A New MRMS Dual Pol Based QPE Product Utilizing Specific Attenuation

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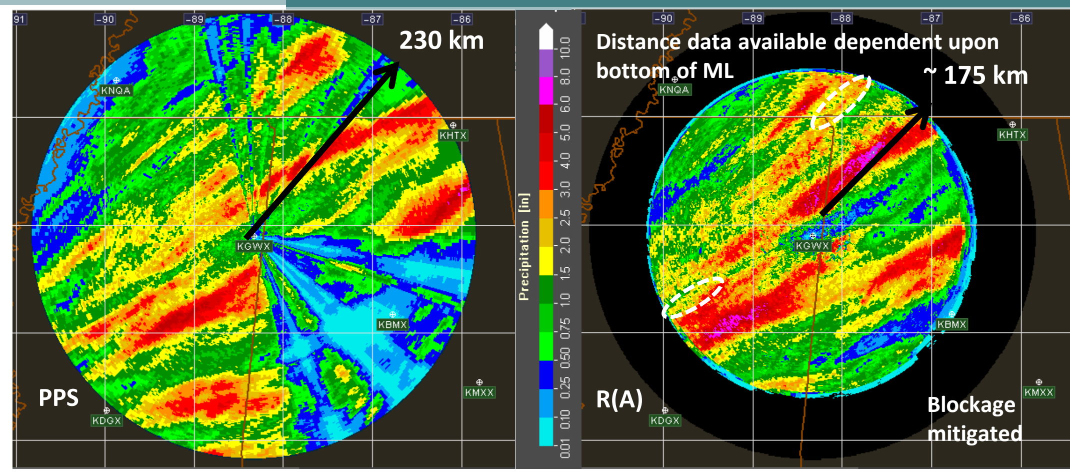

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Operational Radar QPE: A Short Review

- **Until 2010, radar QPE primarily consisted of the use of a single reflectivity to rain rate relationship, or R(Z), to estimate precipitation amounts**
  - *Warm season: convective R(Z)often used…Cool season: list of R(Z)s available*
  - *Any R(Z) changes were forecaster initiated and applied to entire field of view*

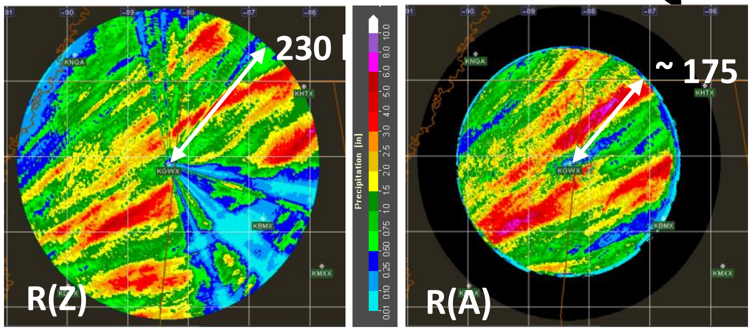
- **Between 2010 - 2014, Dual Pol (DP) & MRMS transitioned to operations QPE algorithms that automatically assigned a rain rate relation depending upon echo classification**
  - *Below [above] melting layer (ML), DP used R(Z,ZDR) & R(KDP) [R(Z)]*
  - *MRMS used multiple R(Z)s and applied Bright Band correction w/in & above ML*

- **Despite advances, need continued for rain relations less sensitive to 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*

- *Ryzhkov et al. (2014) and Wang et al. (2014) indicated good potential in using Specific Attenuation (A) to estimate rain*

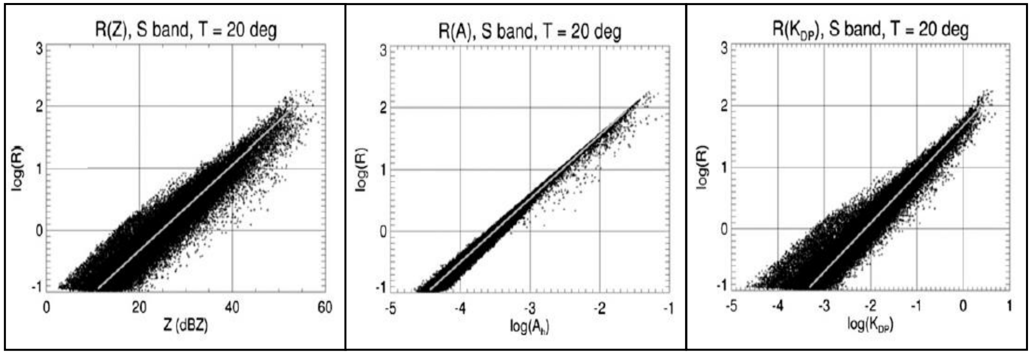
Advantages of Using Specific Attenuation for QPE

1. Immune to calibration, partial blockage, attenuation, & wet radome challenges



2. Higher spatial resolution than $R(K_{DP})$ estimates

3. Less sensitive to the DSD variability than R(Z) and $R(K_{DP})$



CAVEATS

1. Must use R(Z) within/above ML and when $\Delta\phi_{DP} < 3°$

2. Use R(KDP) in hail cores

Specific Attenuation 'A': Equations

- $$A(r) = \frac{Z^b(r)C(b,PIA)}{I(r_1,r_2) + C(b,PIA)I(r,r_2)}$$ *where 'Z' is radial reflectivity*

Radar Radial

$\mathbf{Z(r_1)}$ $\mathbf{\Phi(r_1)}$			$\mathbf{Z(r)}$				$\mathbf{Z(r_2)}$ $\mathbf{\Phi(r2)}$

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

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

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

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

PIA => Path Integrated Attenuation

Total span of PhiDP along radial

- Rain rates from **A** are calculated via: $R(A) = 1420.0A^{1.03}$

where the constants were optimized for S band radars

- *Using methodology of Ryzhkov et al. (2014) a prototype algorithm was developed*

*Parameter '**α**' must be estimated in order to calculate **A** fields*

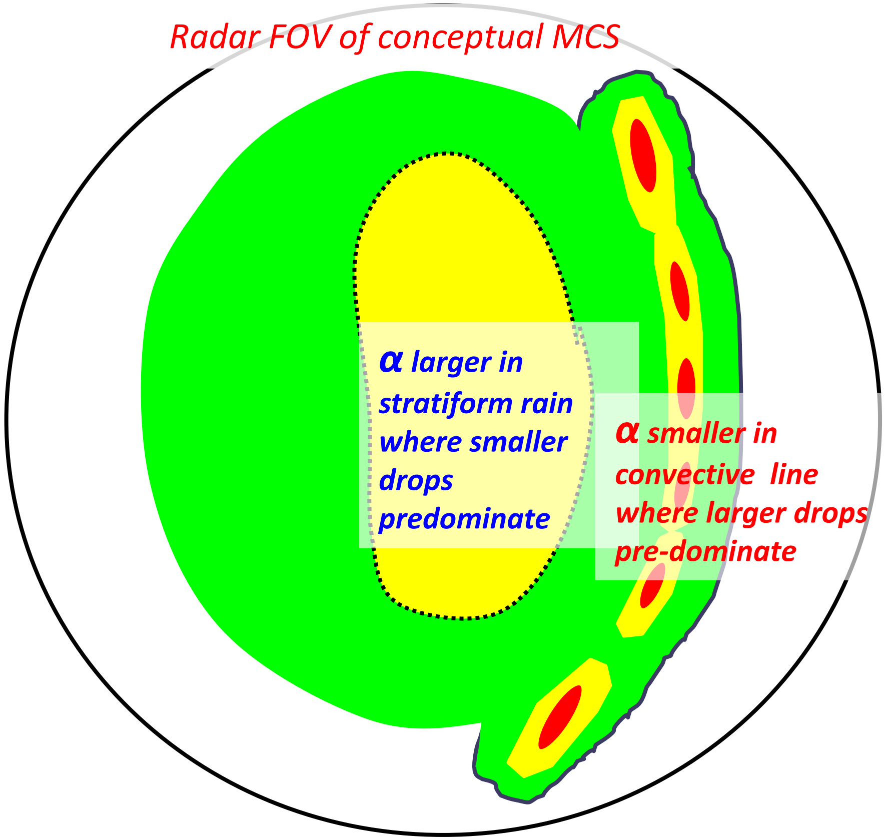
Estimating the Parameter ‘α’

Within a precipitation event, alpha can vary considerably (see right)

- *Alpha smaller (larger) in convective (stratiform) rain*

Three options considered in estimating Alpha:

- *Assume spatially/temporally fixed alpha throughout event*
- *Estimate alpha for radar field of view (FOV)*
  - *assumes spatially uniform alpha for FOV*
  - *Assumes PhiDP span/radial Z enough to modulate **A** fields to allow relevant R(A) rates*
- *Estimate alpha via radar echo classification of precipitation (convective or stratiform)*
  - *required further research before it could be adequately evaluated*

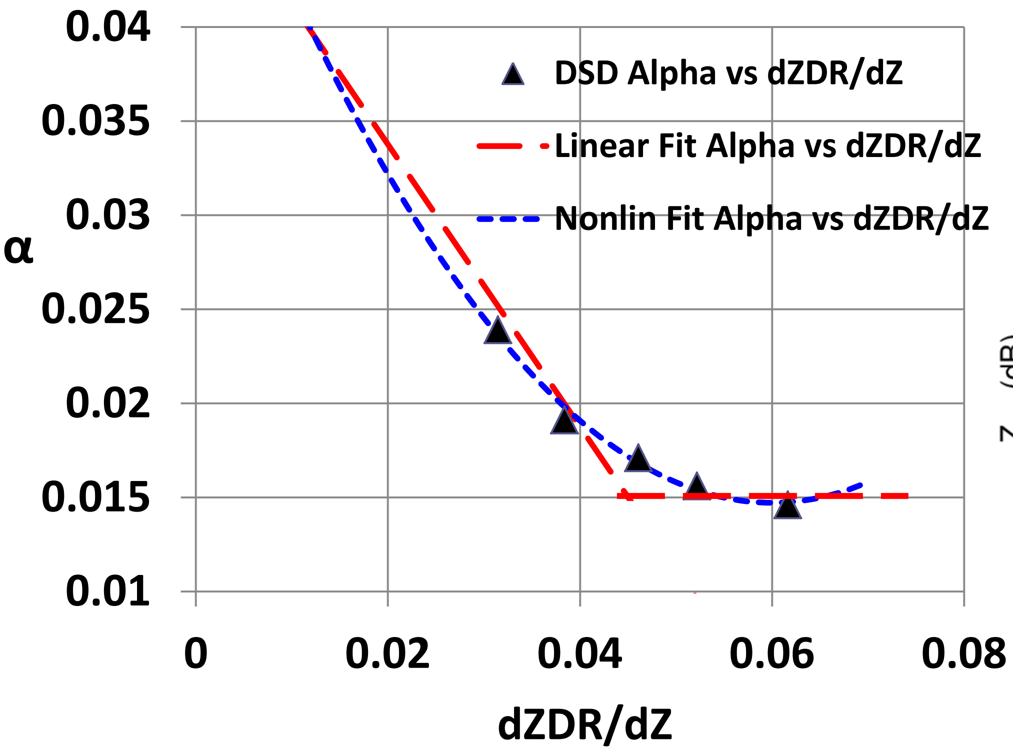


Hence, we calculated rain rates from A fields where alpha estimated via options 1, 2

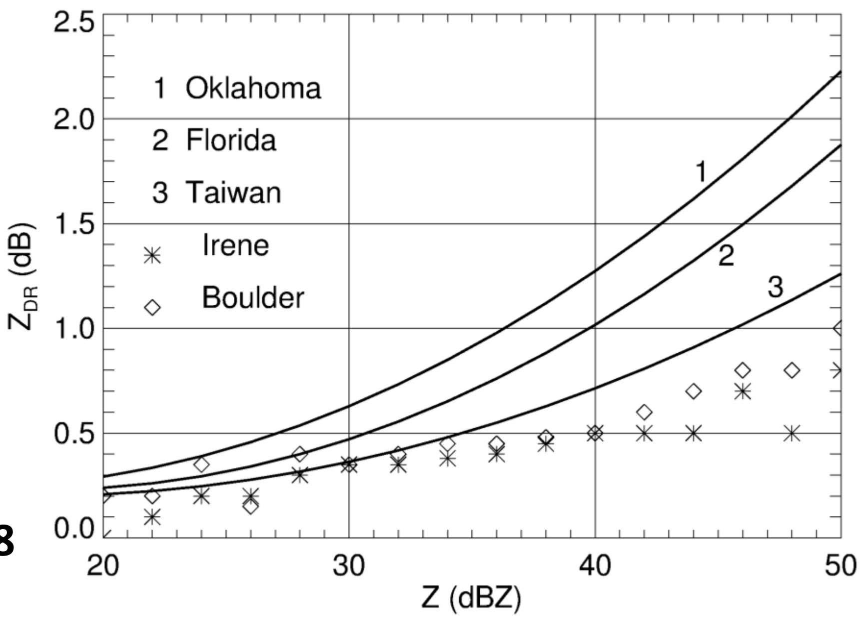
Physical Significance of Parameter *Alpha*

- Previous case study work suggested that :
  - *Higher (lower) concentrations of smaller (larger) raindrops generally lead to higher (lower) alpha values*
  - Hence, ***α*** related to the type of rain regime (Tropical vs Continental)

α vs slope of ZDR/Z

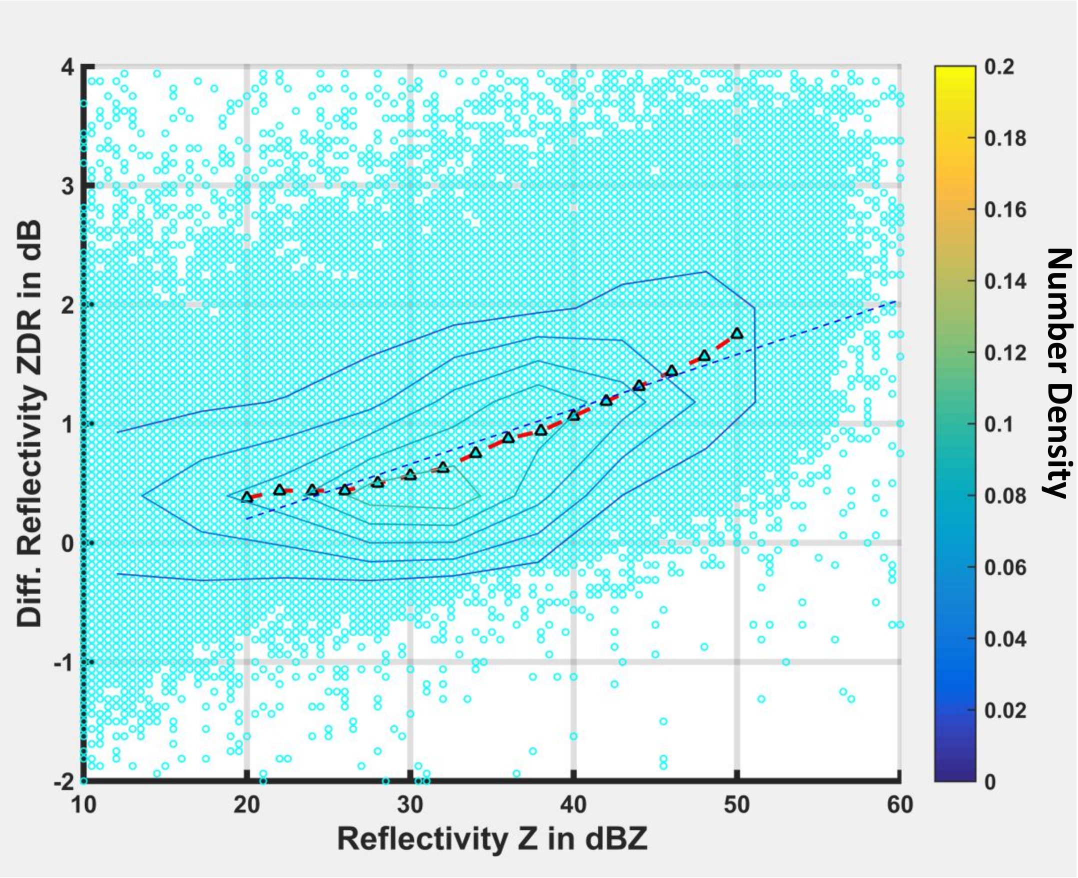


Concept of "Z_{DR} vs Z slope" to identify dominant rain type & reduce dependence of ZDR cal.



