Specific Attenuation Rain Rate

Development and Operational Performance

Dr. Stephen Cocks, Dr. Lin Tang, Dr. Pengfei Zhang, and Dr. Alexander Ryzhkov
Cooperative Institute for Severe and High-Impact Weather Research and Operations (CIWRO), University of Oklahoma
Dr. Heather Grams
NOAA National Severe Storms Laboratory

Operational Radar QPE: A Brief Summary

- Until 2012, radar QPE primarily consisted of the use of a reflectivity (Z) to rain rate (R) relation to estimate precipitation rates [R(Z)]
  - *Warm season: convective or tropical R(Z) often used…Cool season: list of R(Z)s made available*
  - *Any R(Z) changes were forecaster initiated and applied to entire radar field of view*

- After 2012, Radar Operations Center (ROC) & the MRMS Project transitioned to operations QPE algorithms that automatically assigned a rain rate relation depending upon echo classification
  - *Below melting layer (ML), ROC Dual Pol (DP) QPE used R(Z,ZDR) & R(KDP); within ML, a multiplication factor times R(Z) and R(Kdp) (for > 50 dBZs) were used*
  - *MRMS QPE used multiple R(Z)s and applied Bright Band reflectivity corrections w/in & above ML*

- Despite advances, the need continued for rain relations less sensitive to the precipitation microphysics
  - *R(Z) relations sensitive to Z calibration & drop size distributions (DSD) changes*
  - *R(Z,ZDR) sensitive to calibration challenges*
  - *R(KDP) cannot capture all DSD variability and can be noisy*

- Studies by Ryzhkov et al. (2014) & Wang et al. (2014) indicated potential in using Specific Attenuation (*A*) to estimate rain as it was generally immune to the previous challenges
  - *RRDD & WRRD began to work together to develop an automated QPE algorithm utilizing A*

How to Calculate Specific Attenuation

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

$Z(r_1)$ $\Phi(r_1)$			**$Z(r)$**				**$Z(r_2)$ $\Phi(r2)$**

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

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

- Specific Attenuation *A* fields provide a measurement of the amount of attenuation caused by rain (dB/km)
- Despite the complicated equations, all that is needed to calculate *A* are uncorrected radial Z and the span of differential phase along the radial

$$C(b,PIA) = \exp(0.23bPIA) - 1 \quad \textbf{where} \quad PIA(r_1,r_2) = \alpha\left[\varphi_{DP}(r_2) - \varphi_{DP}(r_1)\right]$$

PIA => Path Integrated Attenuation

Total span of PhiDP along radial

- Key to calculating *A* is the Path Integrated Attenuation term (PIA) which is composed of the differential phase span multiplied by the parameter 'α' which needs to be estimated
  - *a is currently estimated by slope of Zdr to Z*
- After calculation of *A* fields, rain rates estimated by the equation at right as long as
  - radar beam remains below ML and adjustments made to span of PhiDP in localized regions along radial where hail likely present

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

constants were optimized for S band radars

R(A) Limitations:

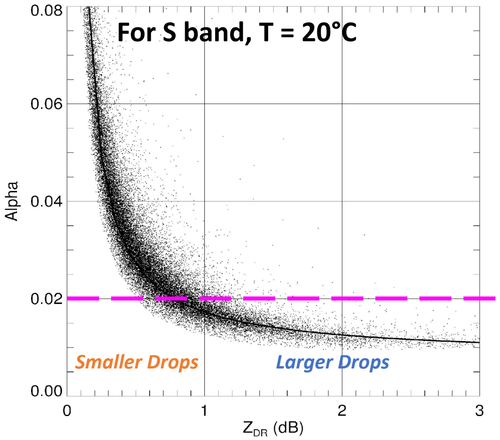
α Variability & Ice Contamination

- Technique developed from ROC/other funds utilized a net α, updated each 0.5 deg tilt, for radar FOV to calculate PIA and hence spec. att. *A*

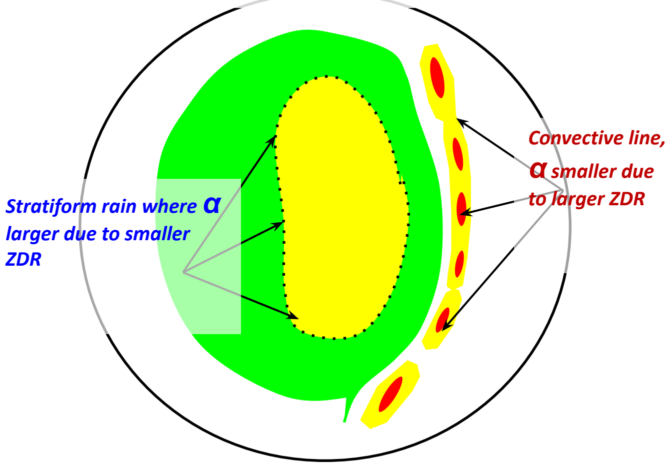
- However, technique doesn't directly address spatial variability of α
  - *Consider conceptual MCS (figures A & B): if net α = 0.020 (dashed purple, figure A) it will be:*
    - *too large (small) w/in convective (stratiform) rain where ZDR is larger (smaller)*
  - *This spatial variability is partly mitigated via the use of :*
    - *Code checks of ZDR vs. Z distribution to determine potential for α mismatches & mitigations applied*
    - *R(KDP) in convection where hail is likely (Z ≥ 50 dBZ)*

- Specific Attenuation also becomes very large in ice, especially from hail but also within melting layer:
  - *Using R(KDP) where hail likely present*
  - *Use of model sounding data to diagnose simplified ML structure*
    - *More recent work uses model 1st guess & Dual Pol RhoHV to diagnose more realistic ML structure*

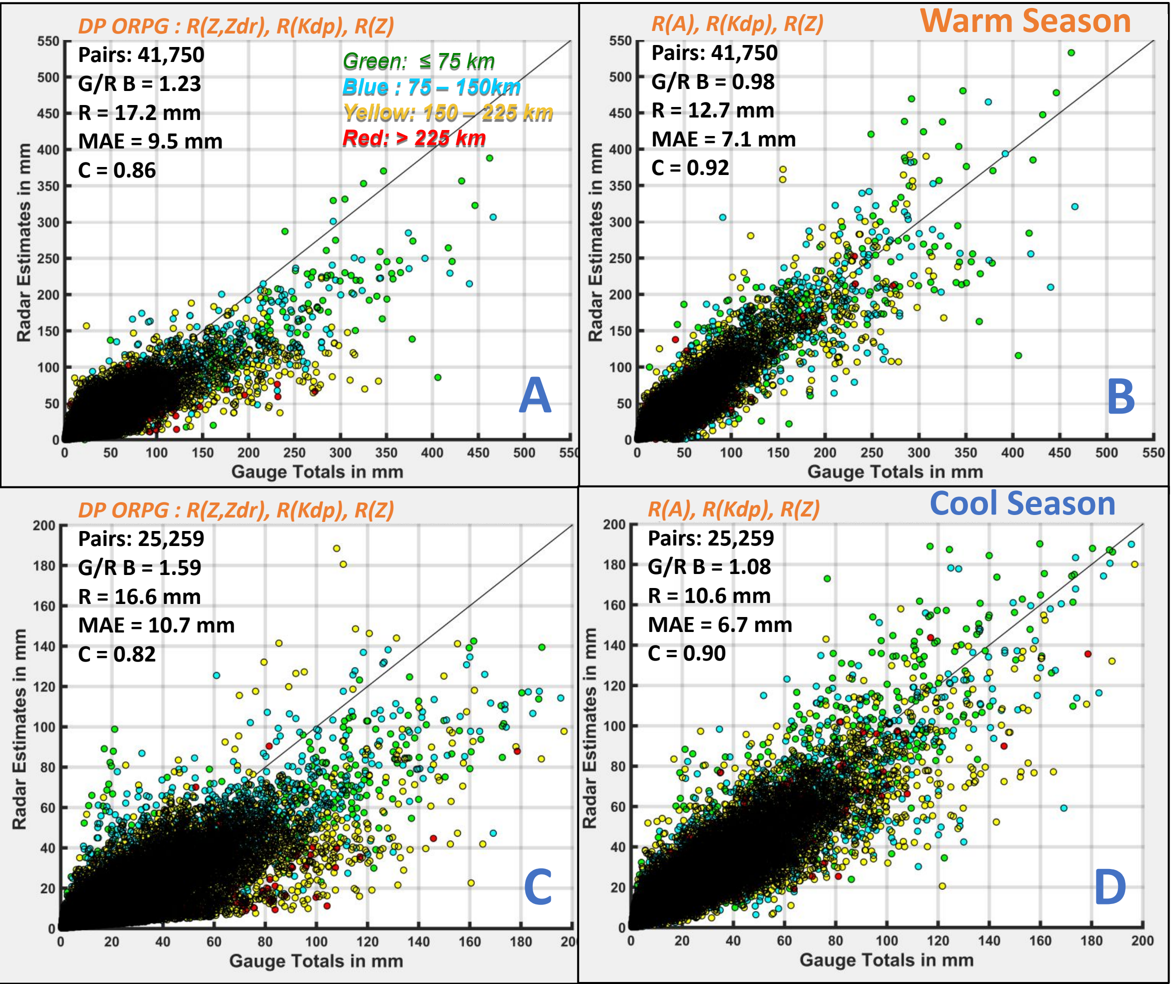
A: *α vs Z_{DR} from disdrometer simulations.*



B: *Radar FOV of conceptual MCS*



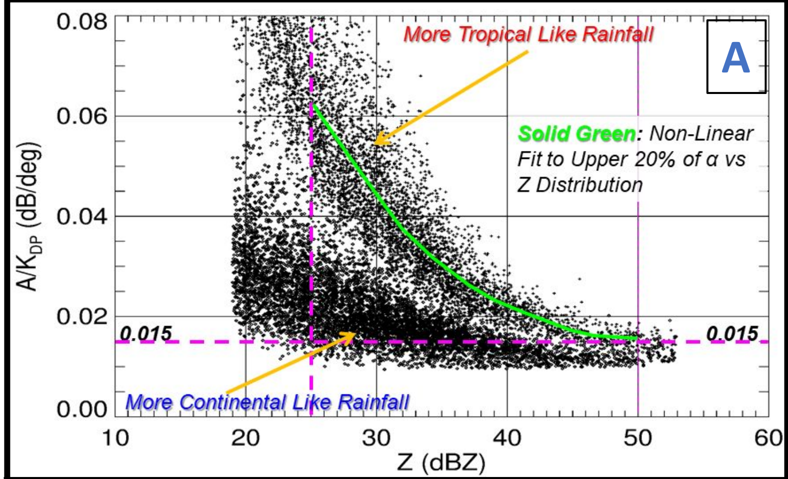
R(A) Version 1 Performance:



