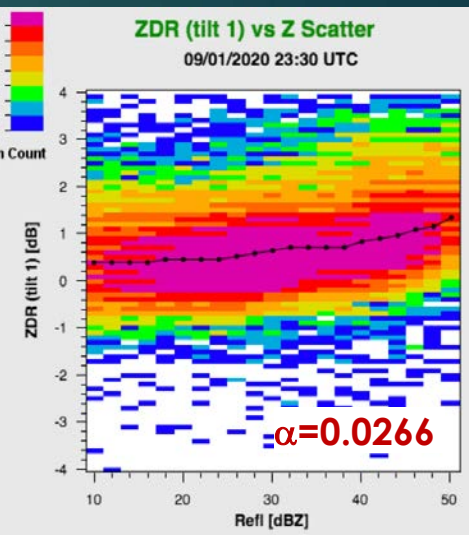










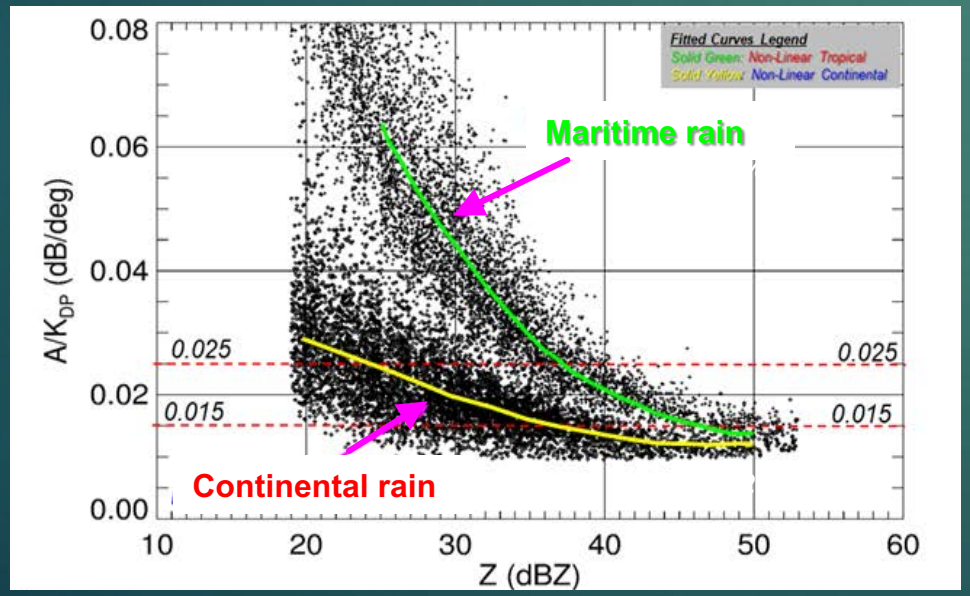


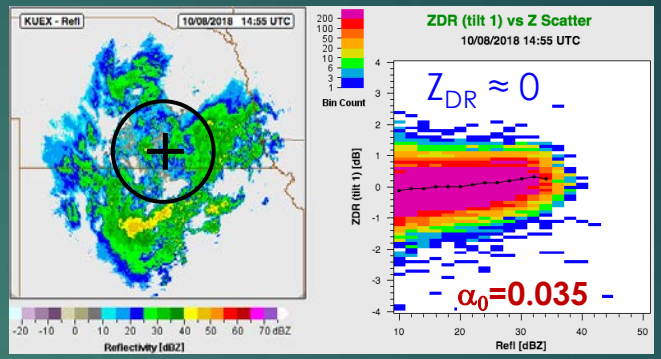
Refinements of R(A)

To account for highly nonuniform DSD distributions:

$$R(A)\ adj. = 4120.0 * A^{1.03} * (\alpha_{adj} / \alpha_0)$$

α_{adj} (Z) curves

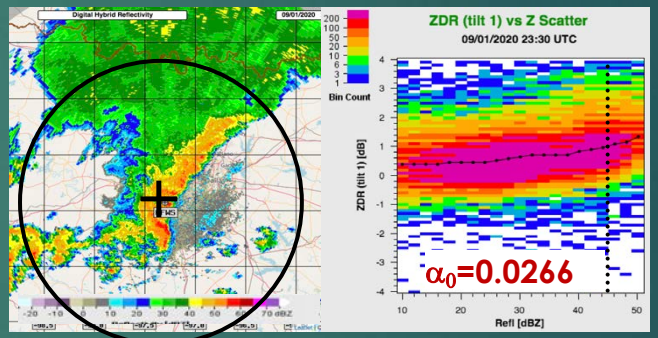




Pure stratiform

Underestimation;