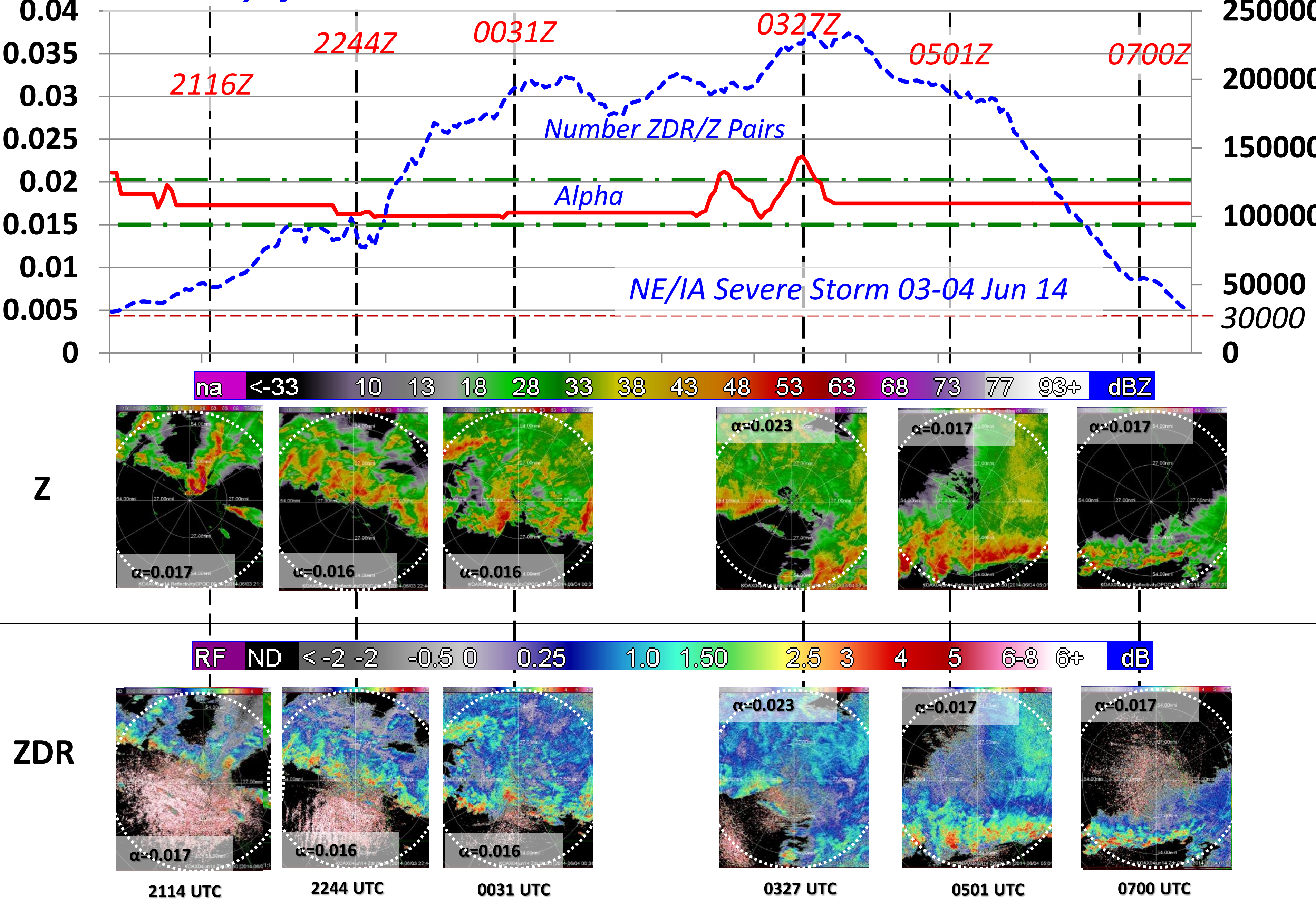
Estimating Parameter ‘α’: Real Time Estimates

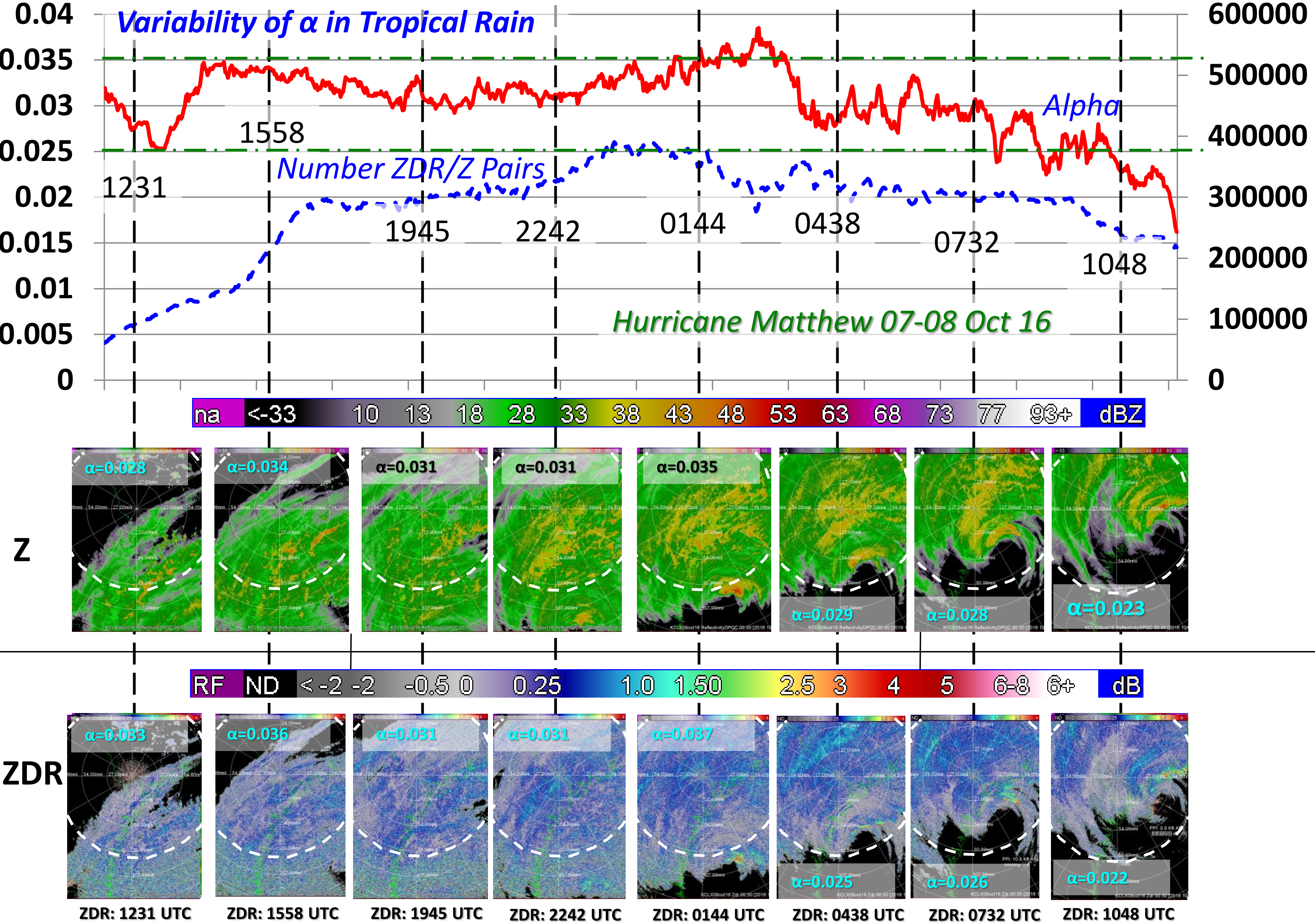
- **For each 0.5° tilt, ZDR/Z pairs within pure rain collected**
  - *Data was binned and medians calculated for bins between Z = 20 and 50 dBZ*
  - *Linear Least Squares fit of paired ZDR/Z medians:*



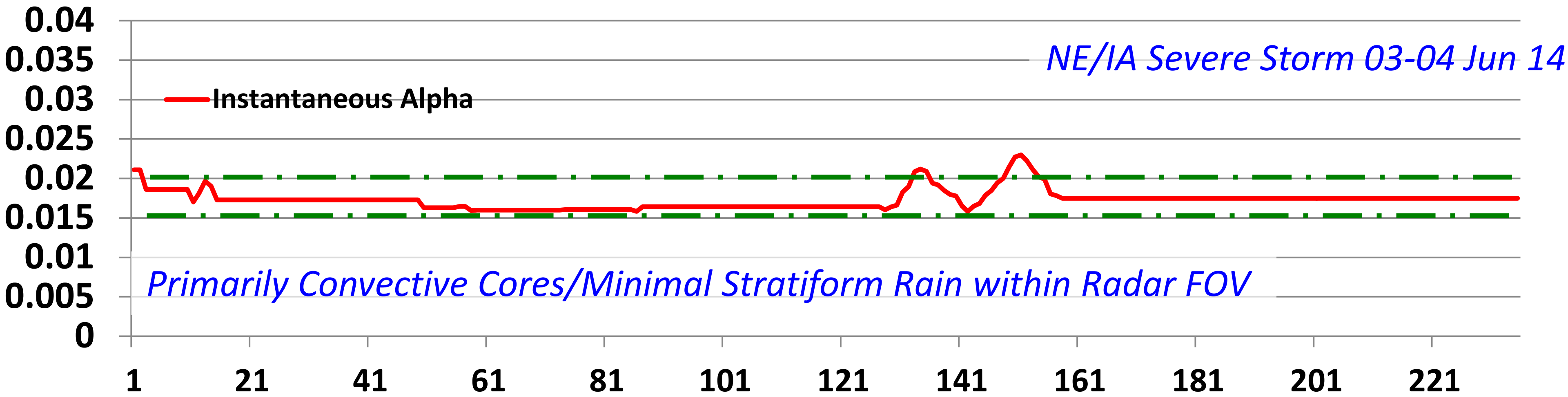
Median ZDRs/line: triangles/red dashed
Linear Fit: blue dashed