- Systematic performance assessments were made of the initial R(A) algorithm and the ORPG Dual Pol (DP) QPEs via comparisons with 24-hr totals from CoCoRaHS rain gauges
- At left: scatter plots of initial R(A) algorithm (B and D) and DP ORPG (A and C) QPEs for warm (May - September 2017) and cool (October 2017 – April 2018) seasons east of the Rockies
- In both seasons there is a dramatic difference between the two QPEs with regards to higher rain totals
  - *The R(A) algorithm generated QPE showed significantly better results*

R(A) Version 2.0:

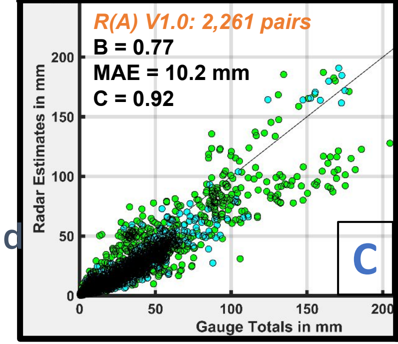
- While 1st R(A) QPE performed well, examples of R(A) wet (dry) bias in convective (tropical/ stratiform) rain were observed
    - This was related to use of net *α* over radar FOV
- To mitigate bias, developed an adjusted alpha ($α_{adj}$) derived from best fit curve to upper 20% of α vs Z distribution (plot A)
    - *Adjusted **α** ($α_{adj}$) is used in a ratio with net **α** to create a correction factor in used in equation at right (B)*
- Overall, R(A) QPE generally does well for net *α* < *0.020* and no correction is needed as rain more continental
- For mixed stratiform/deep convective rain with net *α* ≥ *0.020,* alpha adjusted for higher Z (> 40 dBZs) where variability lower
- For predominantly stratiform rain, alpha adjusted for range of best fit curve from 25 to 35 dBZs to improve performance
- Code is under evaluation in real-time testbed; scatter plots C and D at right show an example of the improvement obtained in stratiform rainfall

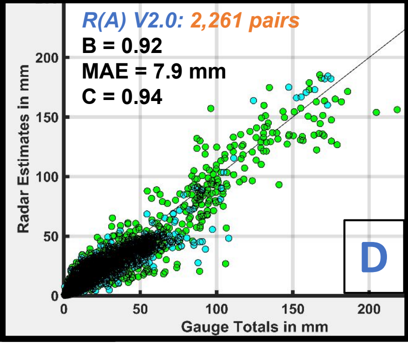


B

$$R(A) = 4120.0 * A^{1.03} * (α_{adj} / α_o)$$

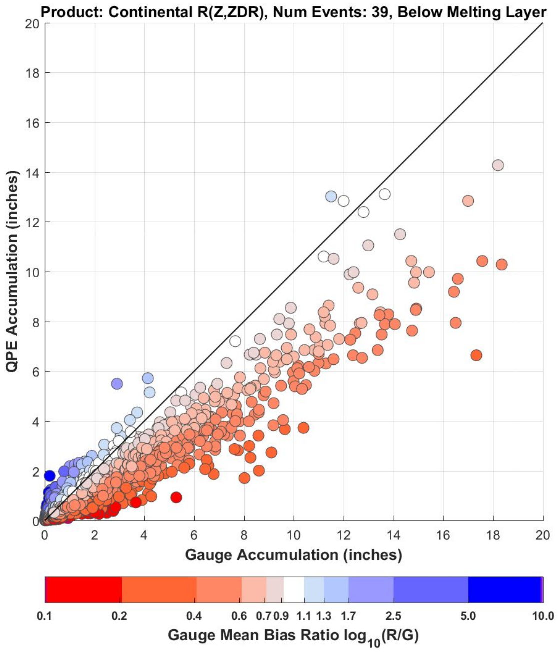
where $α_{adj}$ & $α_o$ are adjusted & net alpha respectively; for $α_{adj} > α_o$ the rates are lowered



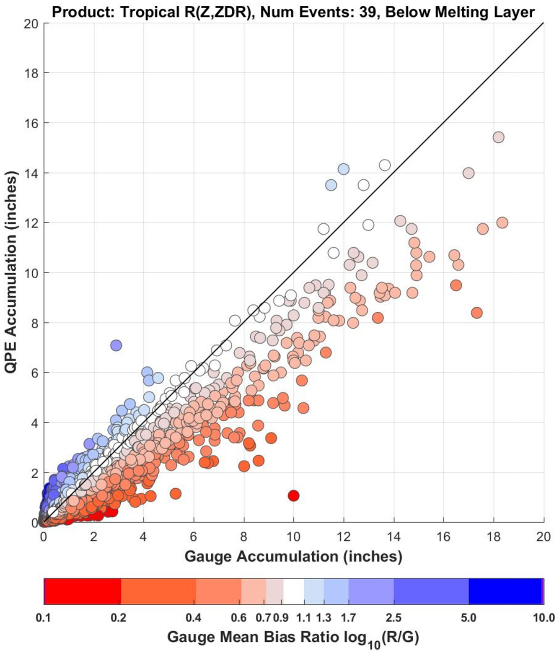


Specific Attenuation Operational Performance

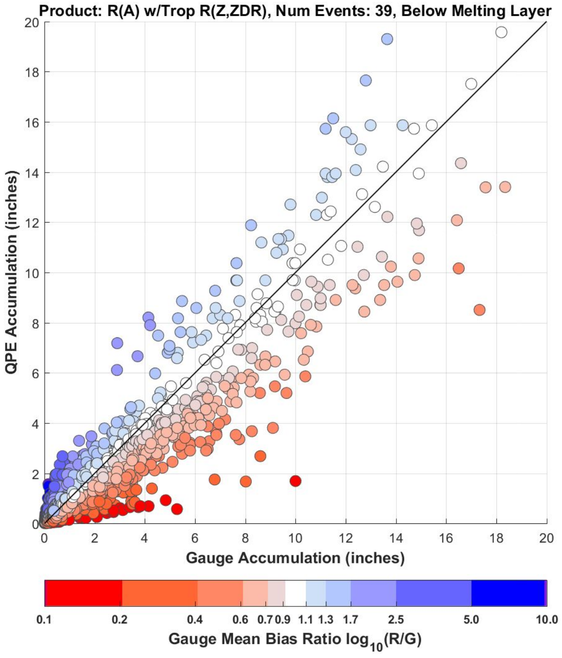
R(A) vs R(Z,ZDR) during Build 19 Testing



Continental R(Z,ZDR)
(default in Build 18)

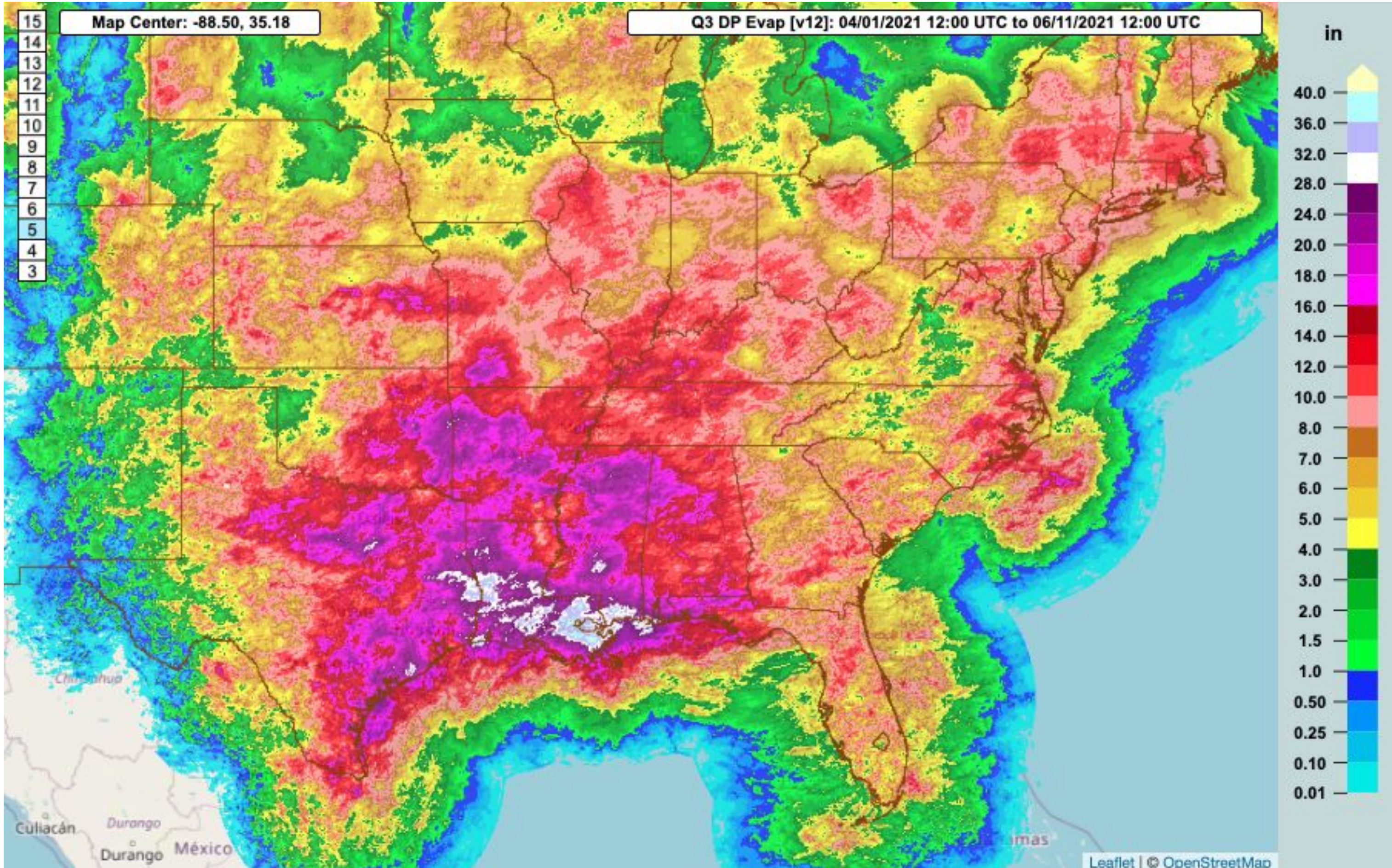


Tropical R(Z,ZDR)

