DP QPE Algorithm Improvement Initiatives

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The problem: strong persistent underestimation of precipitation using both conventional (legacy) and polarimetric algorithms for rain events observed during the period May 2010 – July 2010

Polarimetric algorithm yields slightly higher correlation coefficient between radar and gage estimates but has comparable or even larger negative bias as compared to conventional (PPS)

Conventional algorithm

$$R(Z) = 1.70\,10^{-2}\,Z^{0.714}$$

Polarimetric algorithm

$$R(Z, Z_{DR}) = 1.42\,10^{-2}\,Z^{0.770}\,Z_{dr}^{-1.67}$$ in pure rain

$$R(K_{DP}) = 44.0\,|K_{DP}|^{0.822}\,sign(K_{DP})$$ In rain mixed with hail

Two possible reasons for rainfall underestimation by polarimetric algorithms

1. Data quality

   a. Large positive bias in differential reflectivity (0.4 – 0.6 dB)

   b. Overcensoring of dualpol data using correlation coefficient due to its reduction in the areas affected by nonuniform beam filling (NBF) or its overestimation due to inappropriate correction for noise

2. Algorithm deficiency

   a. The algorithm optimized for continental rain type tends to underestimate tropical rain

   b. Rain rate is automatically set to zero in the areas affected by ground clutter / AP

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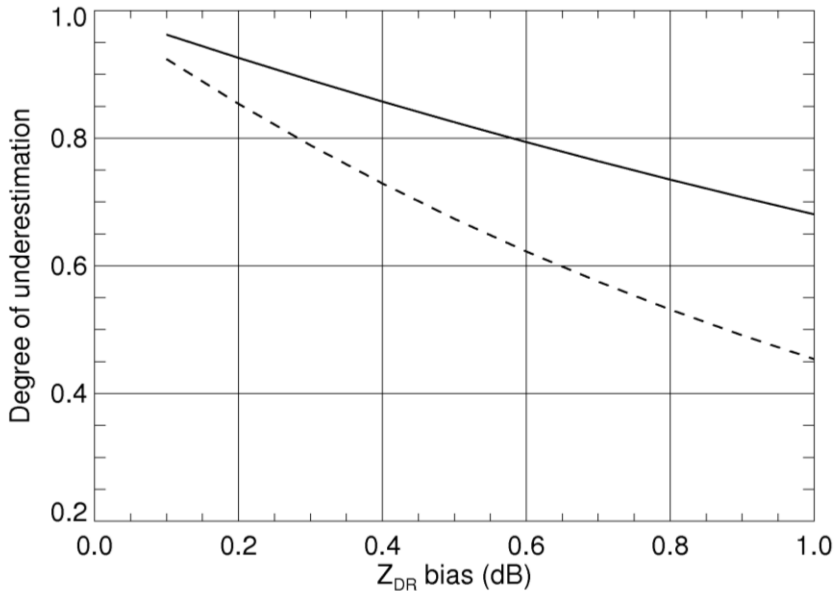
The impact of Zdr bias on the quality of rainfall estimation



$$R(Z, Z_{DR}) = 1.42\,10^{-2}\,Z^{0.770} Z_{dr}^{-1.67}$$ (solid line)

$$R(Z, Z_{DR}) = 6.70\,10^{-3}\,Z^{0.927} Z_{dr}^{-3.43}$$ (dashed line)