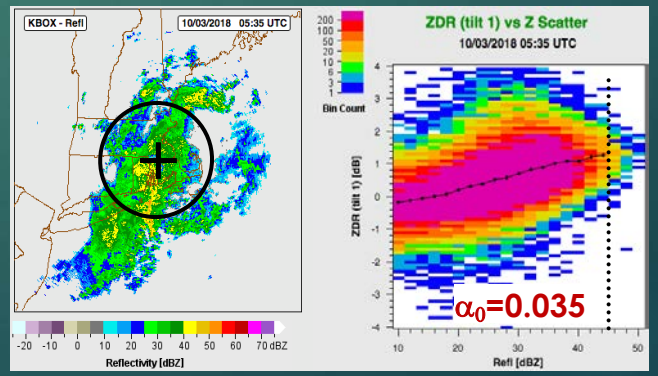
Apply maritime α_{adj} everywhere.



Stratiform/strong convection

Overestimation.

Apply maritime α_{adj} for Z≥45dBZ



Weak convection

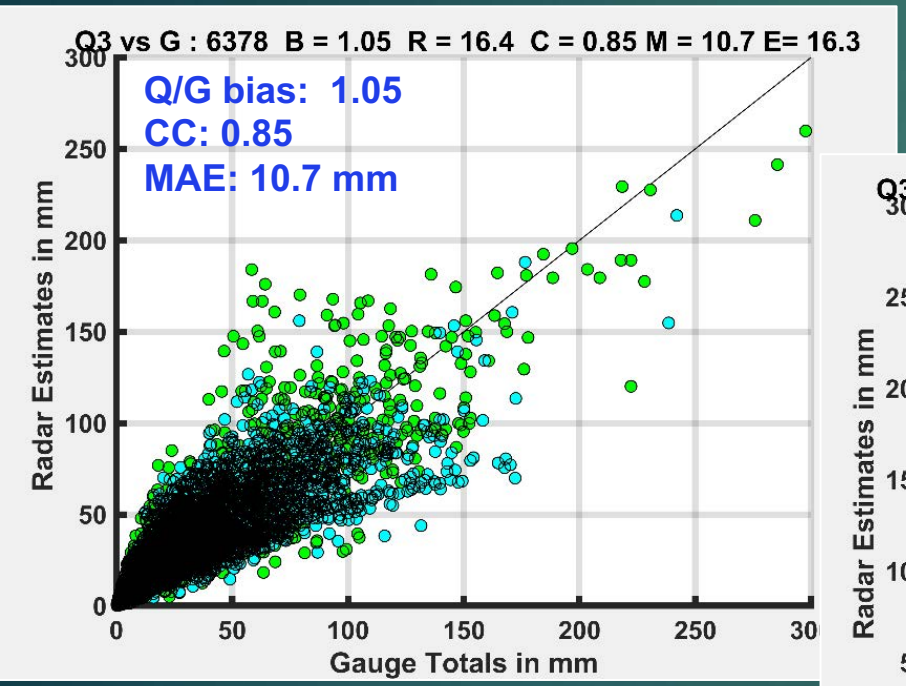
Overestimation

Apply continental α_{adj} everywhere.

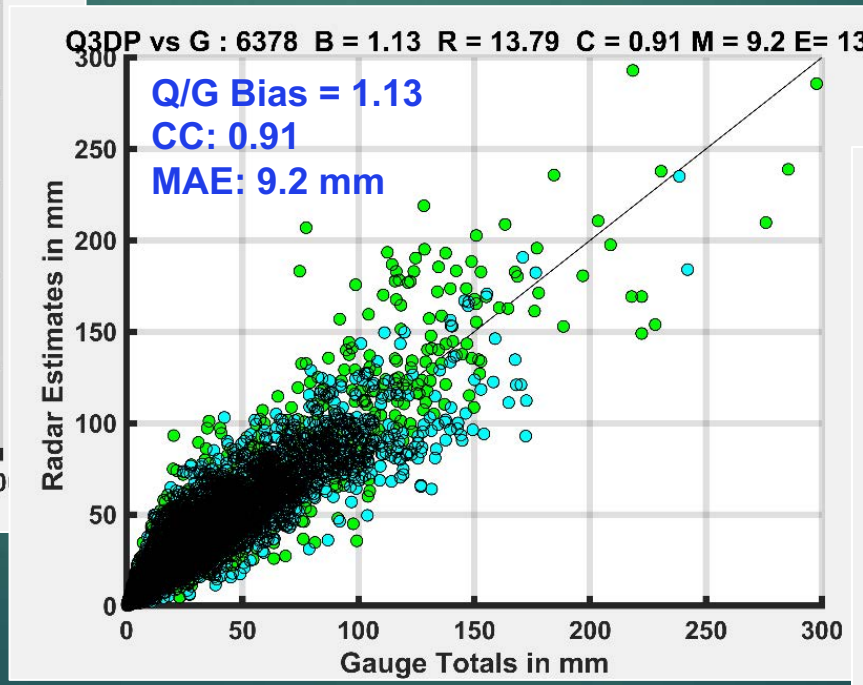
Refined R(A) Performance

Stratiform/convective mixed regimes (77 radar/events)