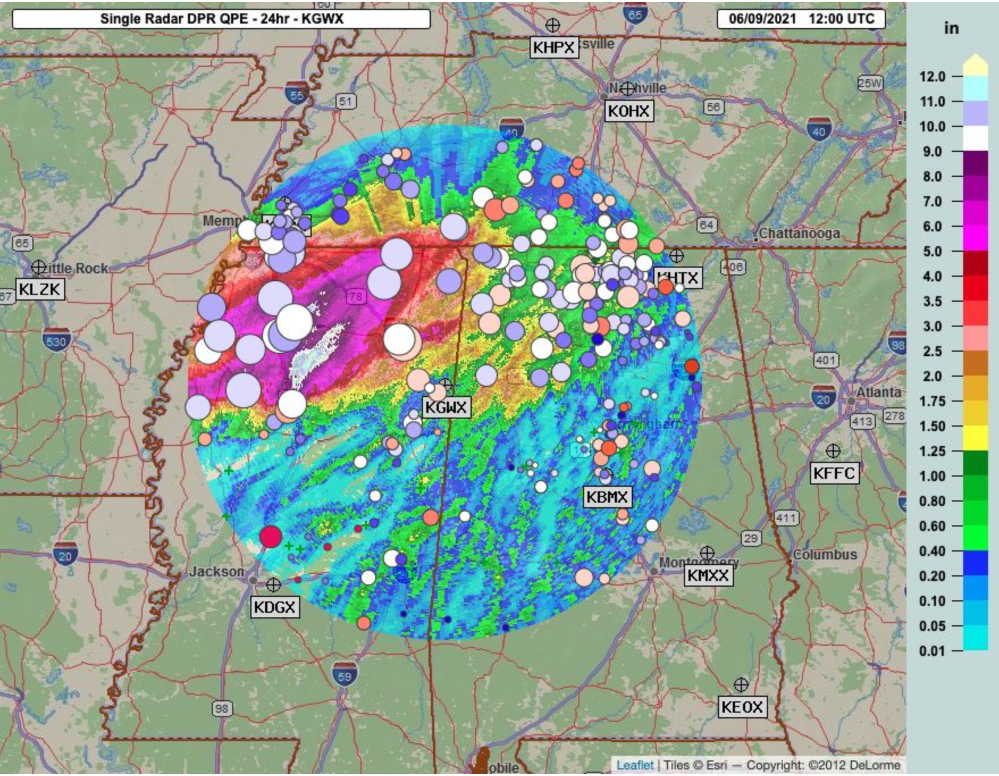


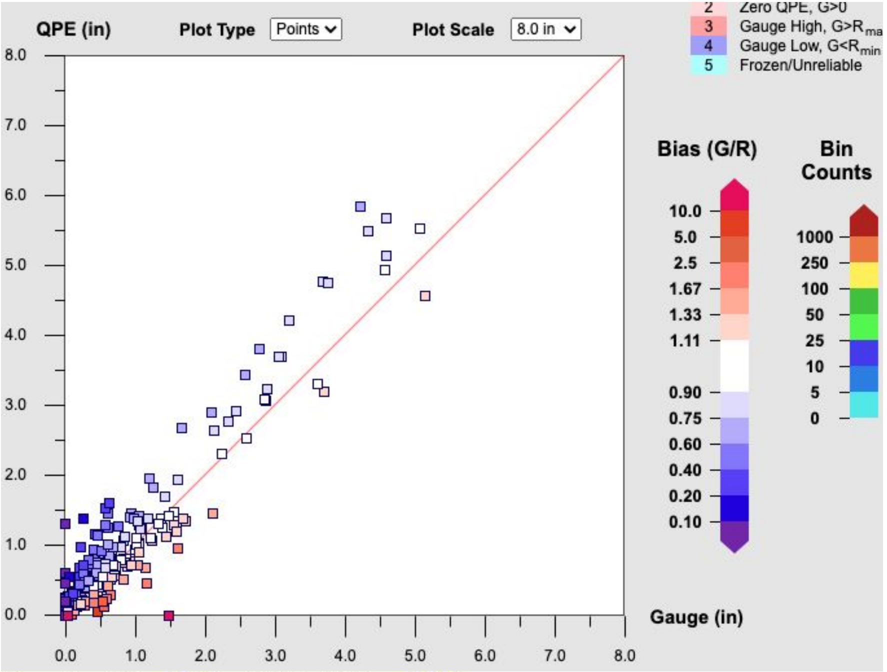
R(A) with Tropical R(Z,ZDR)

Total Rainfall Accumulation - April 1 to June 11, 2021



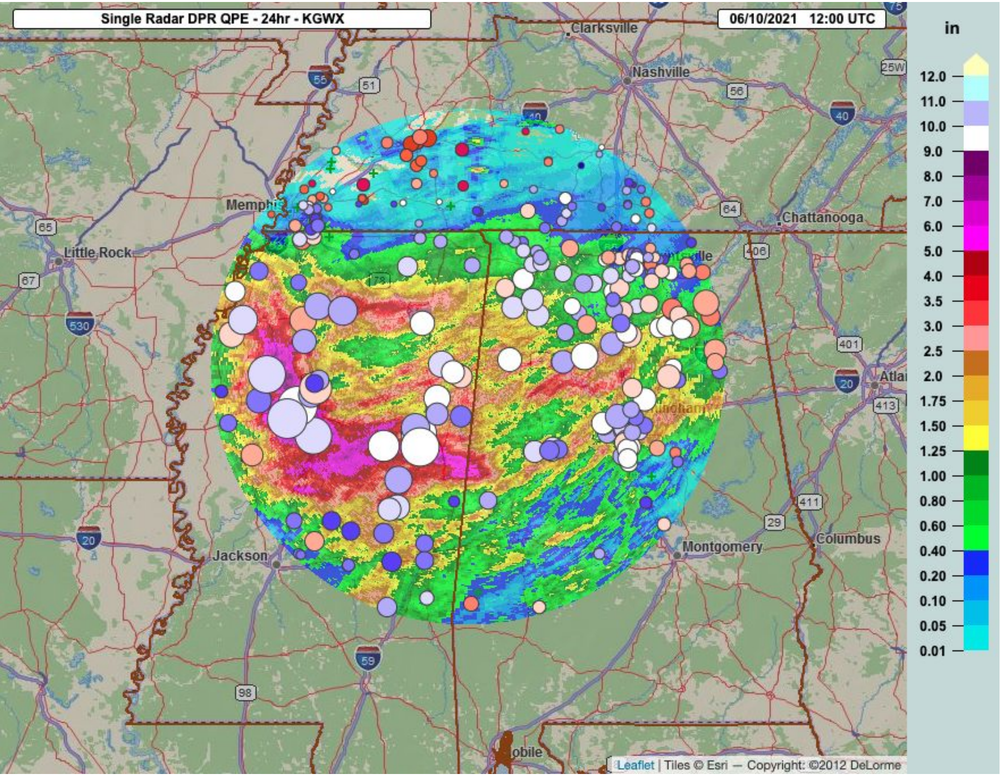
24hr Accumulations from KGWX DP QPE - 12Z 9 Jun 2021

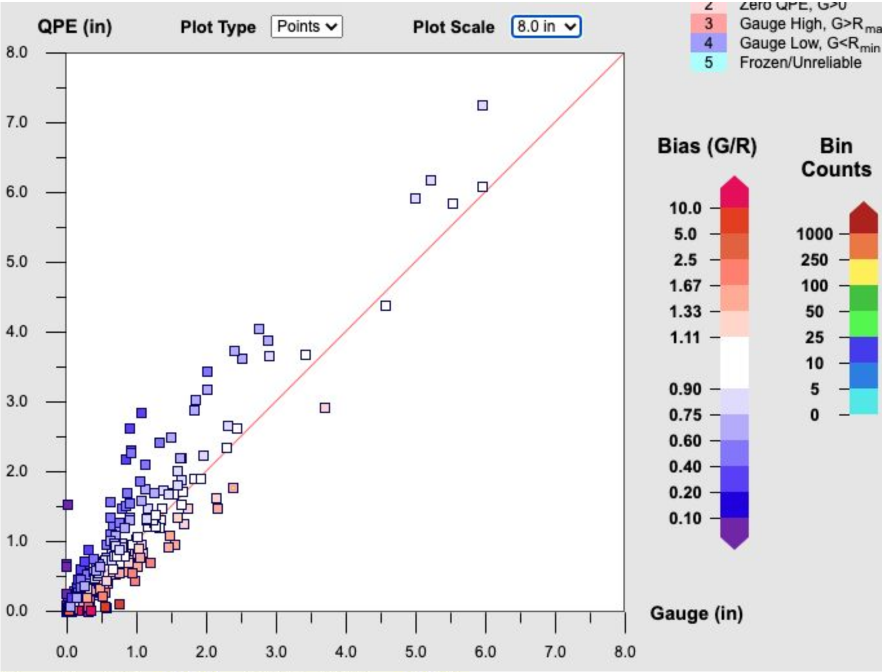




Mean Bias(G/R):	0.851	G-R Err Std Dev:	0.238
Add Bias (G-R):	-35.06	Corr Coeff:	0.954
Mean Err (G-R)/N:	-0.132	Fract Bias:	-0.175
Mean Abs Error:	0.238	Fract RMSE:	0.492
RMSE:	0.371	Fract Std Dev:	0.460

24hr Accumulations from KGWX DP QPE - 12Z 10 Jun 2021





Mean Bias(G/R):	0.833	G-R Err Std Dev:	0.290
Add Bias (G-R):	-41.36	Corr Coeff:	0.937
Mean Err (G-R)/N:	-0.162	Fract Bias:	-0.200
Mean Abs Error:	0.290	Fract RMSE:	0.555
RMSE:	0.451	Fract Std Dev:	0.518

AI6YR @ai6yrham · 22h

Aftermath of that #MS #flash #flood #emergency (here's what happens when you get 10 to 20 inches of rain in a very, very short time).