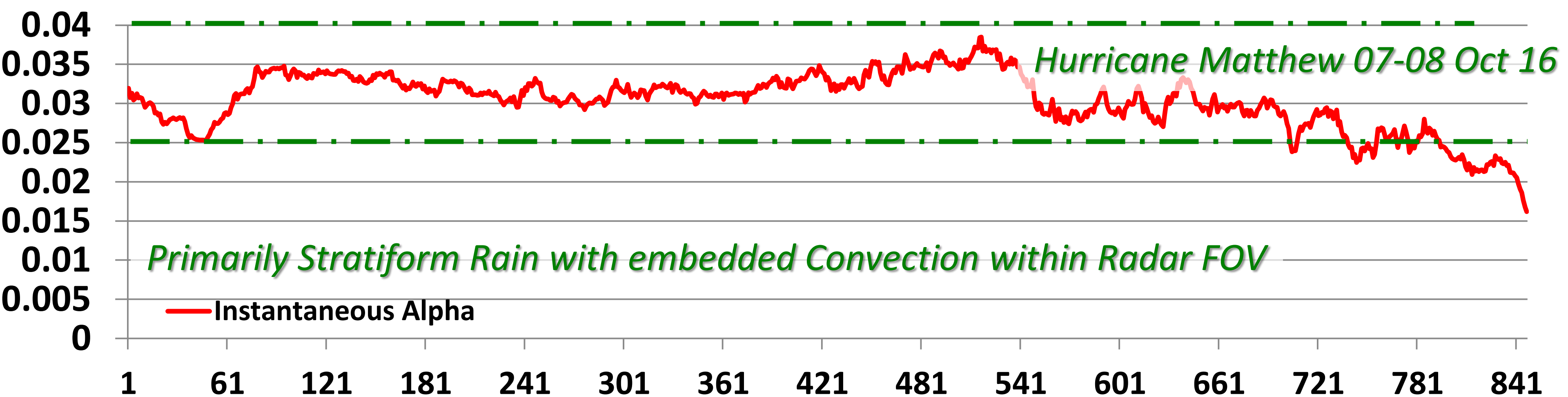
Variability of α in Continental Rain

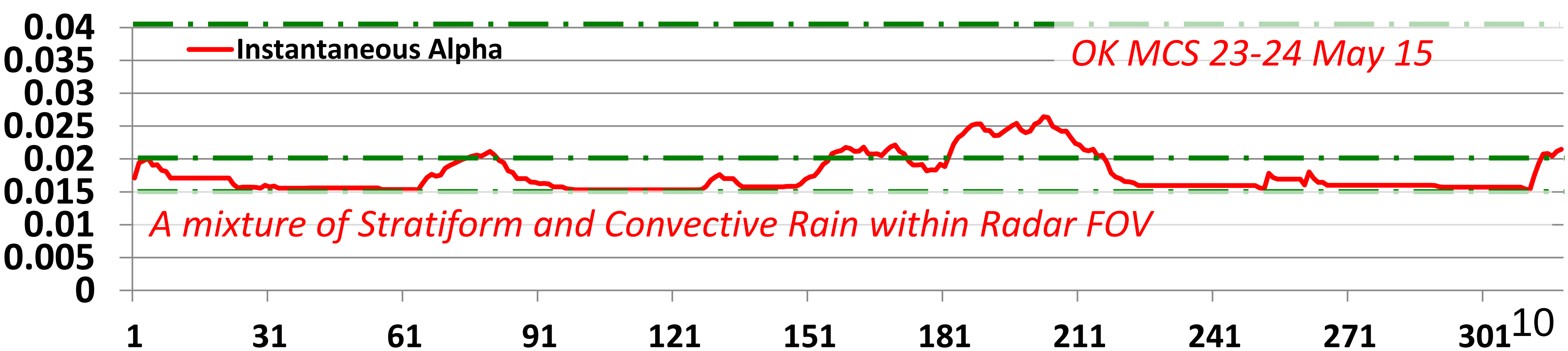




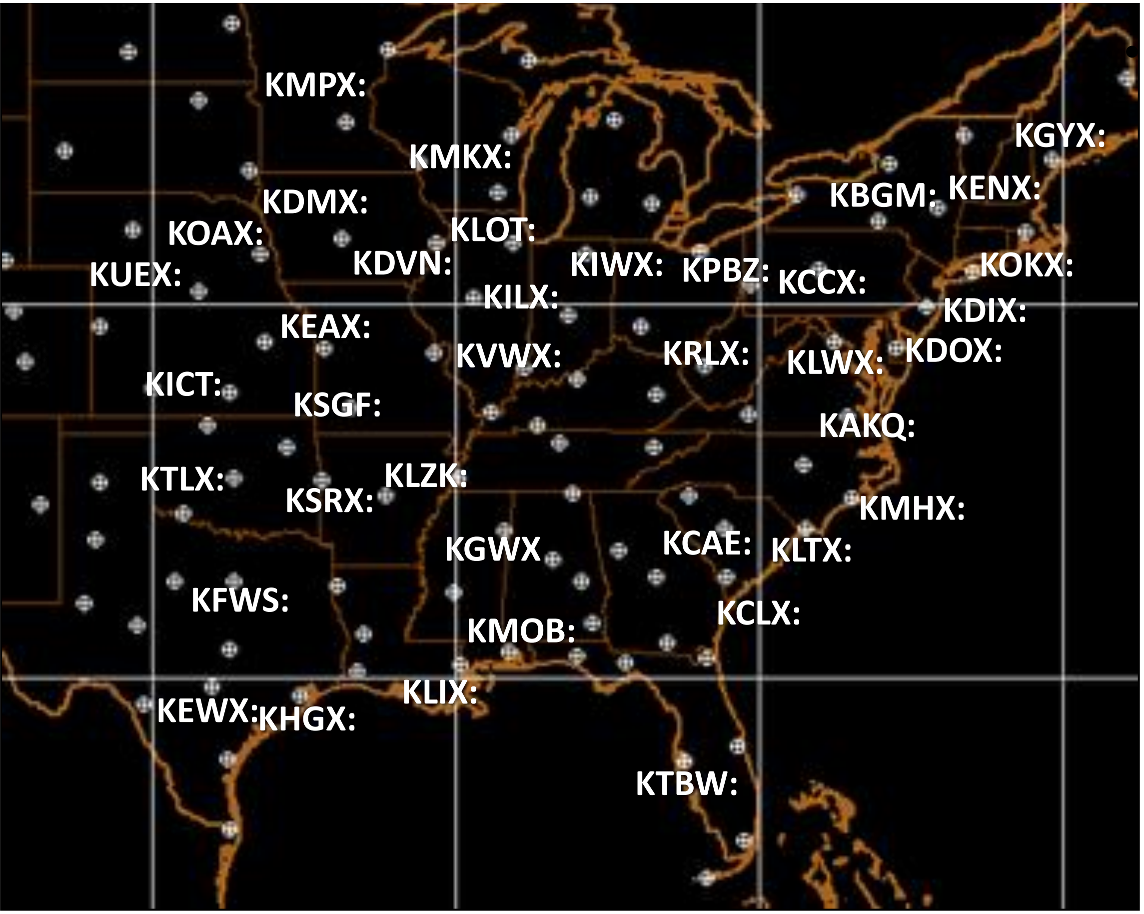
Variability of α in Tropical Rain
Number ZDR/Z Pairs
Alpha
Hurricane Matthew 07-08 Oct 16
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
600000
500000
400000
300000
200000
100000
0
1231
1558
1945
2242
0144
0438
0732
1048
na <-33 10 13 18 28 33 38 43 48 53 63 68 73 77 93+ dBZ
Z
α=0.028
α=0.034
α=0.031
α=0.031
α=0.035
α=0.029
α=0.028
α=0.023
RF ND < -2 -2 -0.5 0 0.25 1.0 1.50 2.5 3 4 5 6-8 6+ dB
ZDR
α=0.033
α=0.036
α=0.031
α=0.031
α=0.037
α=0.025
α=0.026
α=0.022
ZDR: 1231 UTC
ZDR: 1558 UTC
ZDR: 1945 UTC
ZDR: 2242 UTC
ZDR: 0144 UTC
ZDR: 0438 UTC
ZDR: 0732 UTC
ZDR: 1048 UTC


0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
Instantaneous Alpha
NE/IA Severe Storm 03-04 Jun 14
Primarily Convective Cores/Minimal Stratiform Rain within Radar FOV
1
21
41
61
81
101
121
141
161
181
201
221


0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
Hurricane Matthew 07-08 Oct 16
Primarily Stratiform Rain with embedded Convection within Radar FOV
Instantaneous Alpha
1
61
121
181
241
301
361
421
481
541
601
661
721
781
841


0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
Instantaneous Alpha
OK MCS 23-24 May 15
A mixture of Stratiform and Convective Rain within Radar FOV
1
31
61
91
121
151
181
211
241
271
301

VALIDATION OF PROTOTYPE ALGORITHM

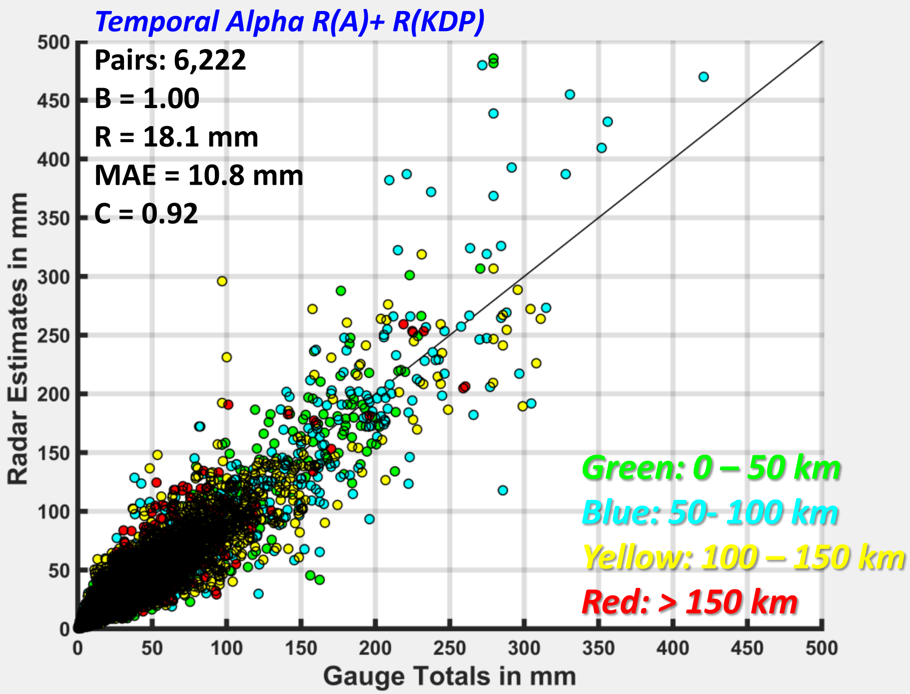


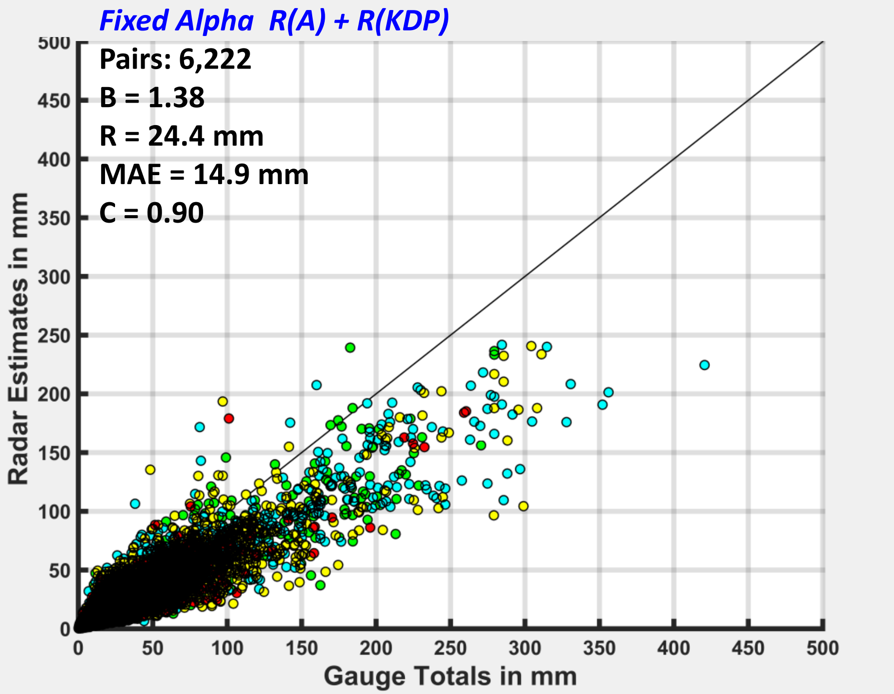
We calculated R(A) + R(KDP) rain rates by: 1) assuming a fixed alpha for duration of precipitation event; and 2) estimating alpha for every 0.5° tilt

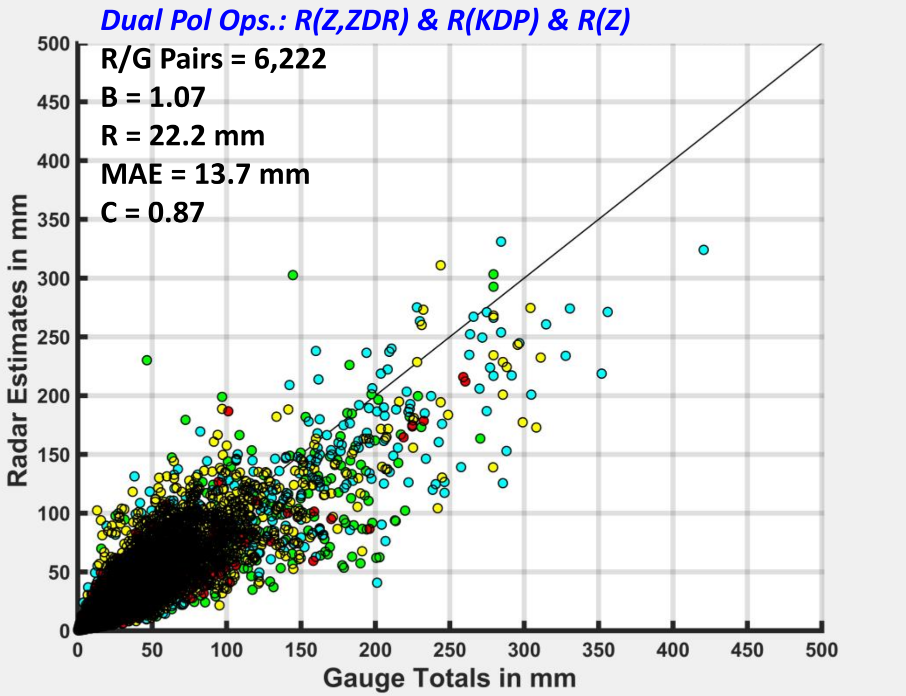
For validation we used data from 37 WSR-88D radars on 56 different calendar days during the 2014 – 2017 warm seasons

- *Radars chosen spanned a large portion of the Eastern US*
- *Most cases comprised of MCSs with tropical, continental or mixed rain regime characteristics*

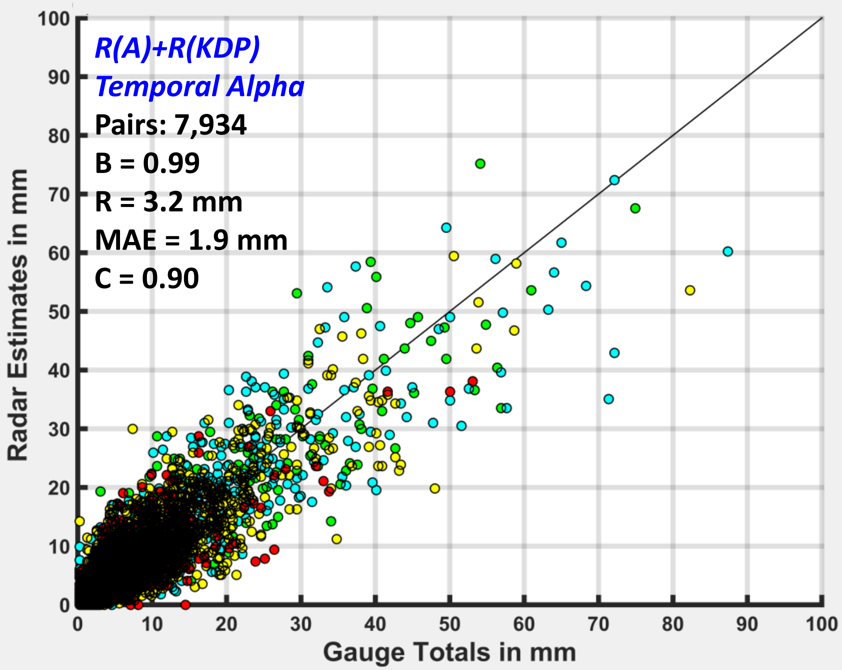
- **R(A) estimates were used below ML while R(KDP) used in strong convection (Z > 50 dBZ)**
- **Results were compared to operational Dual Pol QPE**

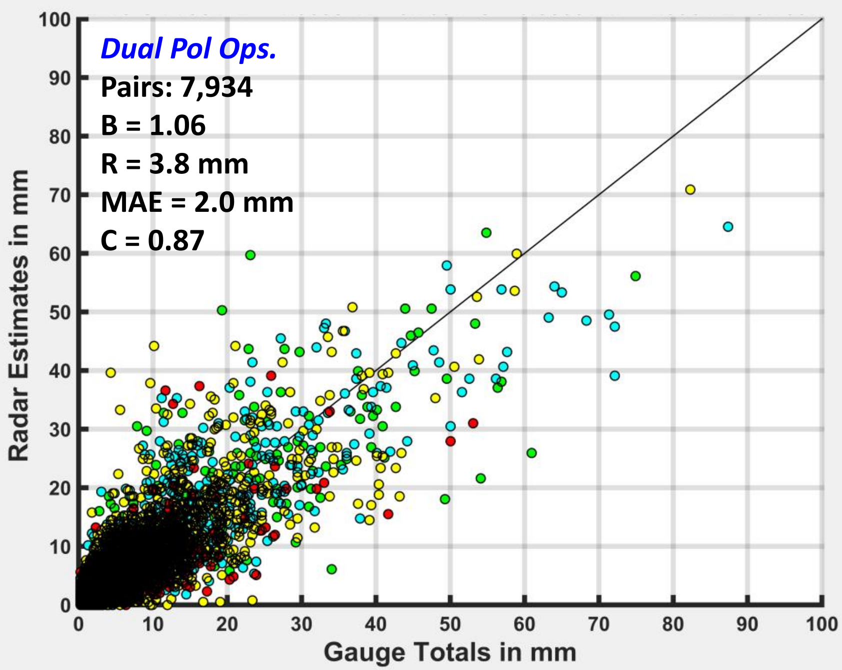






- 24-hr _Temporal (top left), Fixed (top right) & Dual Pol Ops. (bottom right) QPE_ to QC'd CoCoRaHS/automated gauges for ***all cases***
  - Fixed alpha QPE causes significantly higher errors/underestimate bias
- Despite known alpha variability within precipitation events, Temporal Alpha performed better than Dual Pol, *especially for* gauge totals > 150 millimeters