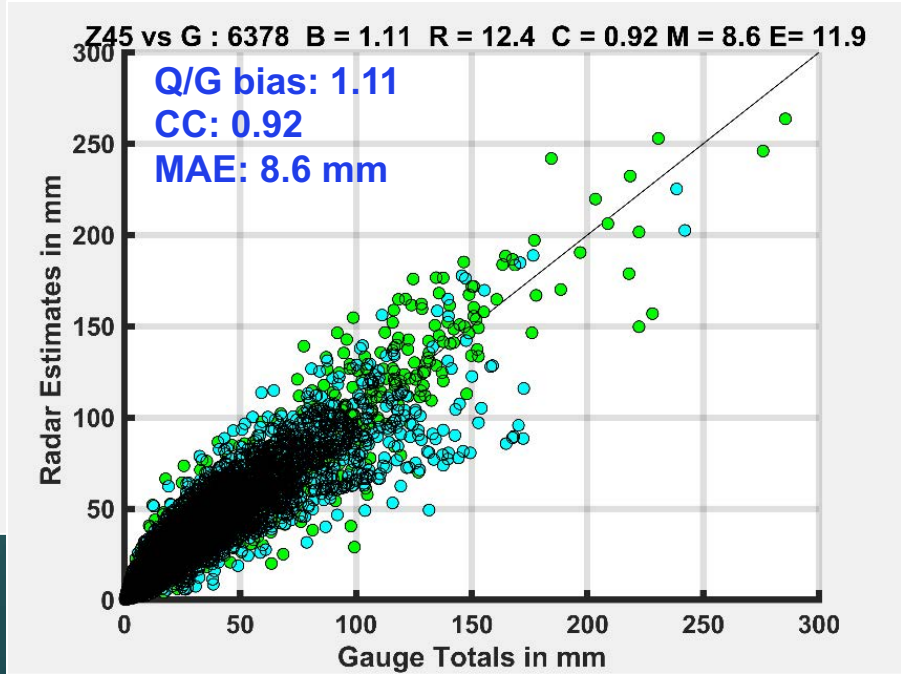
Multi R(Z)



R(A)