Charles Peek @CharlesPeekWX · Jun 10

Flash flood emergency in Greenwood, MS with water in homes and numerous roads closed and flooded. @weatherchannel @GregPostel @WXMolly @NWSJacksonMS #mswx #flooding

NWS Memphis @NWSMemphis

A CoCoRaHS station 3.5 miles SW of Charleston, MS has recorded 15.35" of rain in the past 48 hours. Life-threatening flash flooding continues in Tallahatchie County. #mswx

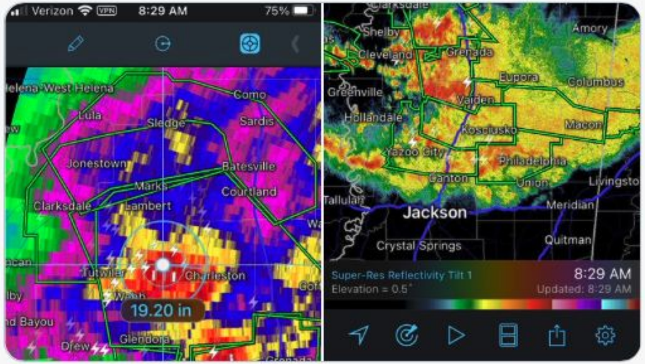
3-Day Total of 19.30"

9:37 AM · Jun 10, 2021 · TweetDeck

11 Retweets **15** Likes

Craig Ceecee @CC_StormWatch · Jun 10

Incredible rainfall this week in parts of Mississippi. Radar estimates of up to 20 inches in the west-central part of the state. **Flash flood EMERGENCY** for a large number of areas. #mswx



2 11

...FLASH FLOOD WARNING REMAINS IN EFFECT UNTIL 1030 AM CDT THIS MORNING FOR CARROLL, GRENADA AND LEFLORE COUNTIES...

At 711 AM CDT, emergency management reported ongoing significant flash flooding across the warned area. Roads are washed out and water rescues are underway. Between 6 and 10 inches of rain have fallen.

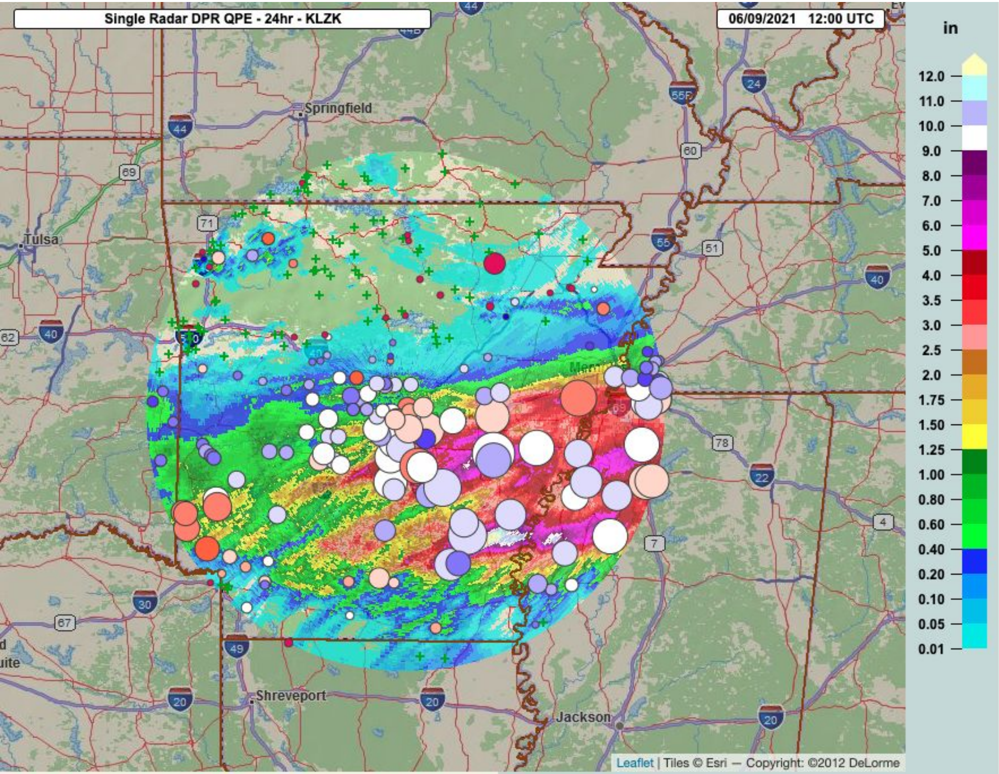
This is a FLASH FLOOD EMERGENCY for Central Carroll Eastern Leflore and Western Grenada Counties. This is a PARTICULARLY DANGEROUS SITUATION. SEEK HIGHER GROUND NOW!

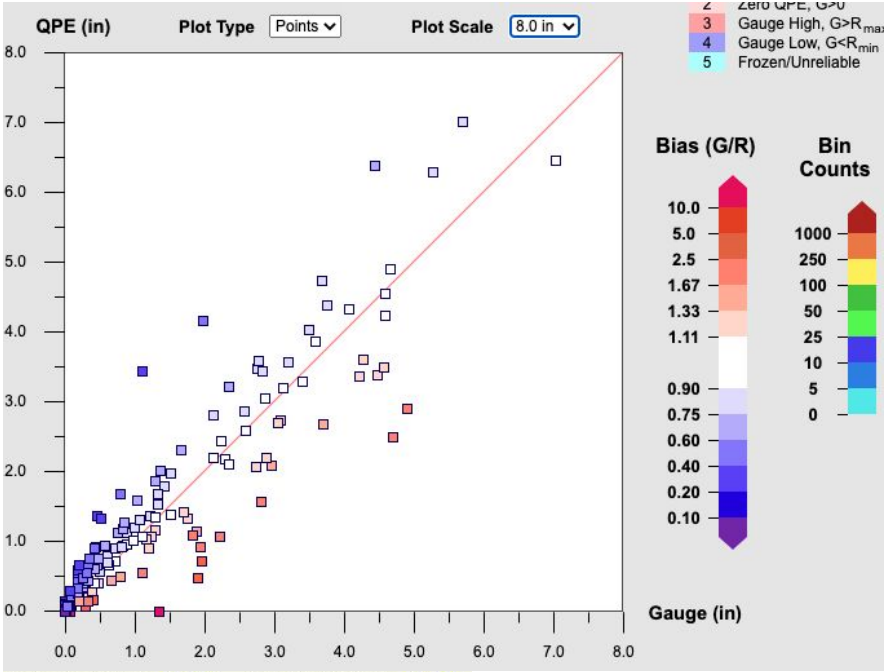
HAZARD...Life threatening flash flooding. Heavy rain producing flash flooding.

SOURCE...Emergency management.

IMPACT...This is a PARTICULARLY DANGEROUS SITUATION. SEEK HIGHER GROUND NOW! Life threatening flash flooding of low water crossings, small creeks and streams, urban areas, highways, streets and underpasses.

24hr Accumulations from KLZK DP QPE - 12Z 9 Jun 2021





Mean Bias(G/R):	0.967	G-R Err Std Dev:	0.223
Add Bias (G-R):	-7.40	Corr Coeff:	0.941
Mean Err (G-R)/N:	-0.027	Fract Bias:	-0.034
Mean Abs Error:	0.223	Fract RMSE:	0.570
RMSE:	0.457	Fract Std Dev:	0.569

Brian Emfinger
@brianemfinger

Video from yesterday's Flash Flood Emergency in Dumas, Arkansas. #arwx Dumas Arkansas Flash Flood Emergency youtu.be/m81ReKfTDA8

9:18 AM · Jun 9, 2021 from North Little Rock, AR · Twitter for iPhone

IEMBot LZK @iembot_lzk · 19h

At 2:00 PM CDT, 4 E Pickens [Desha Co, AR] **EMERGENCY** MNGR reports **FLASH FLOOD**. THE WALL OF AN IRRIGATION CANAL WAS BREACHED WITH WATER FROM THE CANAL FLOODING SURROUNDING FARMLAND.

IEM :: Local Storm Report App
Iowa Environmental Mesonet of Iowa State University
mesonet.agron.iastate.edu