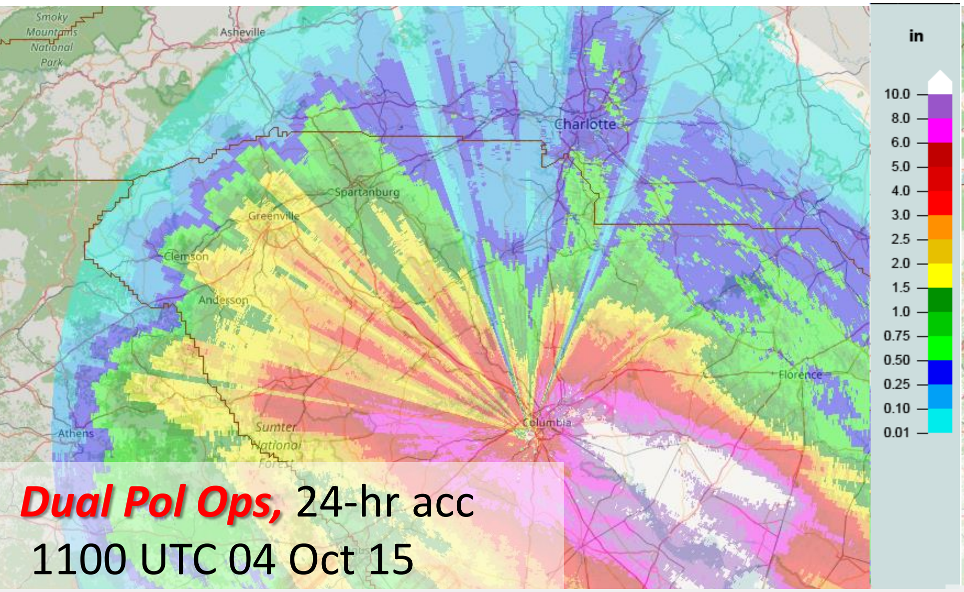


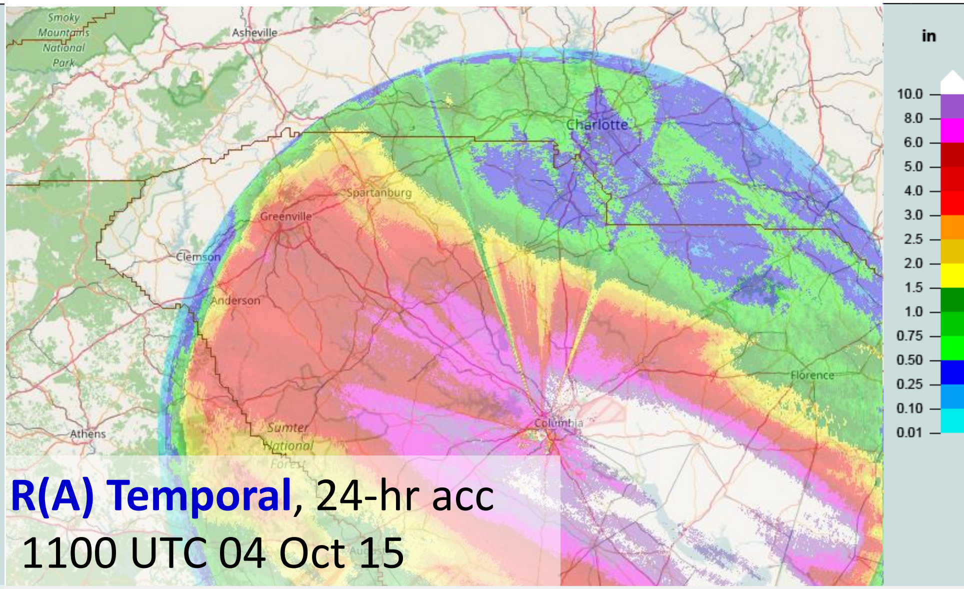


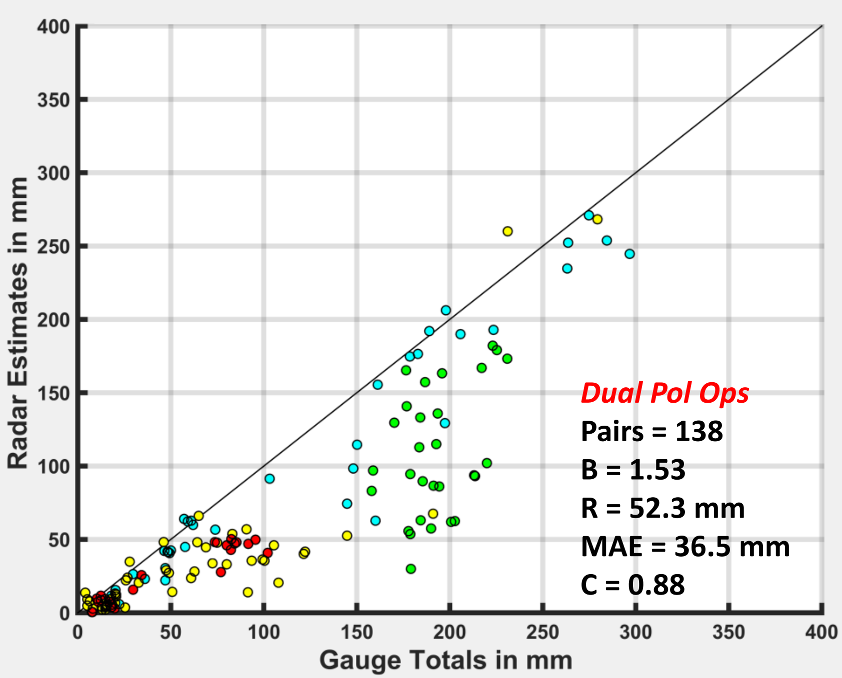
- Comparison of 1-hr *Temporal Alpha (top left), Dual Pol Ops. (bottom left) QPE* estimates to quality controlled automated rain gauges for ***twenty cases only***

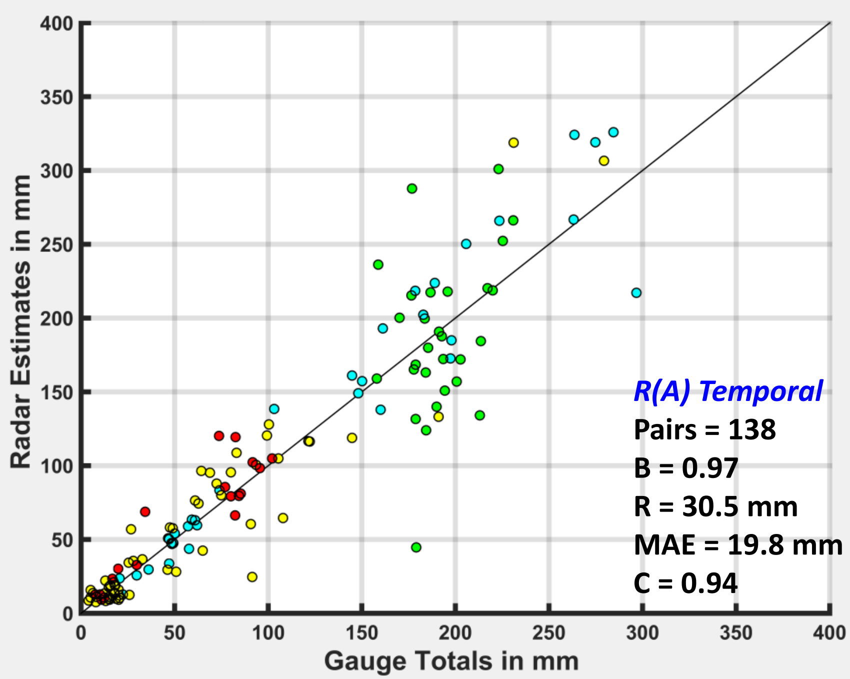
- Differences were more subtle however there was higher correlation and overall less scatter for the R(A) + R(KDP) QPE
    - *Noteworthy was the performance of the new QPE for higher rainfall totals (G > 40 mm)*