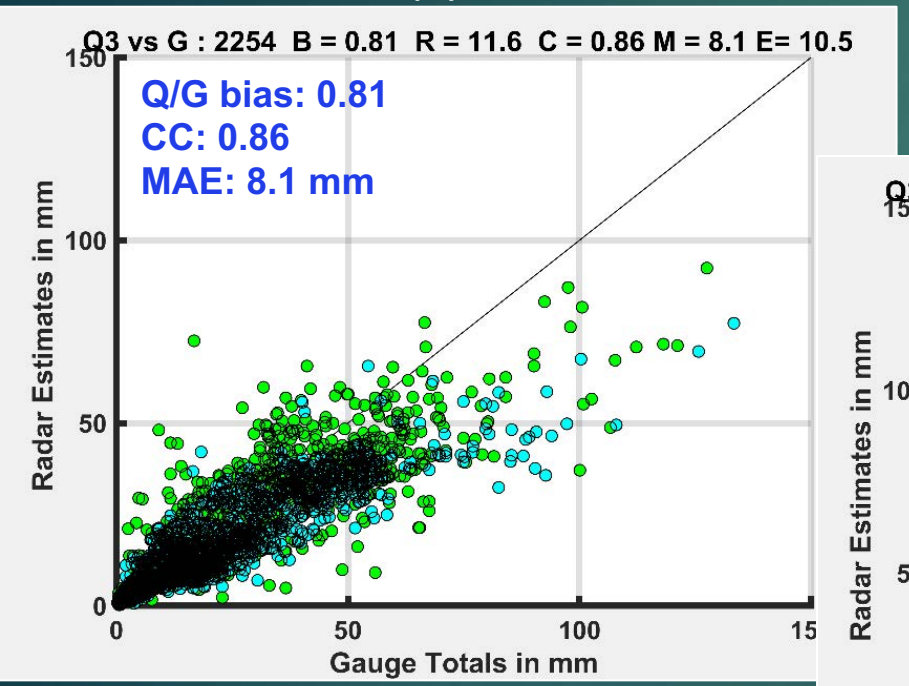
R(A)-adj



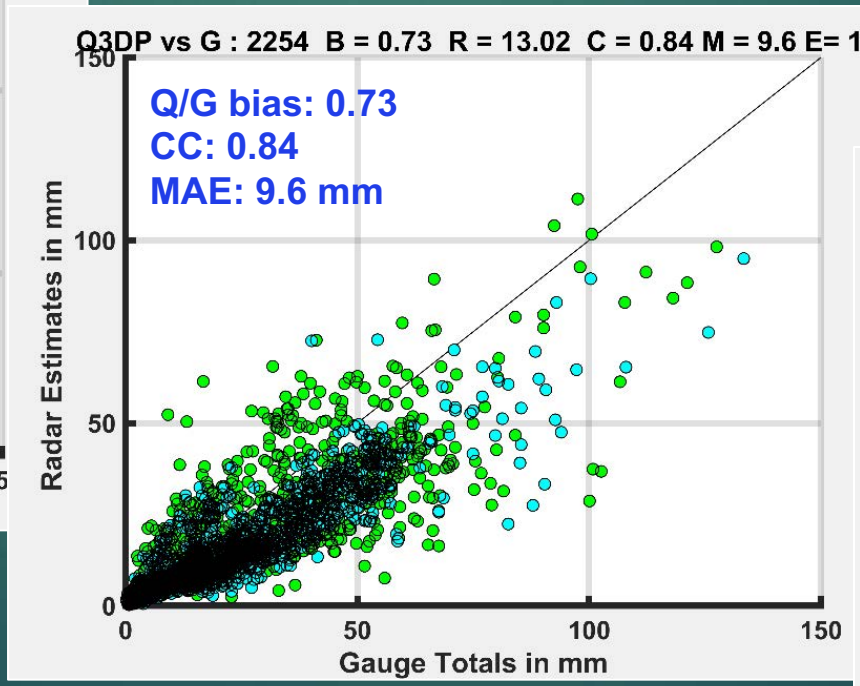
Refined R(A) performance

Pure stratiform regimes (24 radar/events)

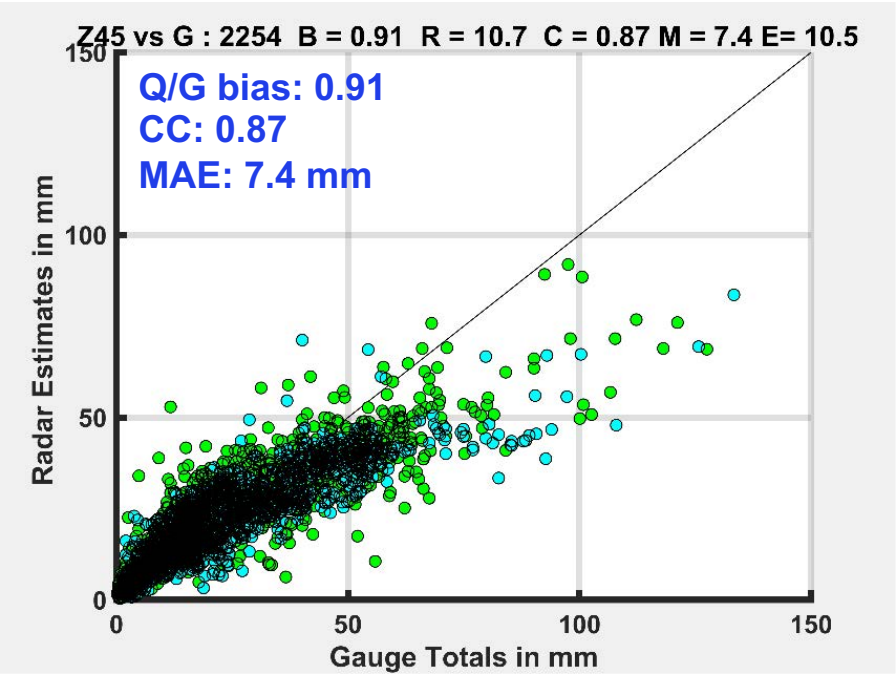
Multi R(Z)



R(A)



R(A)-adj



Summary

- A specific attenuation based S-band radar QPE ("R(A)") was developed *for operations*

- Advantages:
  - R(A) had significantly lower bias and random errors than R(Z) in warm season heavy rain regardless of precipitation regimes
  - R(A) is insensitive to partial beam blockage
  - R(A) is insensitive to systematic errors in Z and Z_{DR}
  - R(A) is insensitive to localized Z_{DR} errors

- Challenges:
  - R(A) is only applicable in liquid phase
  - There was a dry bias of R(A) in *light stratiform rain* due to an unrepresentative α ($=0.035$)
  - R(A) had larger random errors than R(Z) in some stratiform/convective mixed rain due to a domain mean α not capturing highly non-uniform DSD distributions

  - *A Z-based R(A) adjustment is under development to address the non-uniform DSD distributions*

Thanks for your attention!

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