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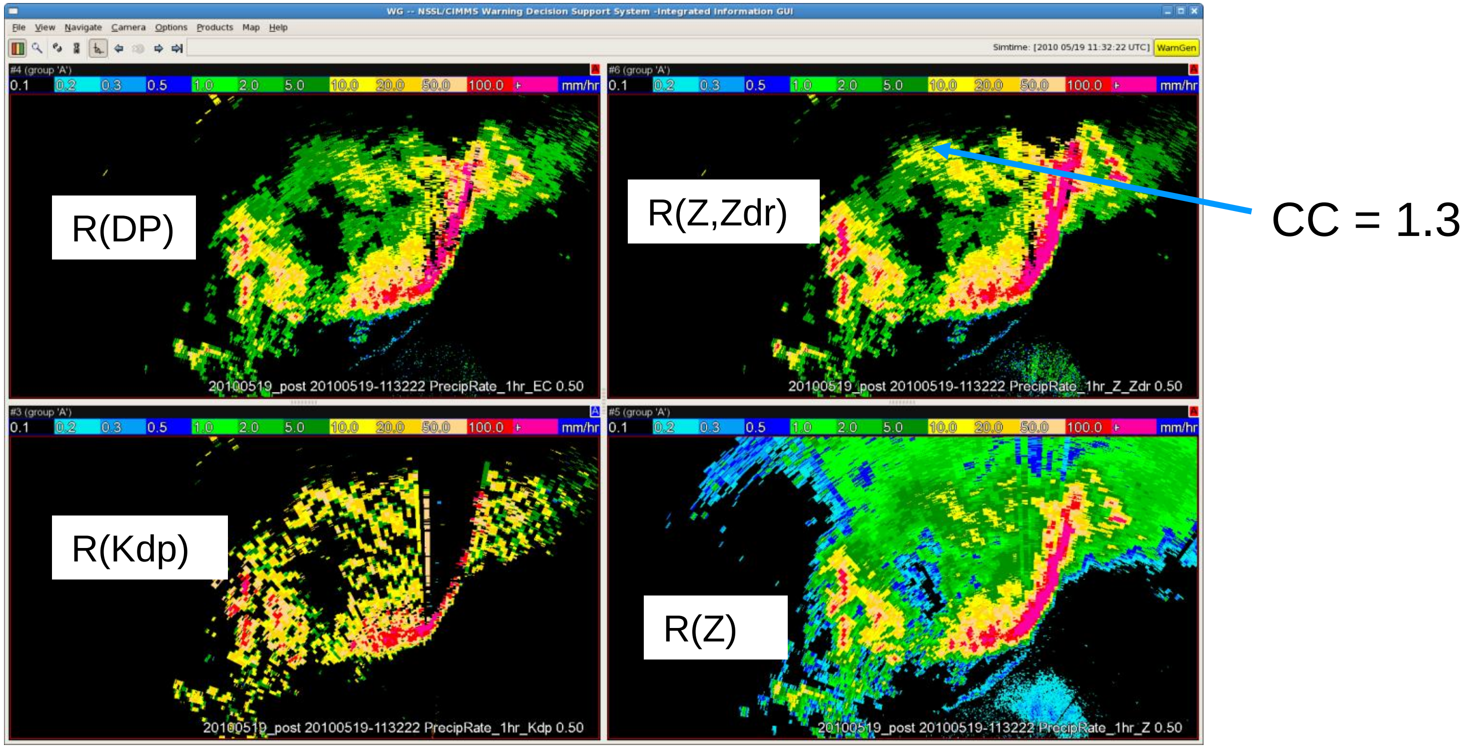
Why does R(Z) show rain in much larger area than polarimetric algorithms?



R(Z) is not censored by correlation coefficient (CC), whereas DP algorithms are.

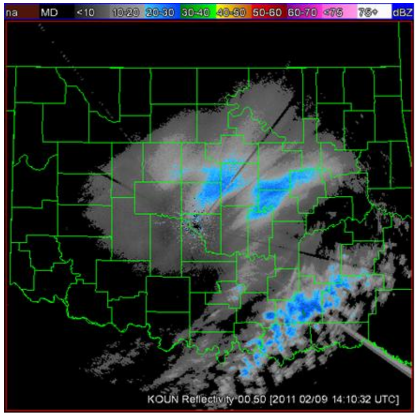
Once overcorrected CC exceeds upper threshold, the data are apparently censored