MITIGATION OF PARTIAL BLOCKAGE

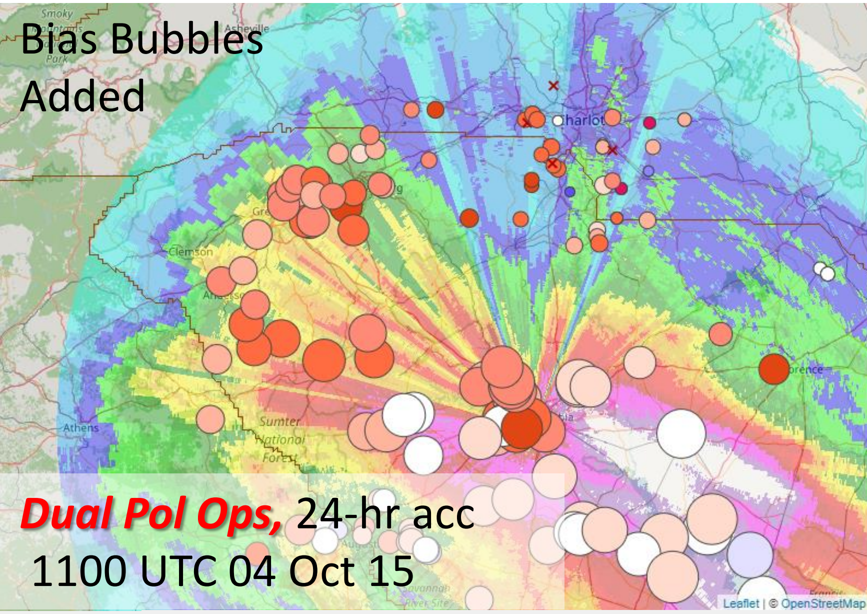


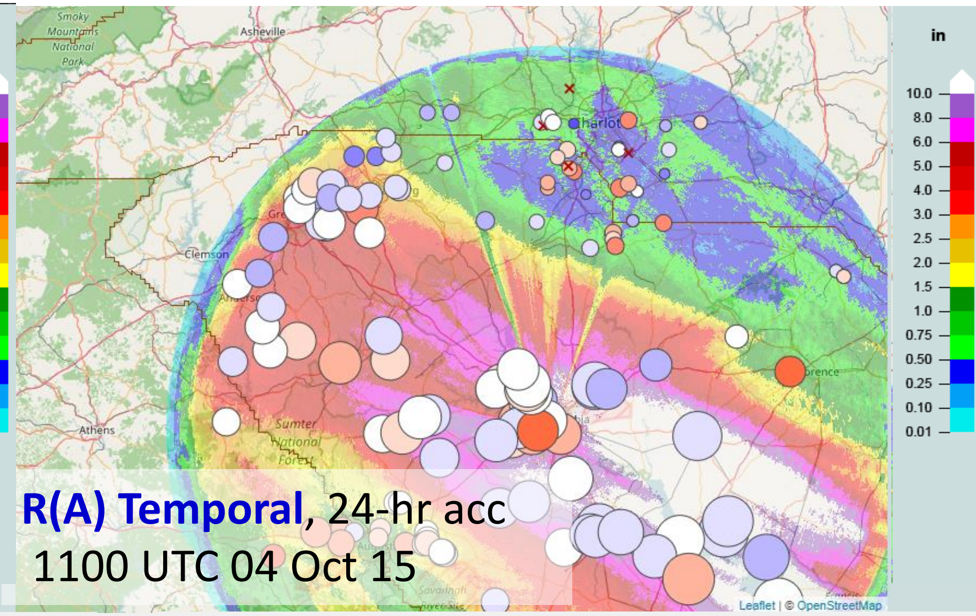


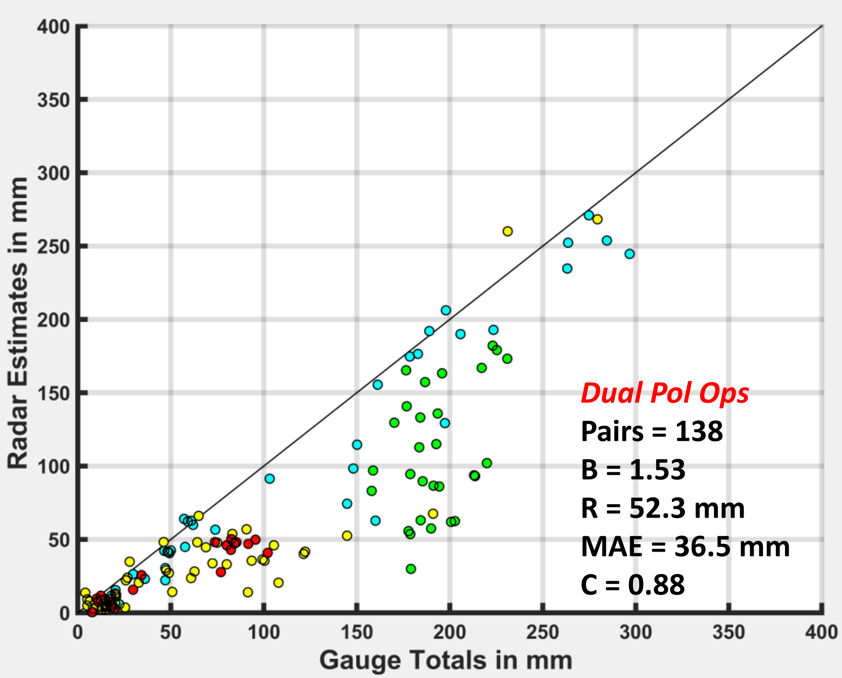


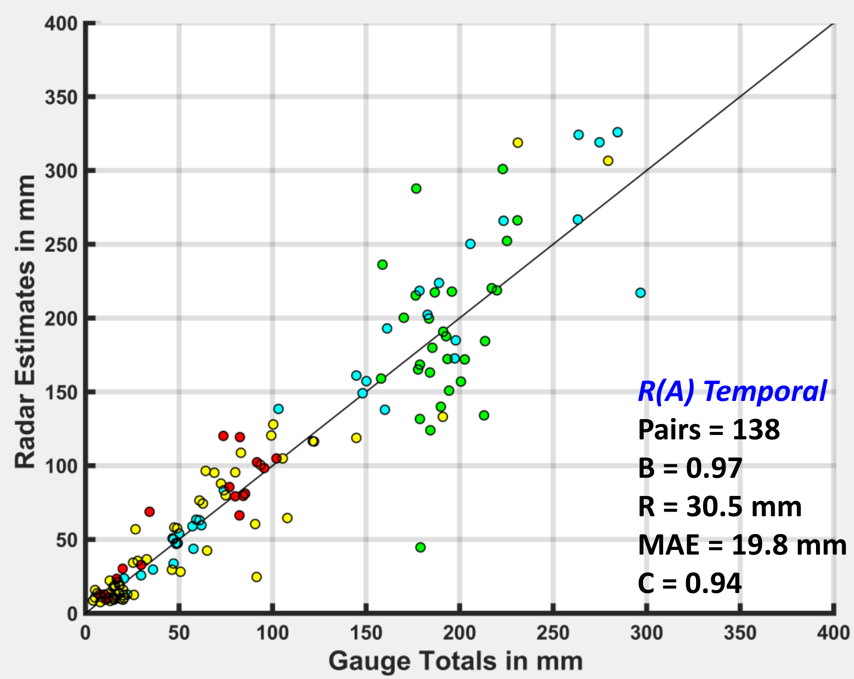


MITIGATION OF PARTIAL BLOCKAGE

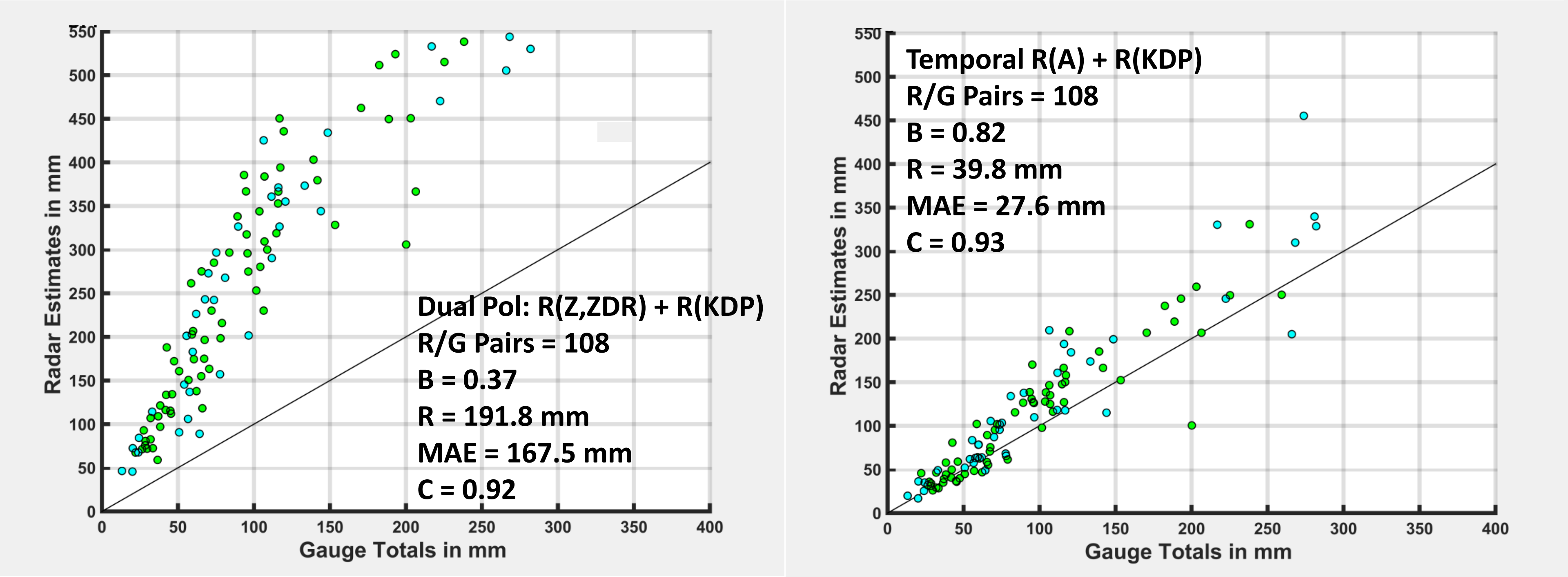








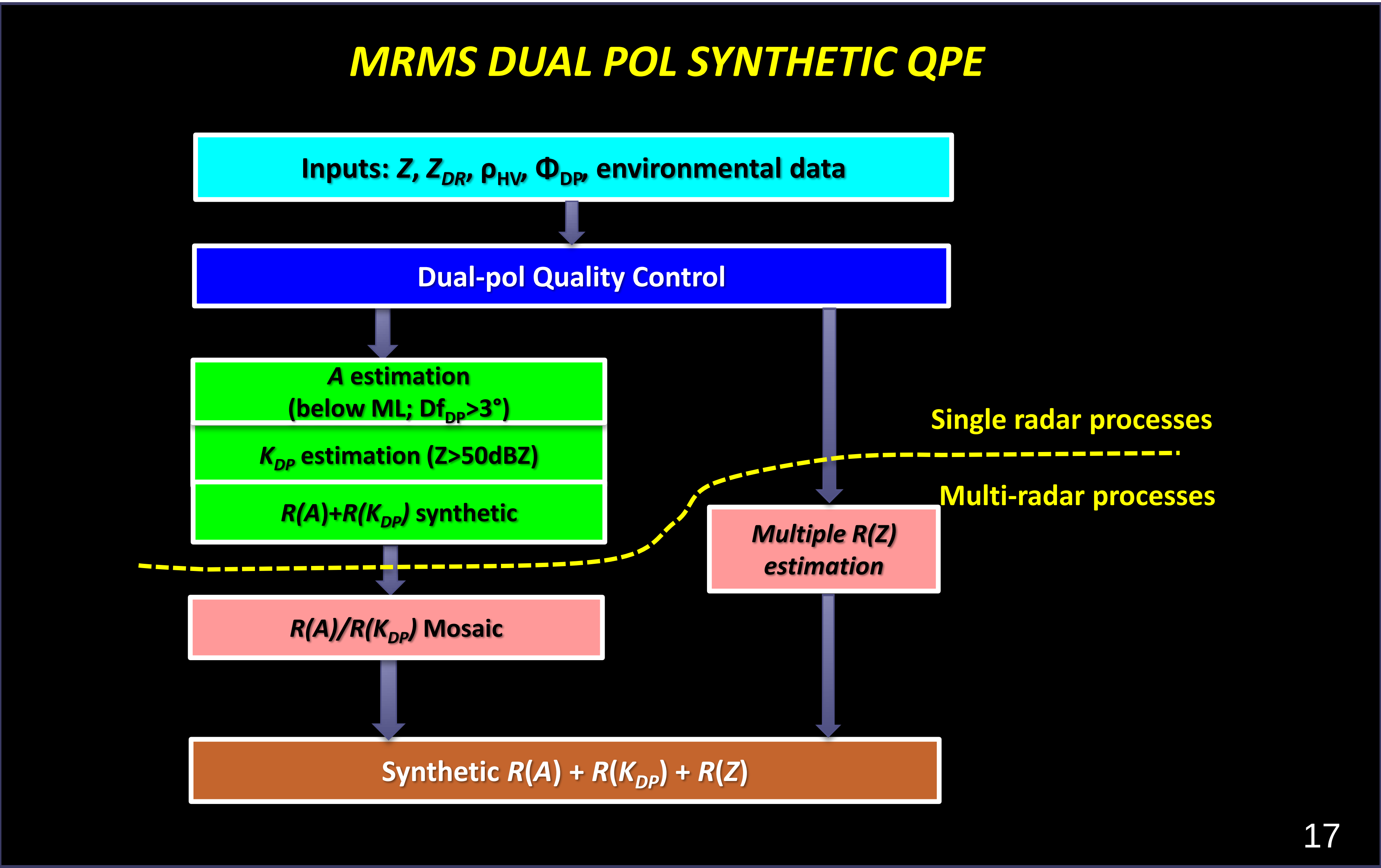
MITIGATION OF ZDR/Z MISCALIBRATION



- *24-h acc. operational Dual Pol (top left) and Temporal R(A) (top right) estimates vs. QC'd. 1200 UTC CoCoRaHS & HADS gauges for period ending 12 August, 2016*
- *Data from KLIX radar in New Orleans, LA; during rainfall event, ZDR (Z) for radar was over 1 dB low (~0.75 dBZ high) resulting in very high 24-h accumulations*
- *Despite ZDR/Z calibration challenges associated with Dual Pol, the new QPE substantially reduced errors*

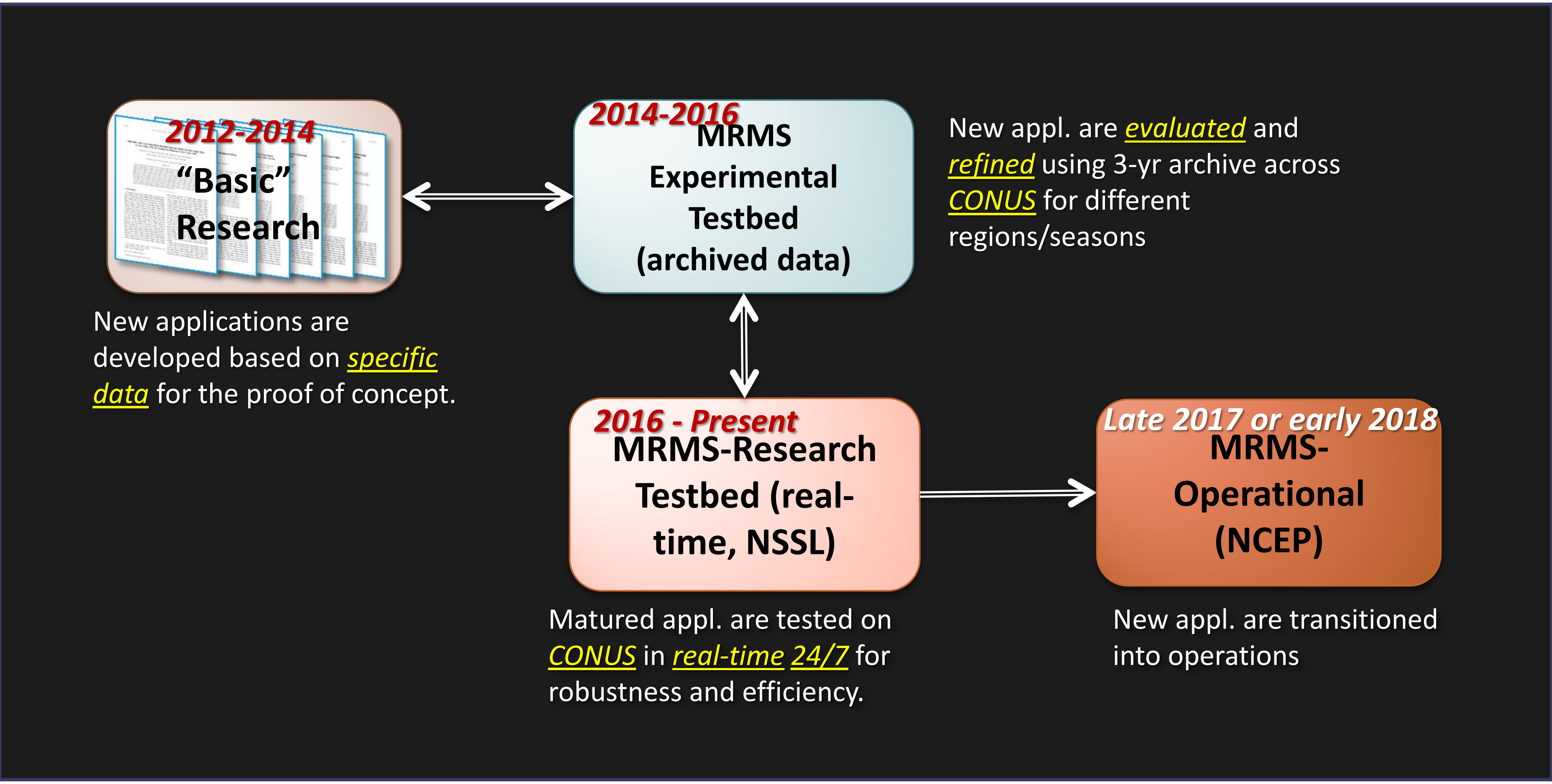
MRMS INTEGRATION

- Prototype algorithm was integrated into MRMS to produce a new QPE product (Q3DP) that uses R(A) below the melting layer, R(Z) within and above and R(KDP) where hail was likely



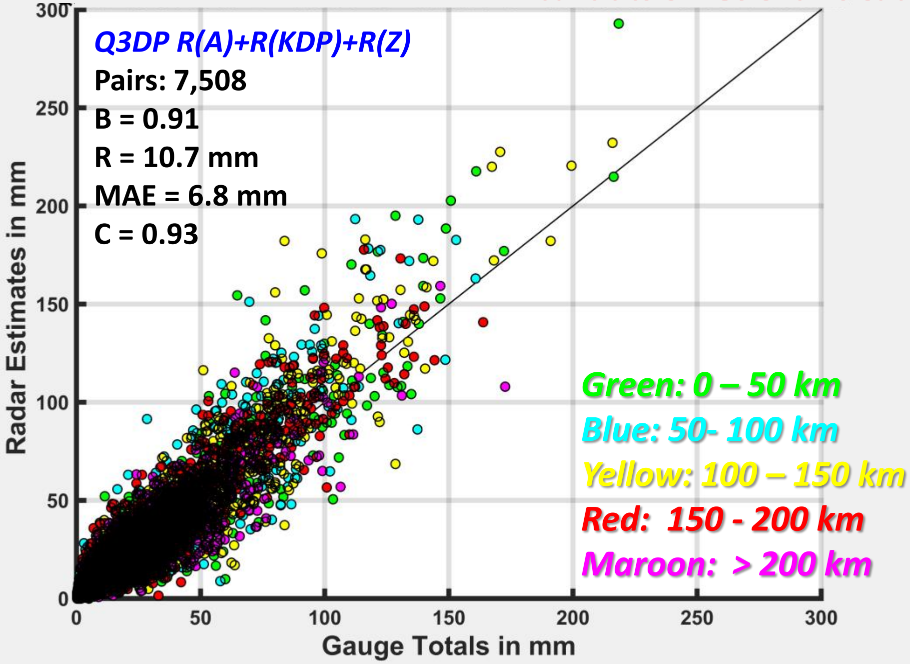
MRMS INTEGRATION

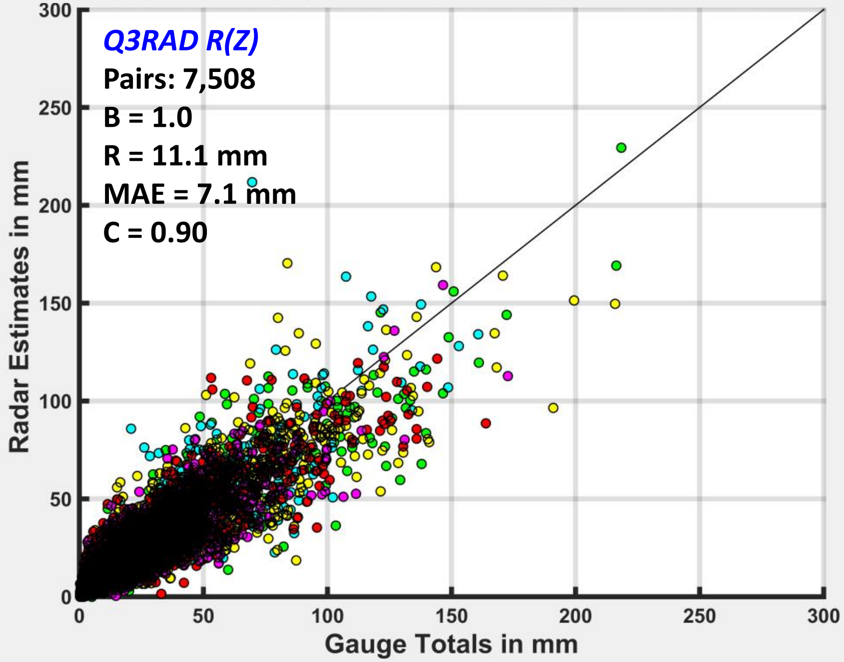
- Currently, the prototype algorithm is running in real-time on the MRMS Research Testbed for testing/evaluation