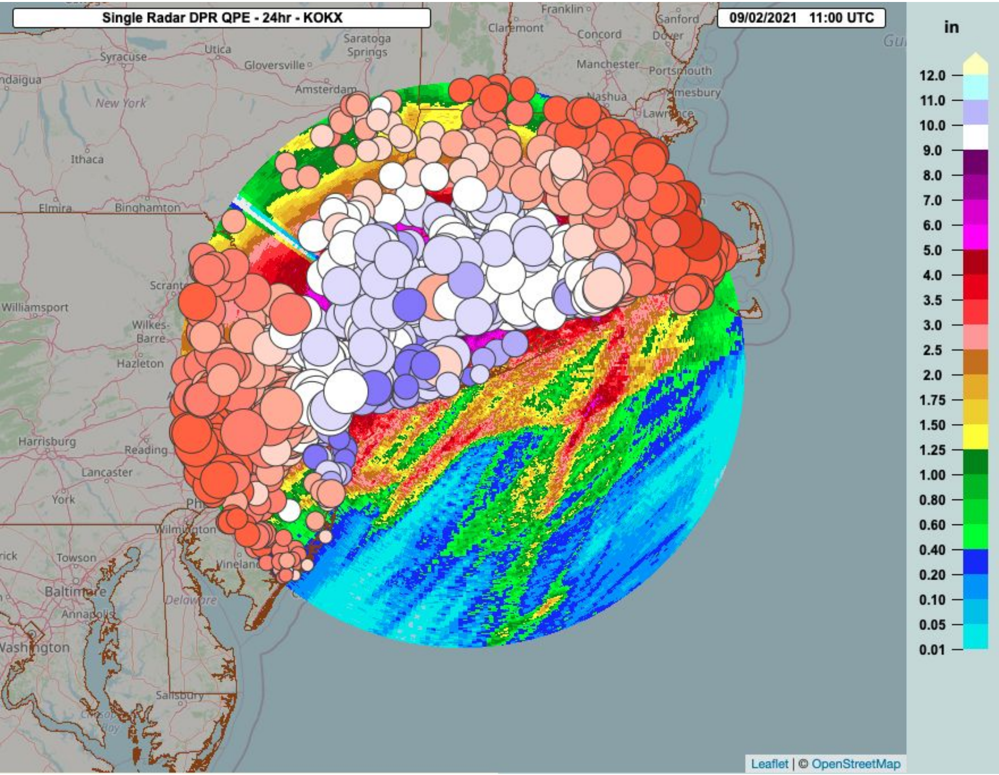
NWS Little Rock
@NWSLittleRock

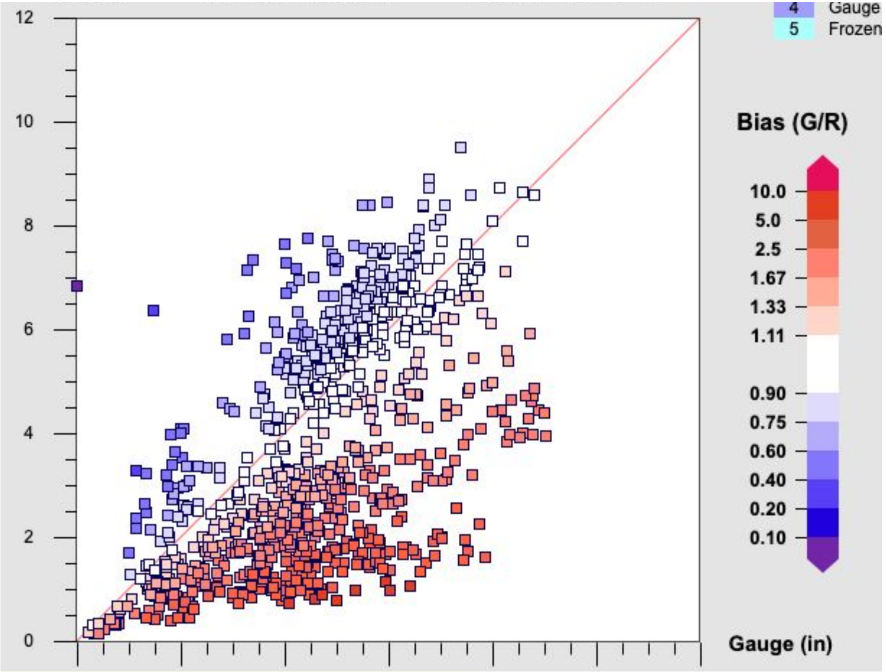
[11:45 AM-June 8] We've issued a Flash Flood Emergency for portions of southeast Arkansas! Locations in this warning have received between 10-15 inches of rain! Avoid the area if possible, widespread flooding is ongoing! #arwx

NWS Little Rock @NWSLittleRock · Jun 8
Flash Flood Emergency including Dumas AR, Mitchellville AR, Tillar AR until 2:40 PM CDT

11:45 AM · Jun 8, 2021 · Twitter Web App

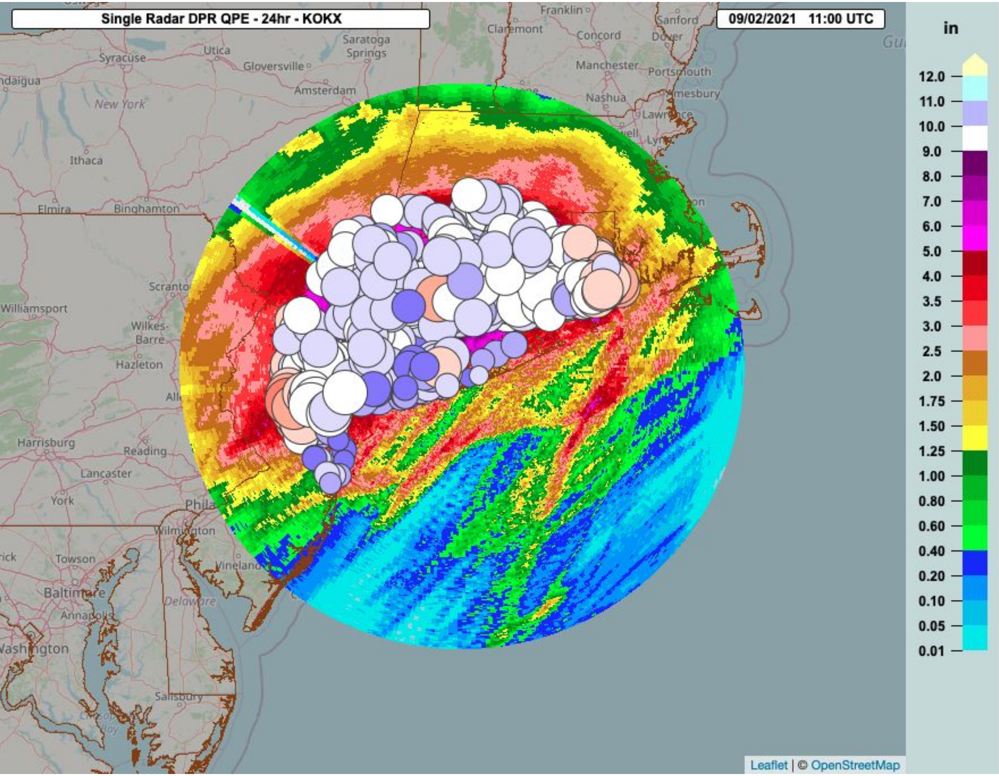
Remnants of Hurricane Ida - 11Z 2 September 2021

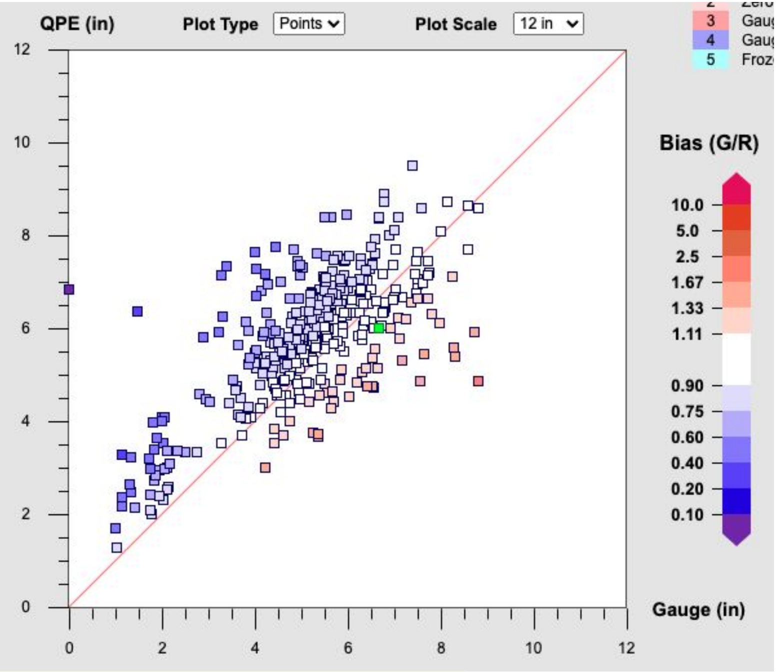




Mean Bias(G/R):	1.237	G-R Err Std Dev:	1.628
Add Bias (G-R):	781.87	Corr Coeff:	0.593
Mean Err (G-R)/N:	0.876	Fract Bias:	0.192
Mean Abs Error:	1.628	Fract RMSE:	0.448
RMSE:	2.046	Fract Std Dev:	0.405

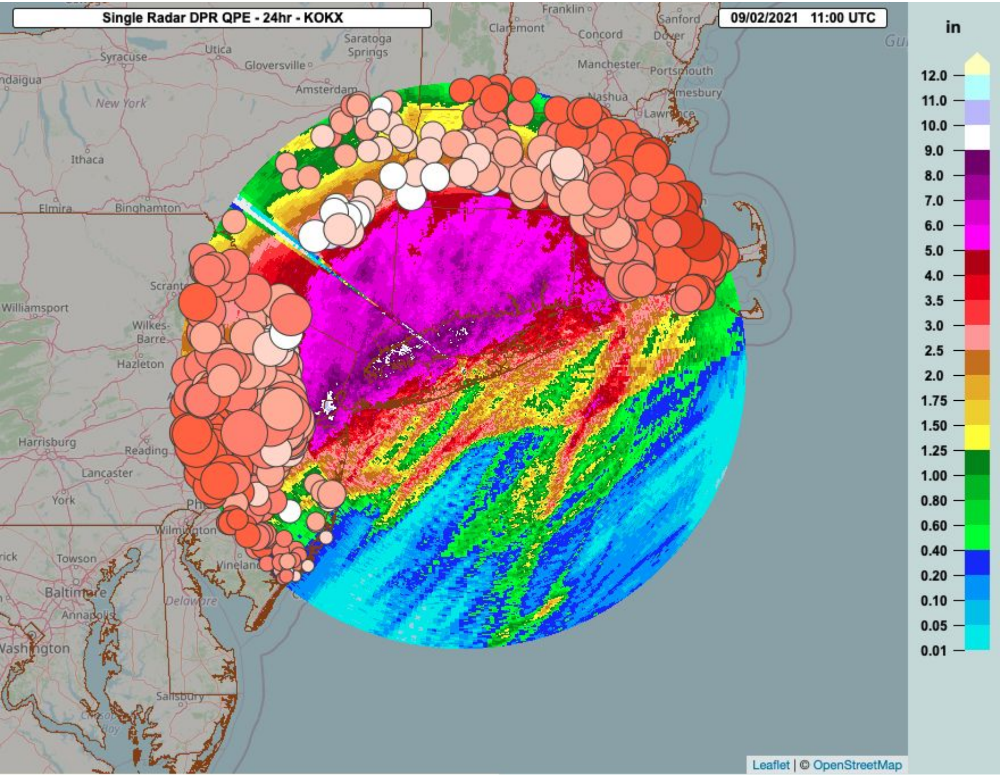
Remnants of Hurricane Ida - Below Melting Layer (<90 nm)