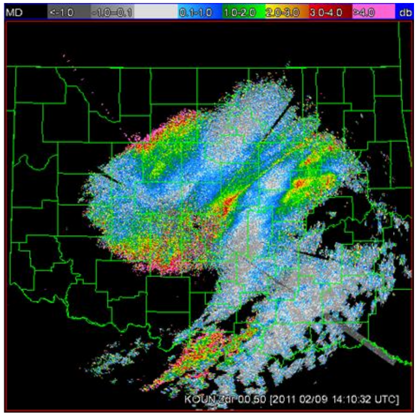
$$\rho_{hv} = \frac{< H^* V >}{(P_h - N_h)(P_v - N_v)^{1/2}}$$

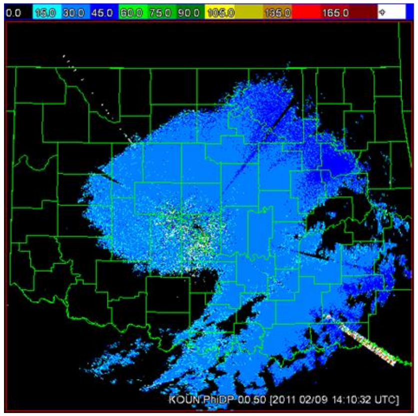
CC is overcorrected if noise floors are overestimated

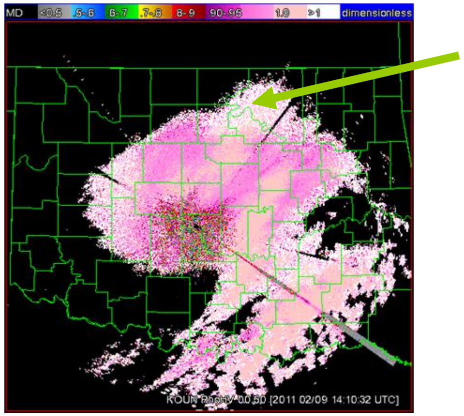
Overcorrection of CC is a persistent problem

One of the recent examples:
snowstorm on 2011/02/09







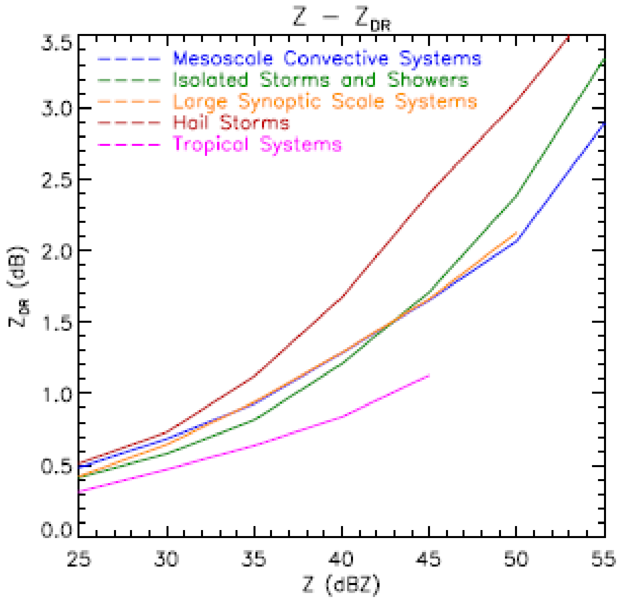


Problems with DP QPE algorithms

Currently accepted DP algorithm was optimized mostly for continental rain type which is prevalent in Oklahoma

The 7-year disdrometer dataset (47114 DSDs) in Oklahoma during 1998 – 2005 shows that “tropical” DSDs constitute only 7% of all DSDs and there was no one significant tropical rain event accompanied by notable flash flood during that period

Most notable flash floods associated with tropical rain in central Oklahoma occurred on 08/19/2007 (remnants of storm Erin) and on 06/14/2010



Schuur et al. 2005

Tropical rain is characterized by very high concentration of relatively small raindrops