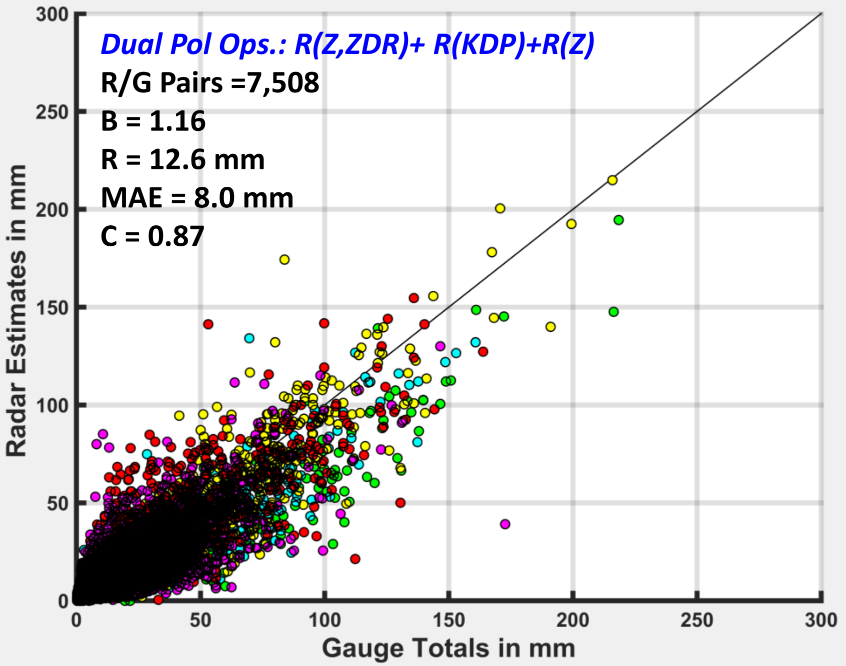


SOME Q3DP OPERATIONAL SUCCESSES AND CHALLENGES

INITIAL VALIDATION: EASTERN US

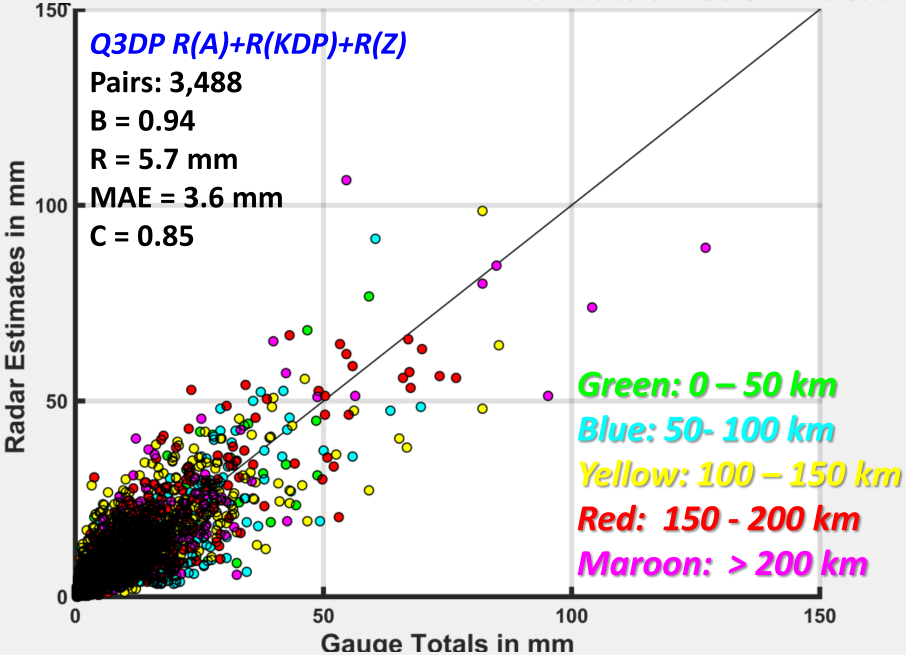


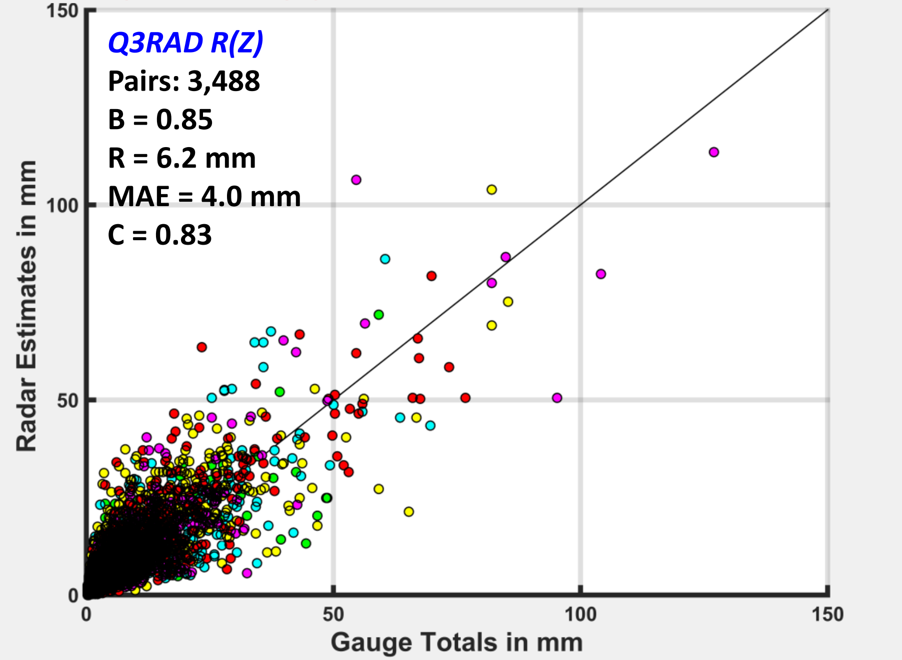


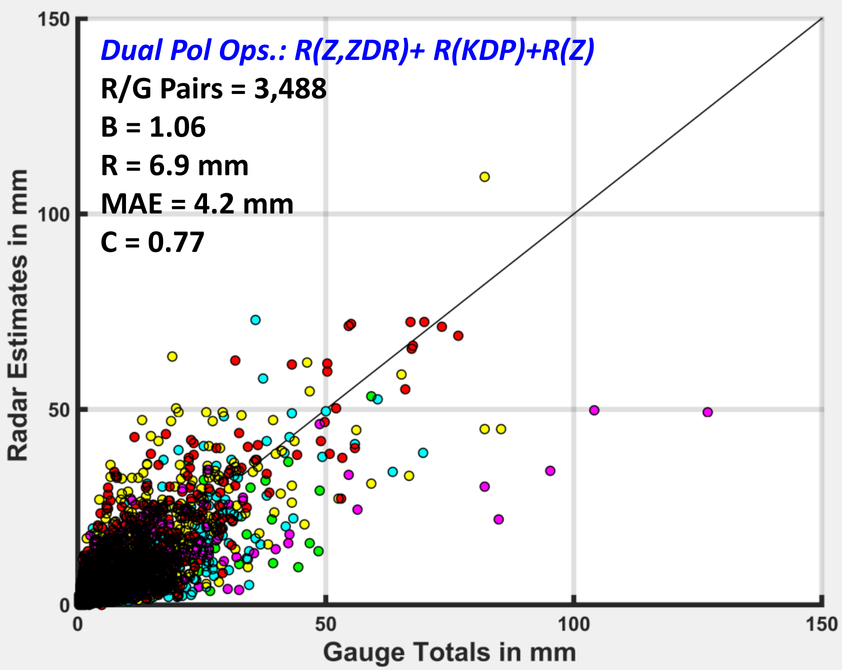


- 24-hr <u>Q3DP (top left), Q3RAD Ops (top right) & Dual Pol Ops. (bottom right) QPE</u> to QC'd CoCoRaHS gauges for ***East of Rockies for ~ 3 week sample (15 Jul – 08 Aug 17)***
- Q3DP has higher overestimate bias than Q3 but less scatter; if consider ~ 3-5% gauge undercatch in sample, then Q3DP better for mdt-high gauge totals
- Dual Pol exhibited an underestimate bias and more scatter/error

INITIAL VALIDATION: WESTERN US

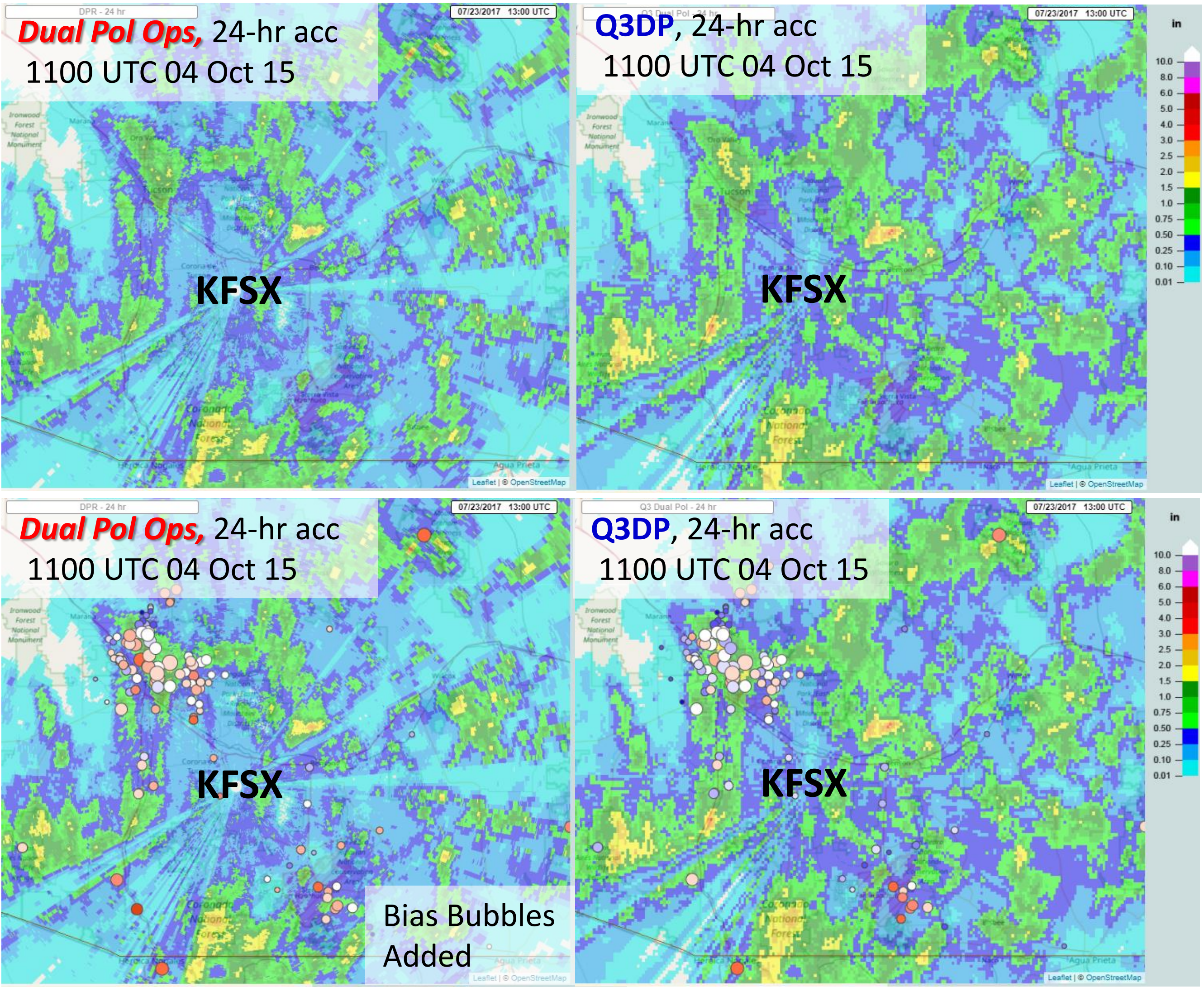






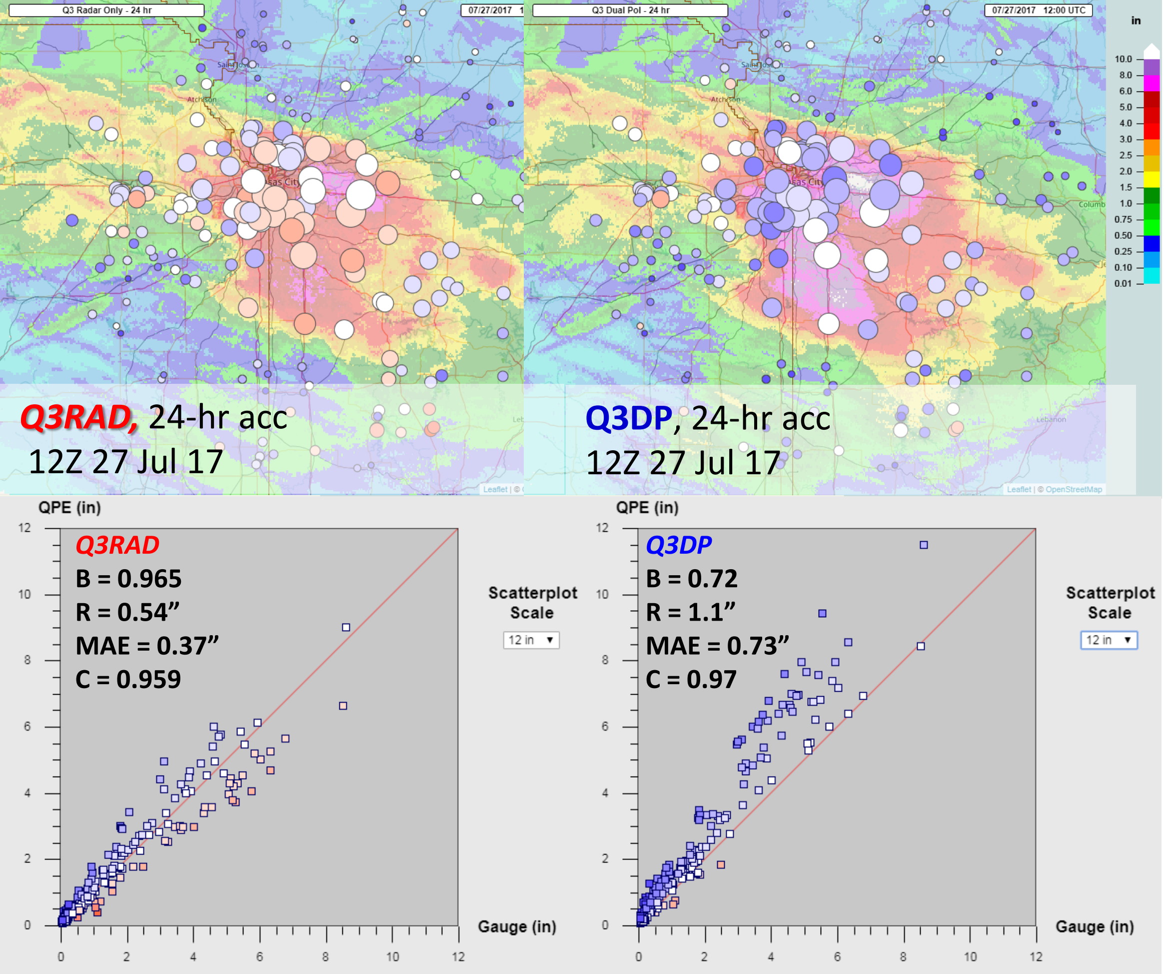
- 24-hr _Q3DP (top left), Q3RAD Ops (top right) & Dual Pol Ops. (bottom right) QPE_ to QC'd CoCoRaHS for radars **along and *West of Rockies for same period***
- Q3DP has less overestimate bias/scatter than Q3
- Dual Pol Ops exhibited an underestimate bias & significantly more scatter