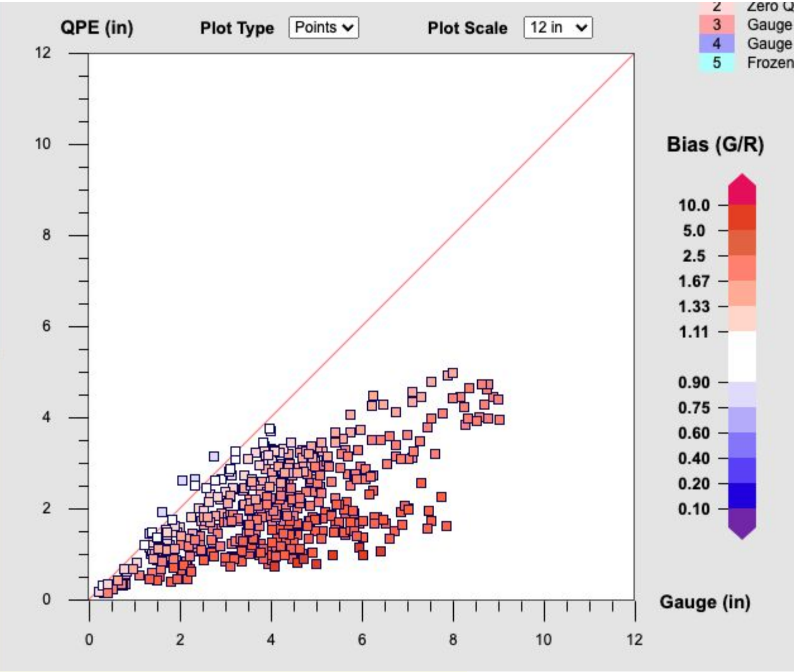




Mean Bias(G/R):	0.886	G-R Err Std Dev:	1.055
Add Bias (G-R):	-257.40	Corr Coeff:	0.696
Mean Err (G-R)/N:	-0.662	Fract Bias:	-0.128
Mean Abs Error:	1.055	Fract RMSE:	0.259
RMSE:	1.336	Fract Std Dev:	0.225

Remnants of Hurricane Ida - Above Melting Layer (> 90 nm)

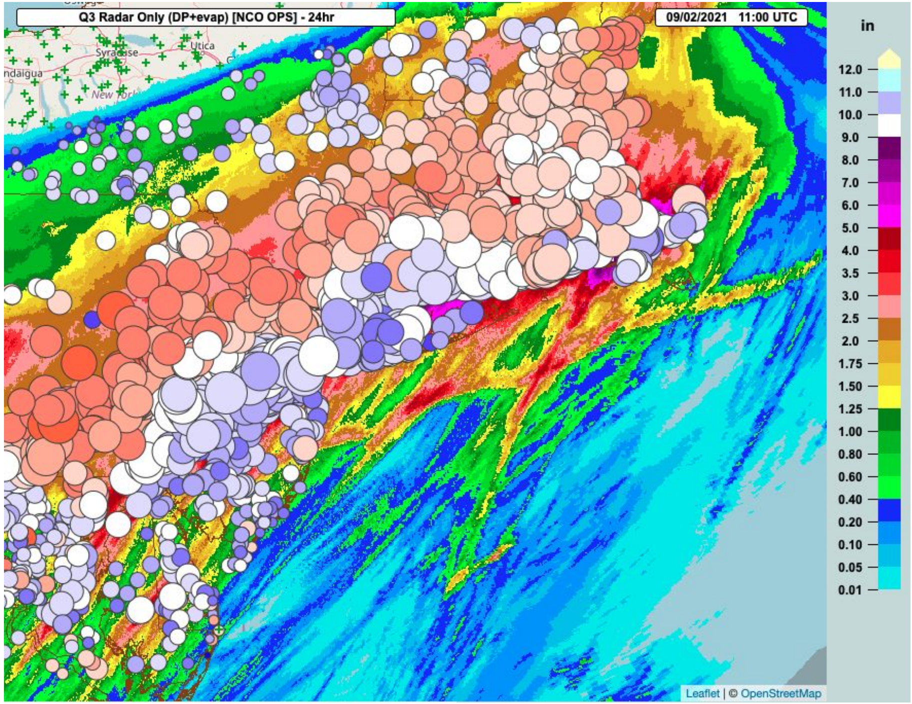




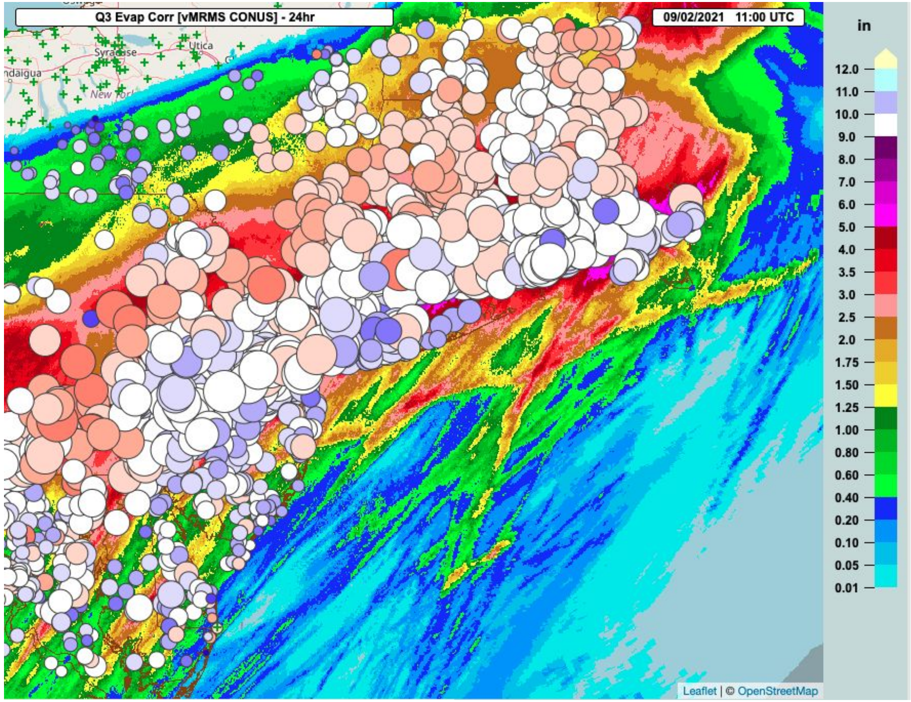
Mean Bias(G/R):	2.010	G-R Err Std Dev:	2.071
Add Bias (G-R):	1039.27	Corr Coeff:	0.687
Mean Err (G-R)/N:	2.062	Fract Bias:	0.502
Mean Abs Error:	2.071	Fract RMSE:	0.599
RMSE:	2.457	Fract Std Dev:	0.326

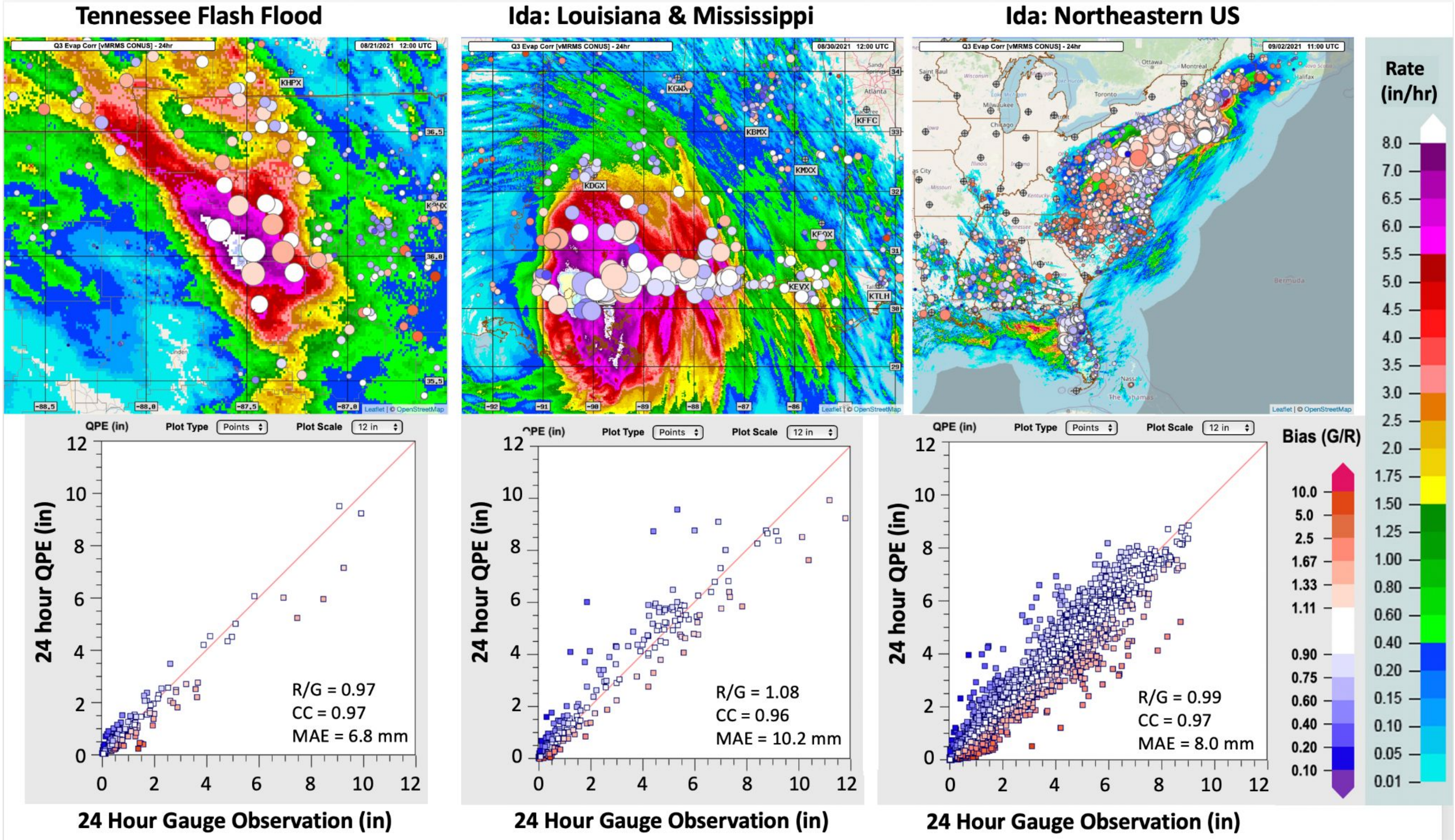
Remnants of Hurricane Ida - MRMS Dual-Pol QPE