Q3DP FILLS IN PARTIAL BLOCKAGE REGIONS



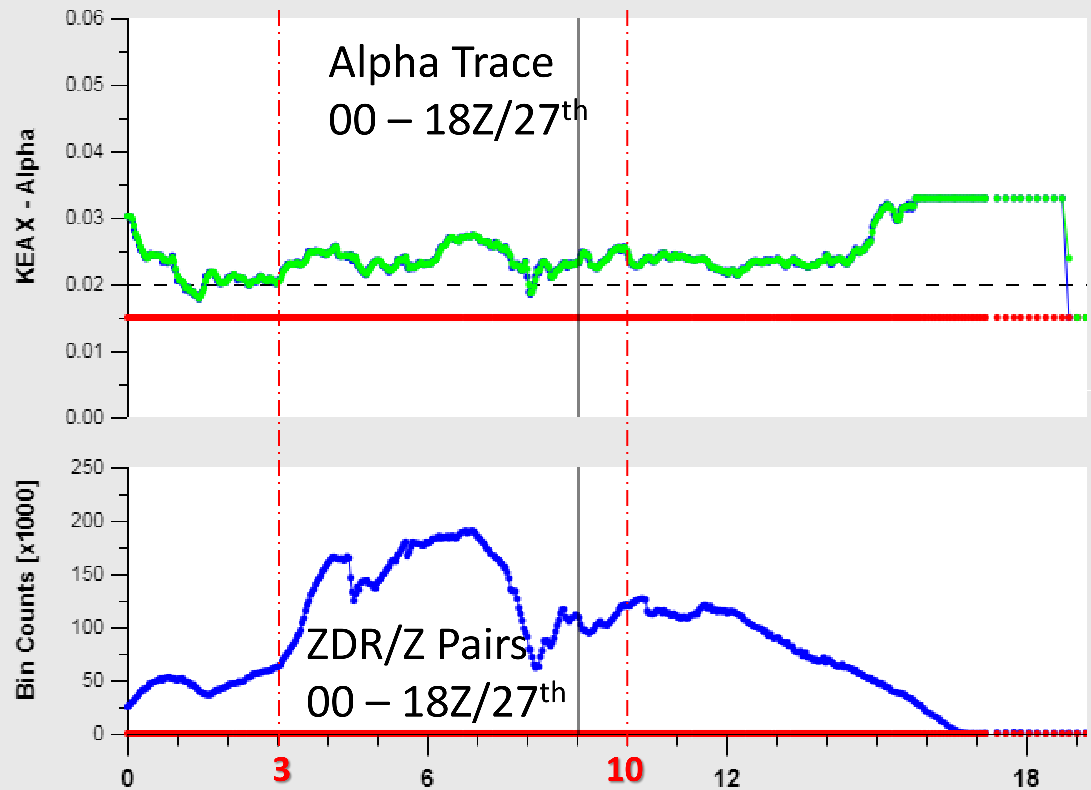
- While the new Q3DP can't fill in gaps where 100% blockage is present, it can provide appreciable QPE for blockage up to 90%
- Example at left from the KFSX radar indicated partial blockage gaps SW, E & NE better filled in than with operational

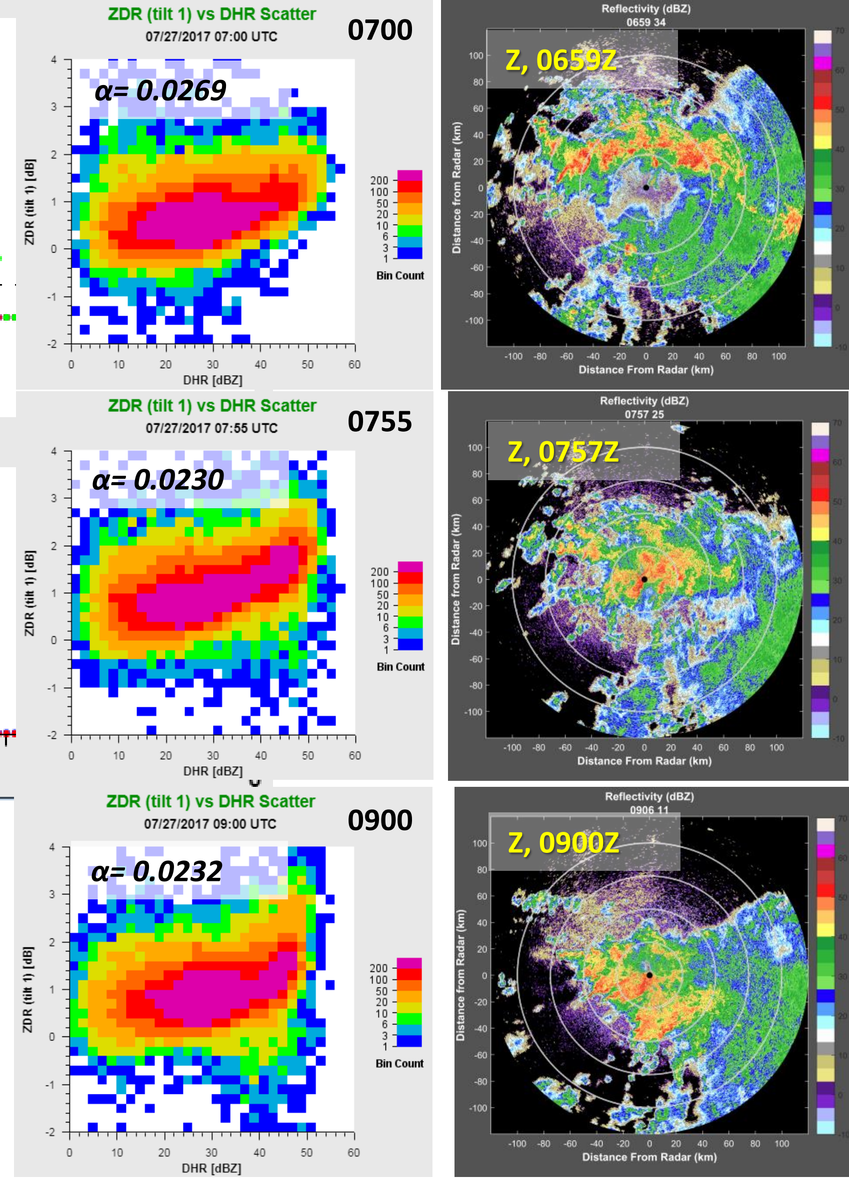
SOME CONVECTIVE RAIN EVENTS



- In some convective rain events, the new QPE exhibits a significant overestimate bias
- An example is shown to the left with Q3RAD (Q3DP) Bias Bubble and QPE shown at top/bottom left (right)
- In this case, Q3RAD exhibited significantly better error statistics
- Examination of Hourly Q3DP, Q3DP rates and Classifications indicated most overestimates associated with Z ≥40 dBZ, e.g. the main convective regions

- Initial analysis indicate the overestimates primarily related to:
  - Application of alpha value, derived from radar FOV, that was unsuitable for convection





- The highest rain rates /overestimates were generally between 03 and 10Z; during that time alpha values were generally above 0.020 with some times above 0.025
  - experientially 0.025 is considered high enough to expect efficient rainfall in progress

Summary

- **Prototype R(A) +R(KDP) algorithm, using methodology of Ryzhkov et al. (2014), tested on large dataset**
  - *56 calendar days/37 S-band radars examined during 2014-2017 warm seasons*

- **Algorithm exhibited better performance than operational Dual Pol QPE**
  - *Algorithm estimates exhibited less bias/less scatter than Dual Pol*
  - *Use of ZDR/Z slope to estimate* **α** *avoids ZDR & Z miscalibration issues*
  - *Technique also mitigates partial beam blockage effects*

- **Parameter 'alpha' key to calculating Specific Attenuation (A) fields**
  - *Parameter sensitive to rain regime; alpha values are higher (lower) for tropical (continental) rain events*

- **Prototype algorithm integrated into MRMS as part of a new MRMS Dual Pol QPE product:**
  - *R(A) used below melting layer, R(Z) within and above it, and R(KDP) where hail is probable*
  - *New product, Q3DP, currently running in real-time with evaluations made to determine where further improvements are needed*

Summary

- **The new Q3DP QPE is slotted for operational use in late 2017 or 2018**

- **Using the MRMS infrastructure allows researchers to:**
  - *examine large numbers of cases in a relatively short period of time*
  - *efficiently test code, developed from basic research, in real time across the entire U.S.*
  - *evaluate performance in different geographical regions (e.g. east vs west) and seasons (warm vs cool)*

Robust testing and validation through MRMS allows for rapid improvement of new technology leading to a smoother transition into operations

- Where to find MRMS technical documents
  - WDTD Training Web-Site: http://www.wdtd.noaa.gov/courses/MRMS/
  - VLAB MRMS Community: https: //vlab.ncep.noaa.gov/group/mrms/wiki

QUESTIONS

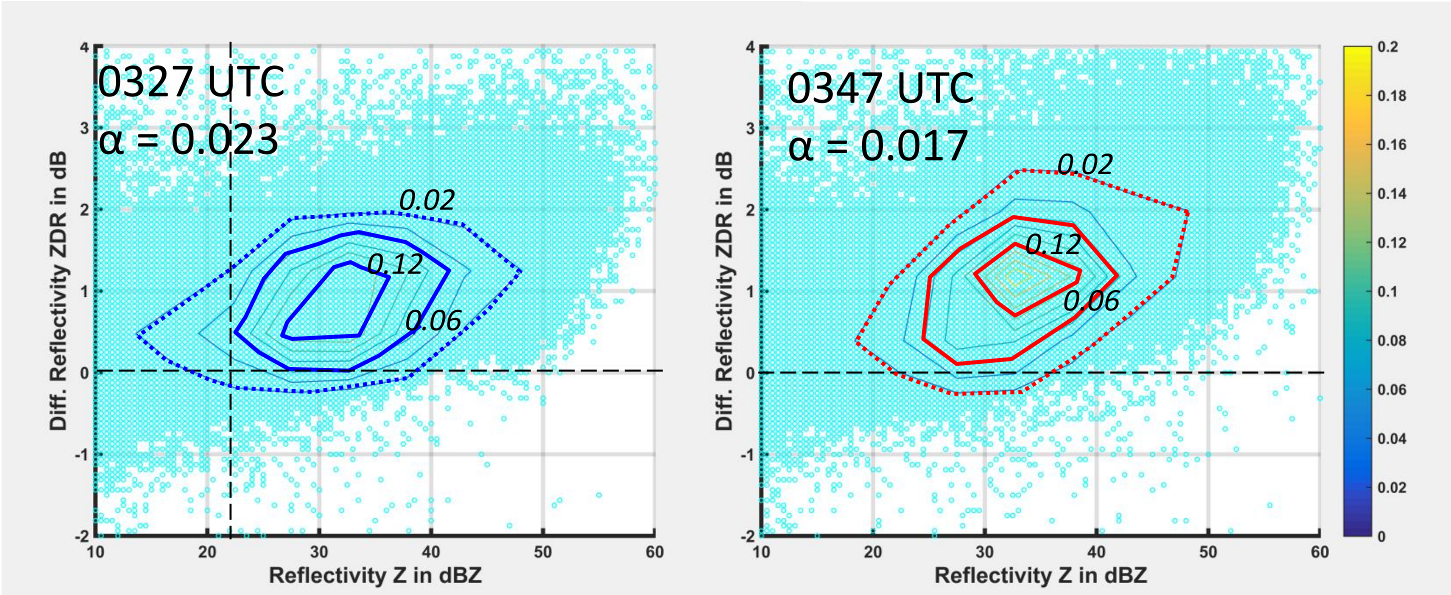
If you have questions regarding MRMS please contact either
Steve Cocks (stephen.cocks@noaa.gov) or Jian Zhang (jian.zhang@noaa.gov)

REFERENCES:

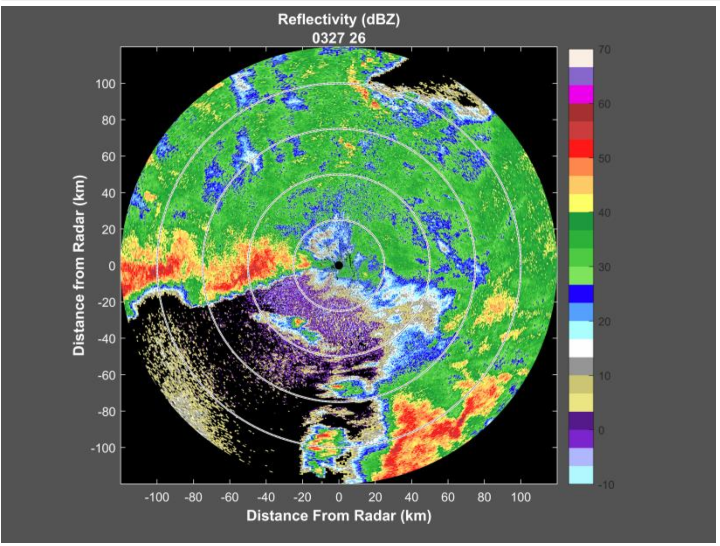
Ryzhkov, A., M. Diederich, P. Zhang, C. Simmer, 2014: Potential Utilization of Specific Attenuation for Rainfall Estimation, Mitigation of Partial Beam Blockage and Radar Networking., J. Atmos. Oceanic Technol., 31, 599-619

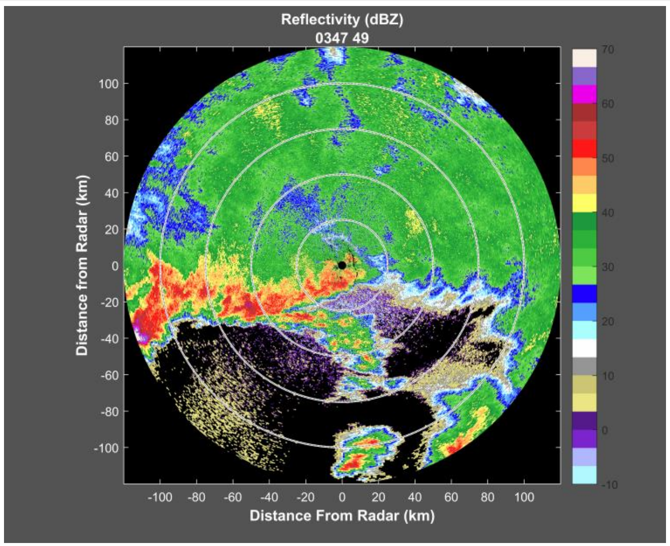
Wang, Y., P. Zhang, A. V. Ryzhkov, J. Zhang, P. L. Chang, 2014: Utilization of specific attenuation the tropical rainfall estimation in complex terrain., Journ. Hydromet., 15, 2250-2266