Without R(A) Rate Adjustment and
Dual-Pol VPR Correction



With R(A) Rate Adjustment and
Dual-Pol VPR Correction

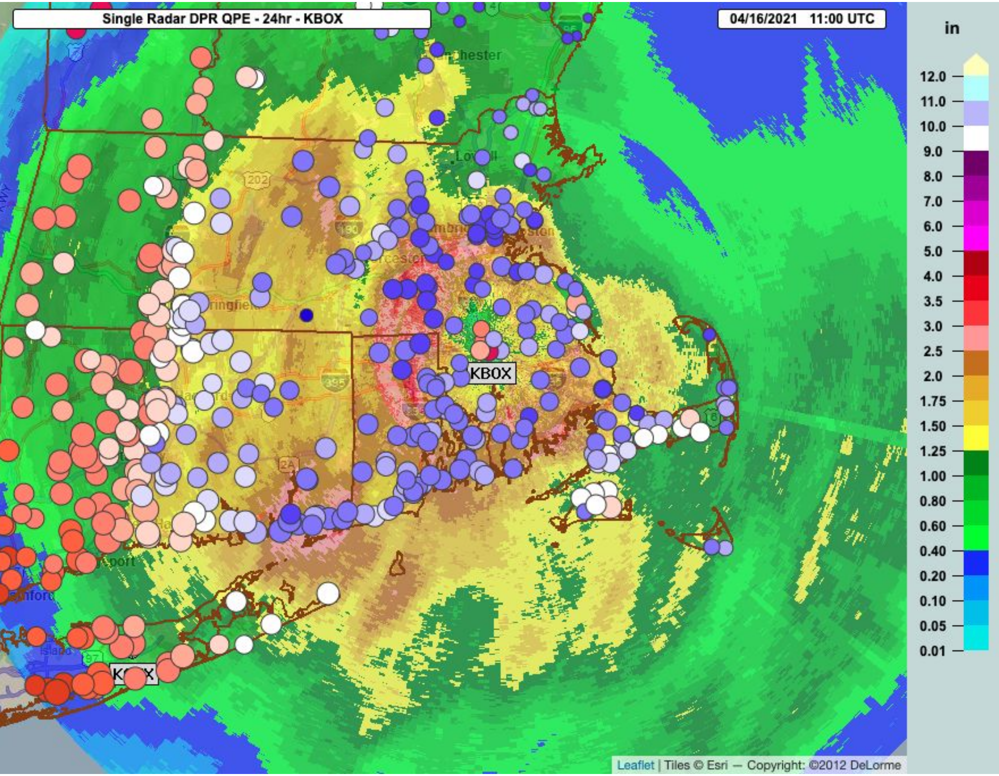


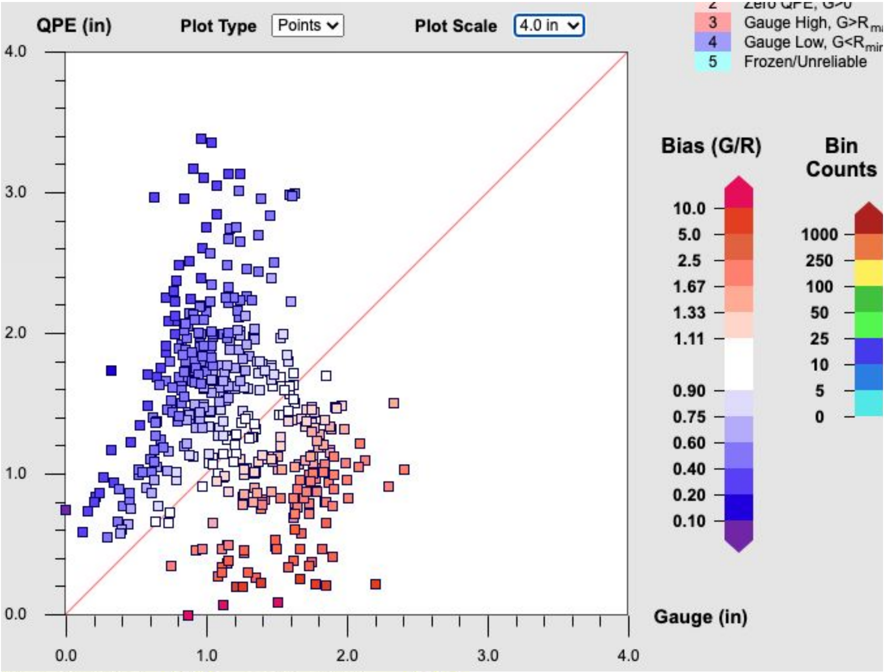


Tennessee Flash Flood
Ida: Louisiana & Mississippi
Ida: Northeastern US
Q3 Evap Corr [vMRMS CONUS] - 24hr
08/21/2021 12:00 UTC
08/30/2021 12:00 UTC
09/02/2021 11:00 UTC
Rate (in/hr)
Bias (G/R)
QPE (in)
Plot Type
Points
Plot Scale
12 in
24 hour QPE (in)
24 Hour Gauge Observation (in)
R/G = 0.97
CC = 0.97
MAE = 6.8 mm
R/G = 1.08
CC = 0.96
MAE = 10.2 mm
R/G = 0.99
CC = 0.97
MAE = 8.0 mm

Remaining Challenges

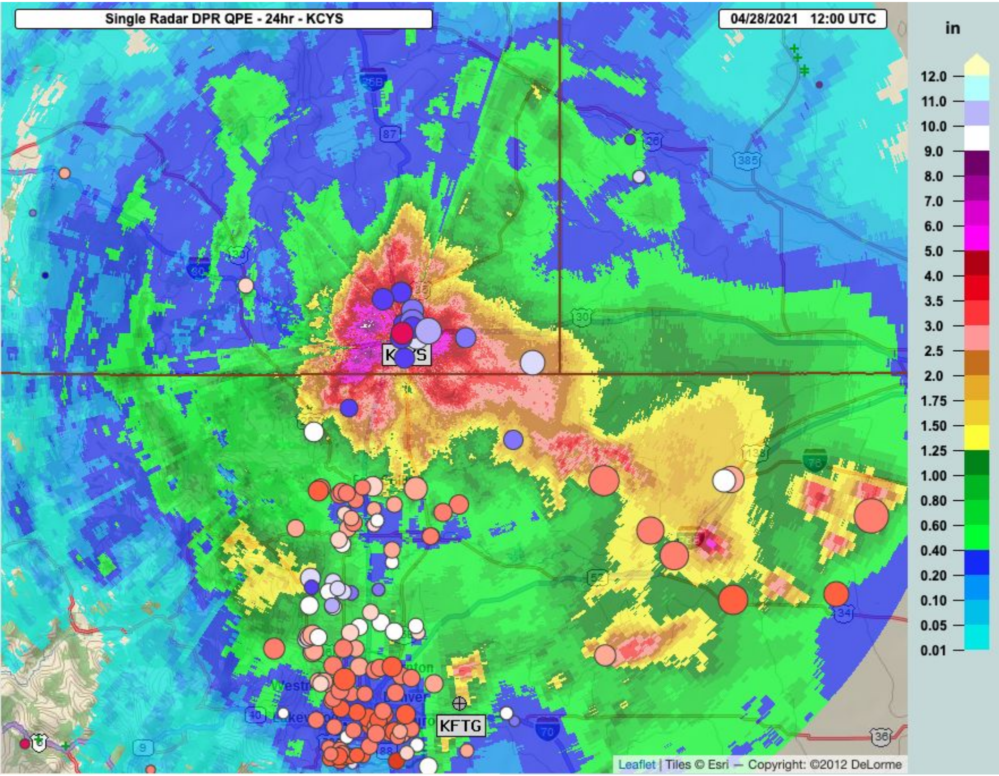
24hr Accumulations from KBOX DP QPE - 11Z 16 April 2021

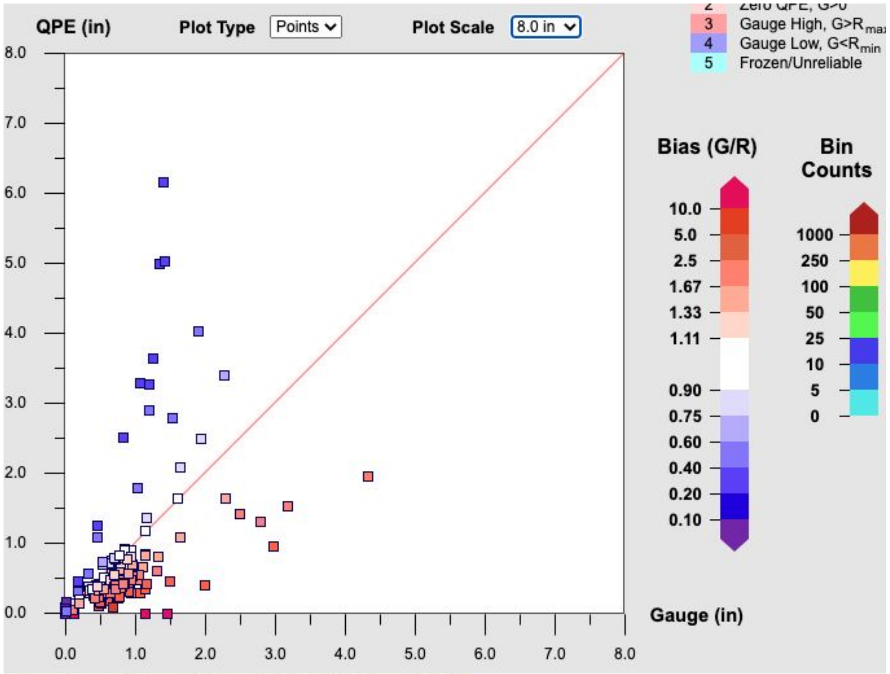




Mean Bias(G/R):	0.832	G-R Err Std Dev:	0.724
Add Bias (G-R):	-103.69	Corr Coeff:	-0.144
Mean Err (G-R)/N:	-0.241	Fract Bias:	-0.202
Mean Abs Error:	0.724	Fract RMSE:	0.716
RMSE:	0.855	Fract Std Dev:	0.687