BACKUPS



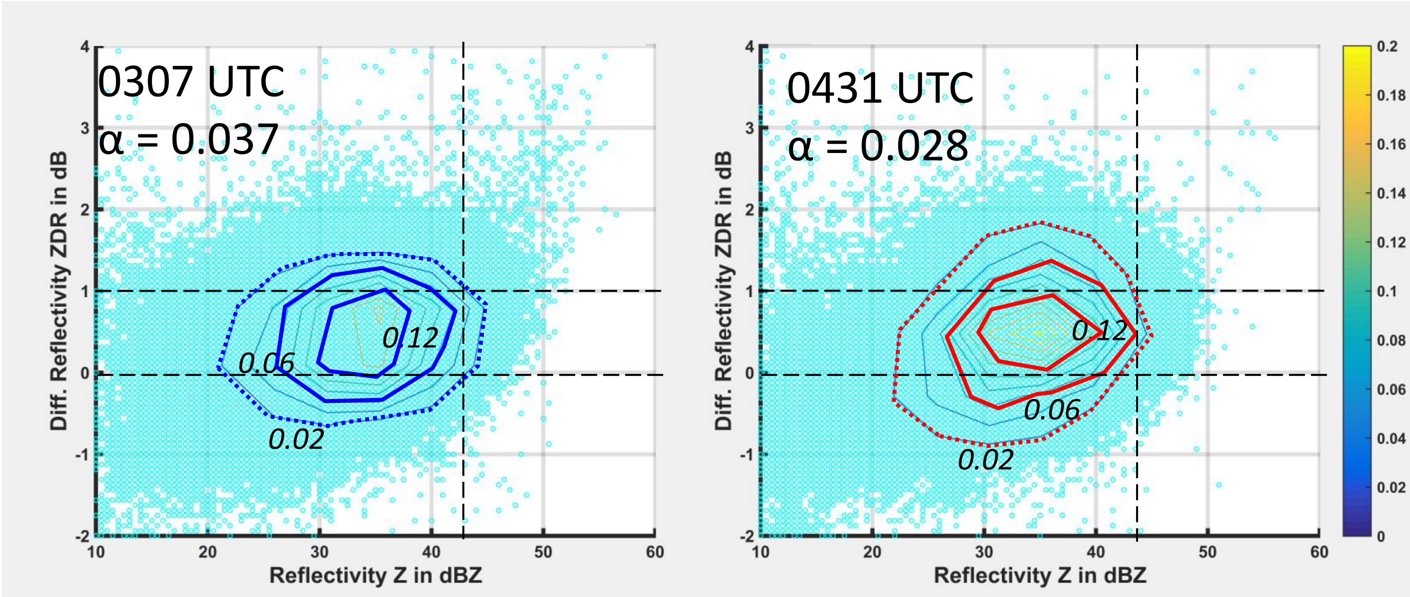
ZDR/Z Scatter/ Density Plots (top) & 0.5 deg Z (out to 120km) for 0327 (2nd Alpha peak) & 0347 (after peak) on 04 June 2014

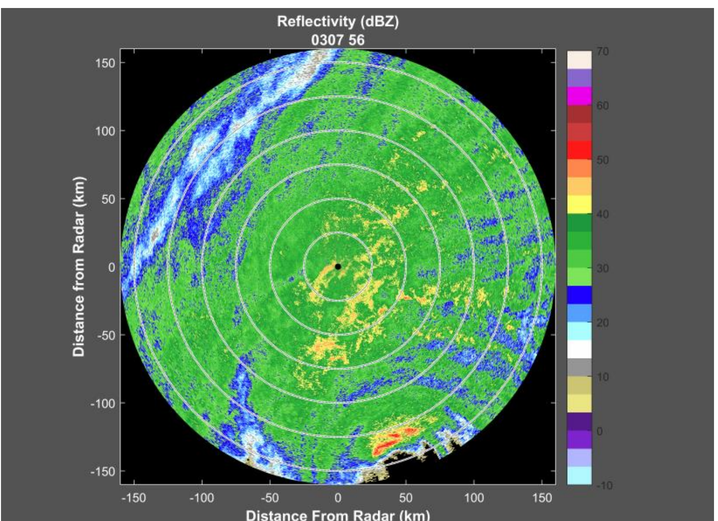


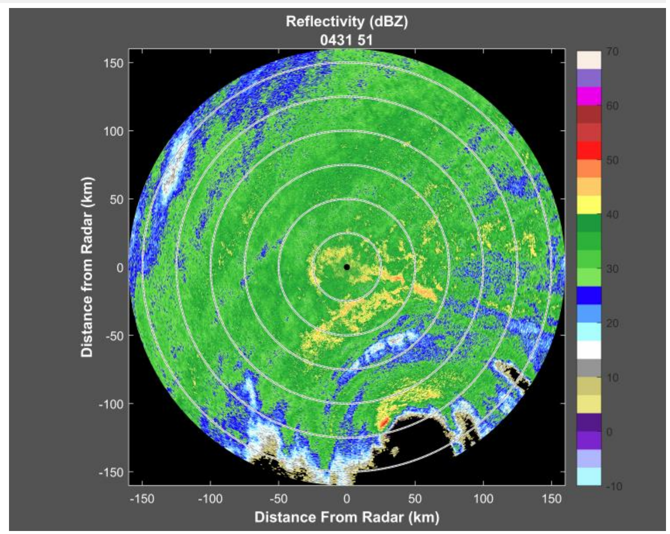


At 2nd alpha peak, higher densities of ZDR/Z pairs evident for Z values between 23 – 37 dBZ & ZDR values between 0.0 and 1.75 dB (see 0.06 & 0.12 dark blue contours) resulting in a flatter ZDR/Z slope

- After peak, same contours (red) shifted higher and to right of plot indicating significant increases (subtle decreases) of larger (smaller) drops at higher (lower) Z values; this information is impossible to deduce with Z images



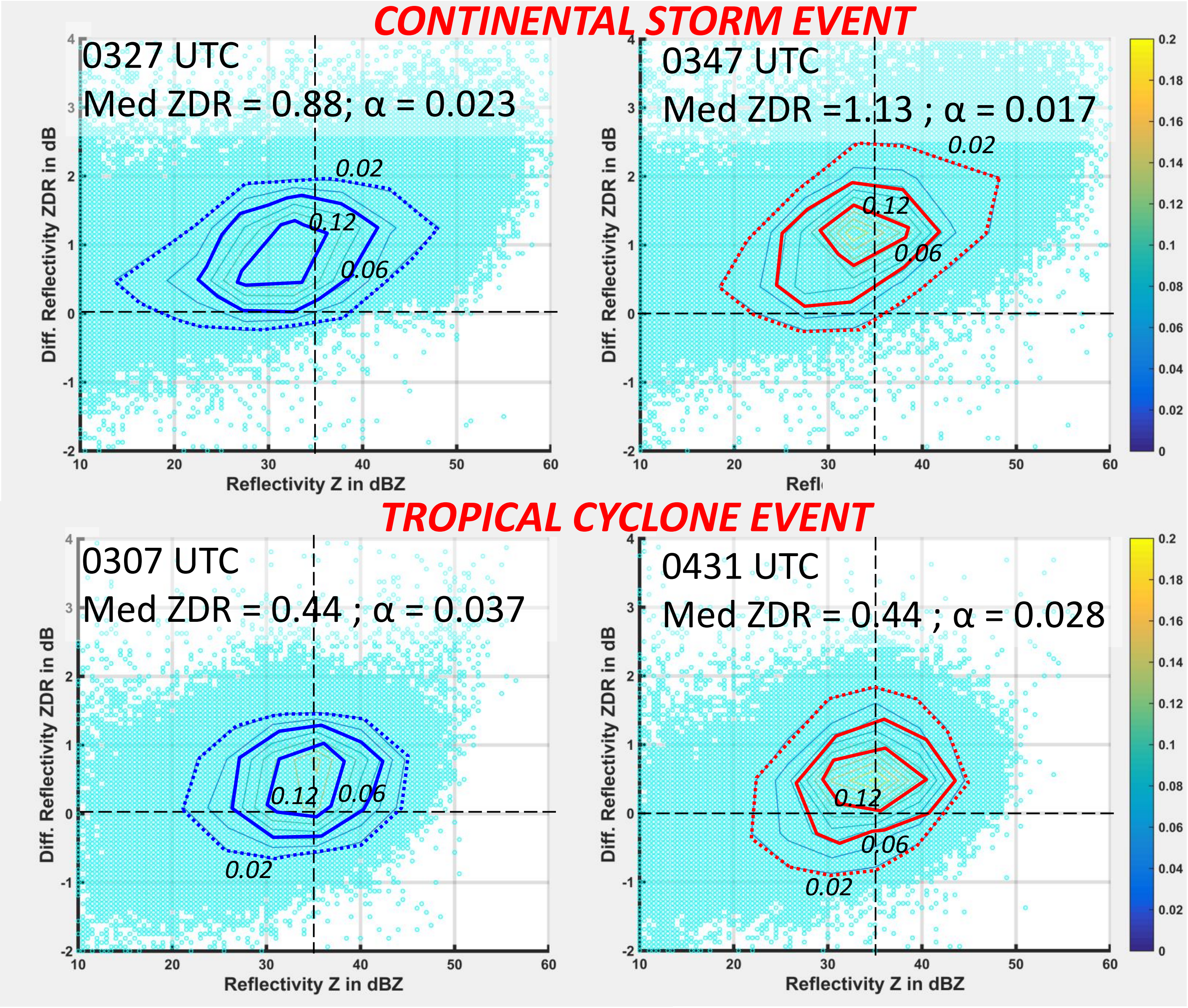




- ZDR/Z Scatter/ Density Plots (top) & 0.5 °Z (out to 160 km) for 0307 (Prior to Alpha drop) & 0431 UTC (after drop) on 08 October 2016
- Comparing the two scatter/density plots a subtle but discernable shift is noted in the 0.02 contour to larger (smaller) ZDR values between Z = 28 and 43 (20 and 28) dBZ n 22 & 32 dBZ

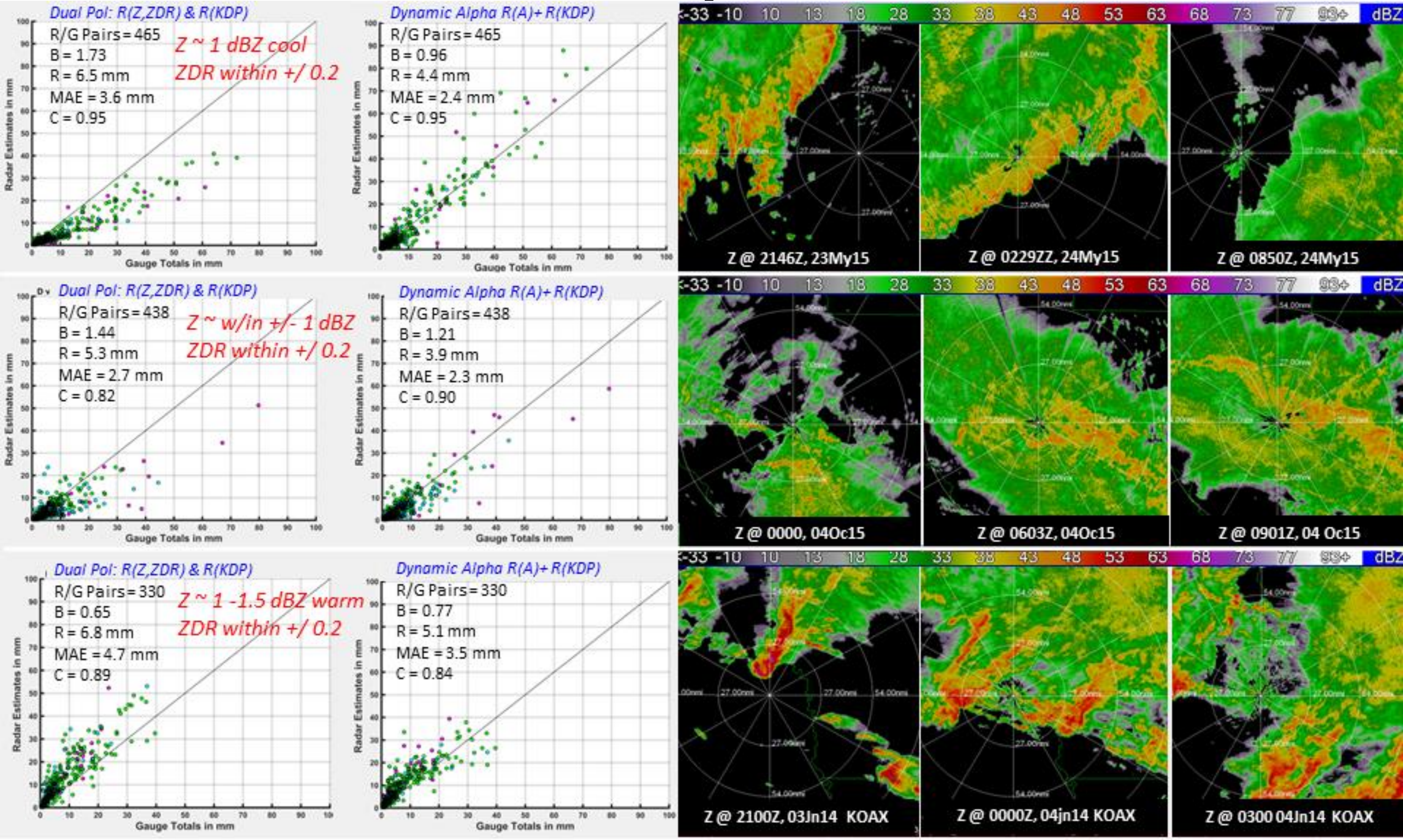
- However, there was also a significant increase in ZDR/Z pairs between 32 and 38 dBZ with ZDR < 1.0 dB; hence the overall result was a slight increase in slope resulting in a lower alpha

- this example illustrates the linear model used to estimate alpha from ZDR/Z slope can be sensitive to small changes which are not discernible in Z PPI plots alone



- Comparing Cont. and Tropical scatter/density plots for these two precipitation events, it is easy to see the overall shift of ZDR/Z pairs toward significantly smaller ZDR values (a proxy for the mean drop diameter) in the latter
- A comparison of the two time periods examined for each precipitation event showed the Tropical median ZDR to be at least half that of the Continental event

MITIGATION OF ZDR/Z MISCALIBRATION



- **1hr QPE vs gauges (left 2 columns) & Z (right 3 columns) for 23-24 May 15 (top), 03-04 Oct. 15 (middle) and 03-04 Jun. 14 (bottom):** *R(A)+R(KDP) exhibited better performance than Dual Pol although overestimate bias present in some convective events (bottom row)*