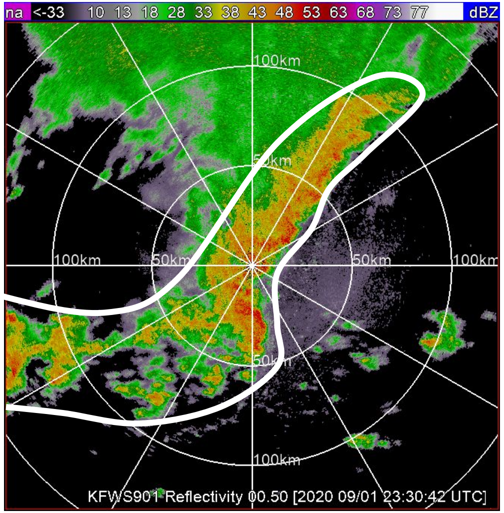
24hr Accumulations from KCYS DP QPE - 13Z 28 April 2021

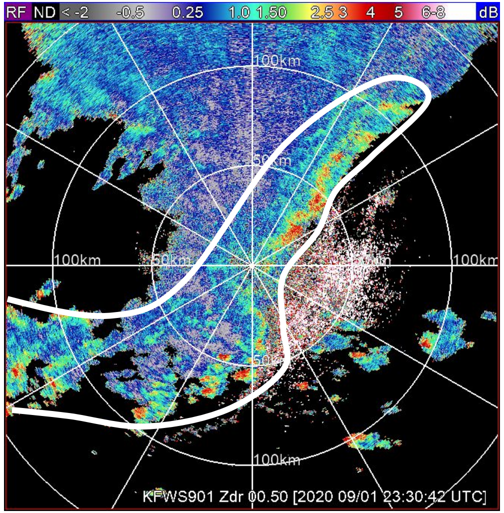


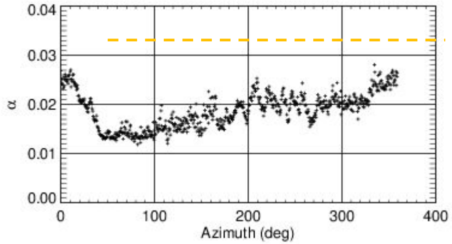


Mean Bias(G/R):	1.128	G-R Err Std Dev:	0.491
Add Bias (G-R):	15.35	Corr Coeff:	0.504
Mean Err (G-R)/N:	0.094	Fract Bias:	0.113
Mean Abs Error:	0.491	Fract RMSE:	1.019
RMSE:	0.846	Fract Std Dev:	1.012

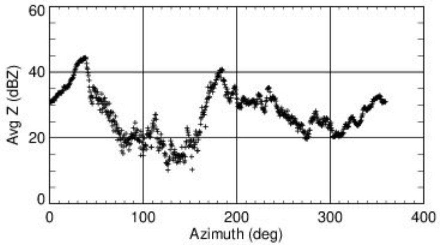
R(A) with azimuthally dependent α



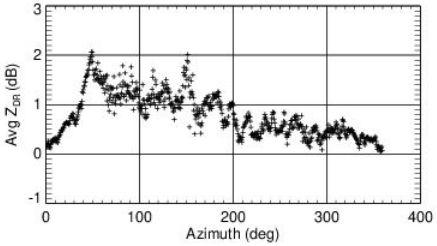




α(θ)



AvgZ(θ)



$AvgZ_{DR}(\theta)$

1) Constant α for the whole scan in current version;

2) In order to reflect the variations of DSD in a single scan we propose a new way to estimate $\alpha(\theta)$ for each radial:

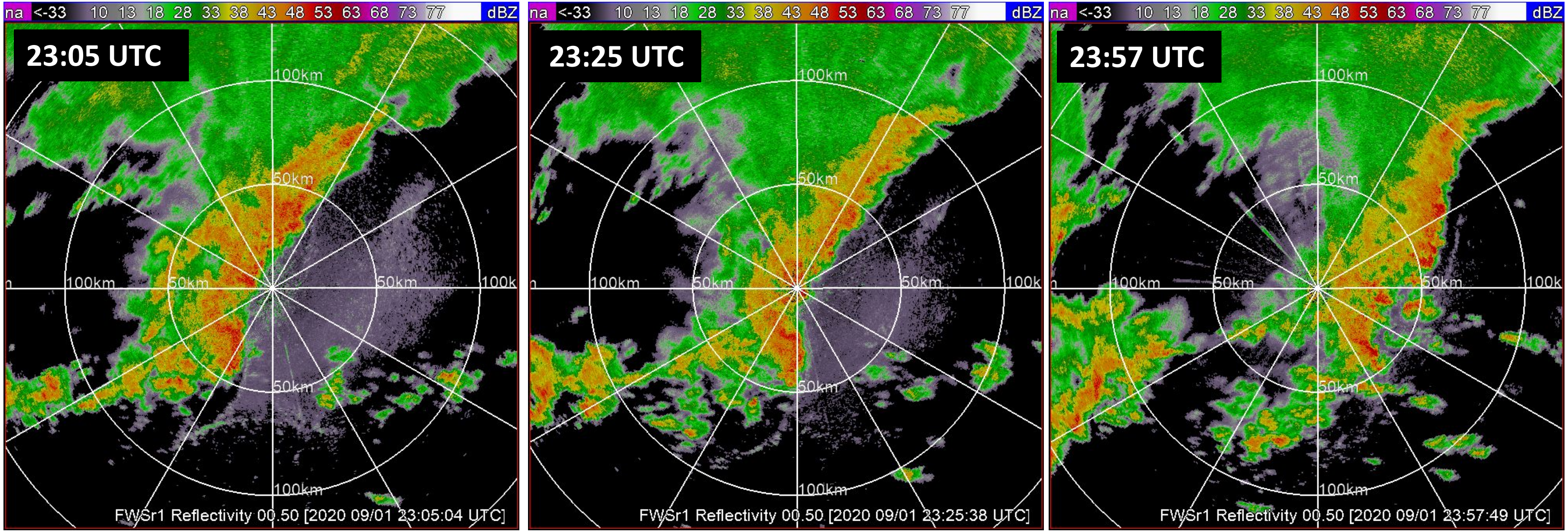
$$<\alpha> = \frac{\int Z^b(r)dr}{\int \frac{Z^b(r)}{\alpha[Z_{DR}(r)]}dr}$$

where

$$\alpha(Z_{DR}) = 0.008 + \frac{0.009}{Z_{DR}(dB) - 0.03}$$

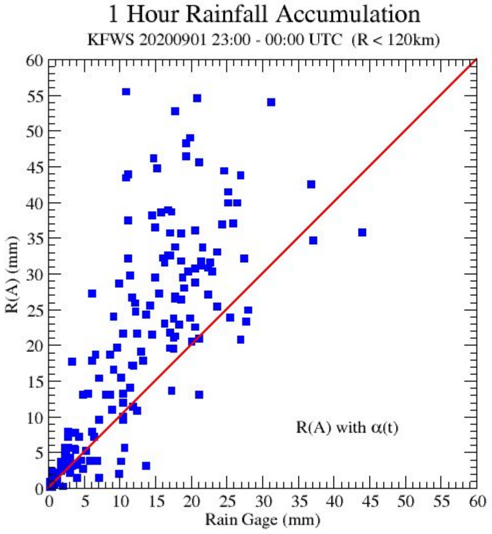
KFWS 20200901 23-00 UTC El=0.5⁰

Reflectivity

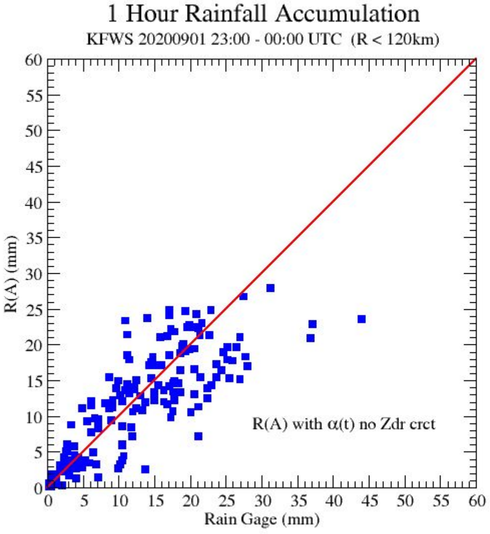


1 Hour Rainfall KFWS 20200901 23-00 UTC

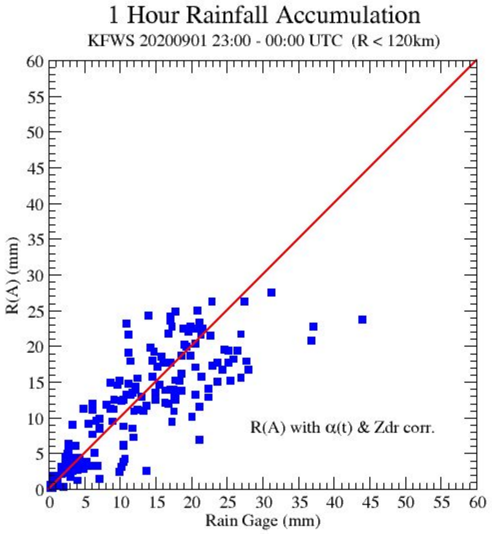
R(A) w/ α(t)



R(A) α(t,θ) w/o Z_{DR} correction



R(A) α(t,θ) w/ Z_{DR} correction



23:00 – 00:00 UTC	*Correlation*	*Bias Ratio*	*FRMSE*	*MFRMSE*
R(A) w/ α(t)	0.763	1.639	1.061	0.454
R(A) w/ α(t,θ) no Zdr corr.	0.824	0.929	0.410	0.213
R(A) w/ α(t,θ) & Zdr corr.	0.823	0.935	0.411	0.206

NumberRG=174

Wet radome causes Zdr bias

Discussion

- Specific Attenuation was deployed operationally in DP QPE with Build 19, with additional improvements under development

- Main focus of recent research is on optimization of the alpha parameter for different types of precipitation and for spatial variability

- In FY22, tech transfer efforts is examining R(A) sensitivity to severe beam blockage, and RPI/R2O is pursuing further testing of the azimuthally varying alpha.

Conclusions

- Implementation of specific attenuation in Build 19 led to dramatic improvement of DP QPE performance in intense rainfall events compared to previously used methods like R(Z) and R(Z,ZDR).

- Since the operational deployment of R(A), impacts on the QPE from partial beam blockage has been significantly reduced.

- NSSL continues to investigate methods to improve R(A) in light precipitation and in convective/stratiform mix events.