For a given Z, Zdr is lower in tropical rain than in continental

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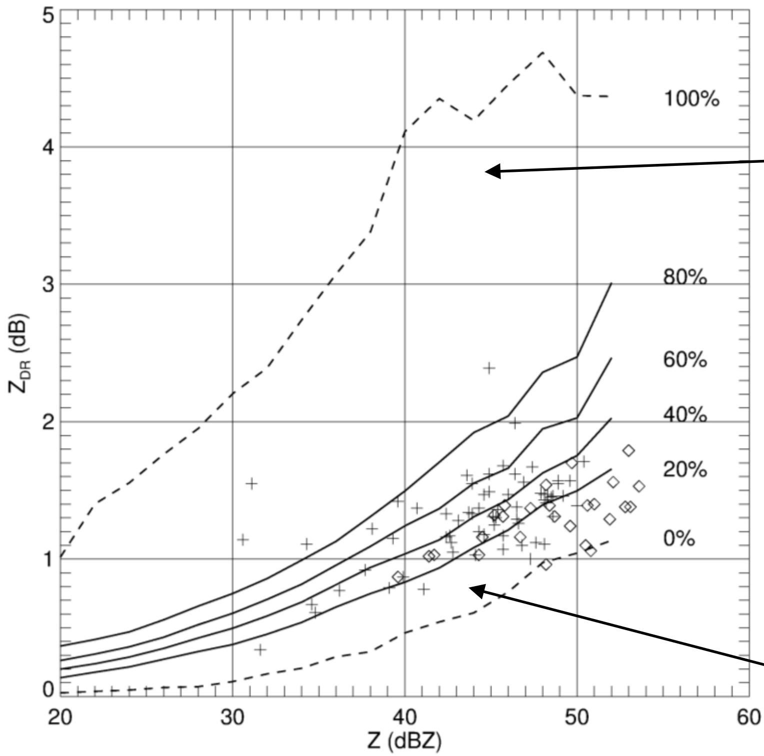
Disdrometer-based segregation of different rain types in the Z – Zdr plane



Very “continental” rain

Crosses and diamonds indicate the Z – Zdr pairs measured by KOUN at locations of the gages receiving largest amount of rain during flash flood events on 08/19/2007 and 06/14/2010

Very “tropical” rain

A single R(Z) or R(Kdp) relation optimized for a whole dataset inevitably overestimates very “continental” rain and undererstimates very “tropical” rain, however, the biases are much larger for the R(Z) relation

The challenge is to find the algorithm which automatically takes into account drastic differences between DSDs in continental and tropical storms and is sufficiently robust with respect to the measurement errors of polarimetric radar variables

Two possible ways to optimize DP algorithm performance

Strategy 1. More aggressive use of Zdr combined with Z or Kdp

Use relation $R(K_{DP}, Z_{DR}) = 95.9 K_{DP} Z_{dr}^{-1.89}$ for Z > 40 dBZ (1)

and relation $R(Z, Z_{DR}) = 6.70\,10^{-3} Z^{0.927} Z_{dr}^{-3.43}$ for Z < 40 dBZ or all Z (2)

The estimators (1) and (2) better capture large DSD variability and are more sensitive to changes in Zdr than the relations recommended for “synthetic” algorithm (Ryzhkov et al. 2005):

$$R(Z, Z_{DR}) = \frac{R(Z)}{0.4 + 5.0\,|\,Z_{dr} - 1|^{1.3}}$$ R(Z) < 6 mm/h

$$R(K_{DP}, Z_{DR}) = \frac{R(K_{DP})}{0.4 + 3.5\,|\,Z_{dr} - 1|^{1.7}}$$ 6 < R(Z) < 50 mm/h

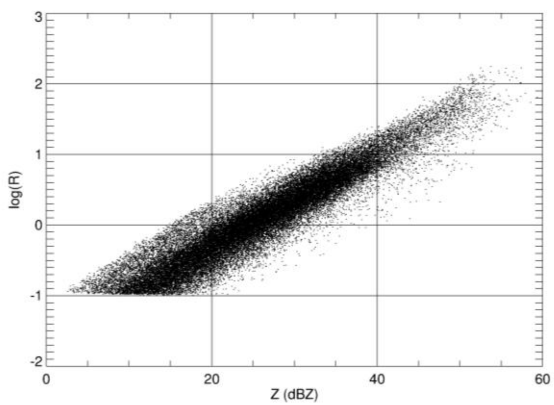
or currently used WSR-88D relation

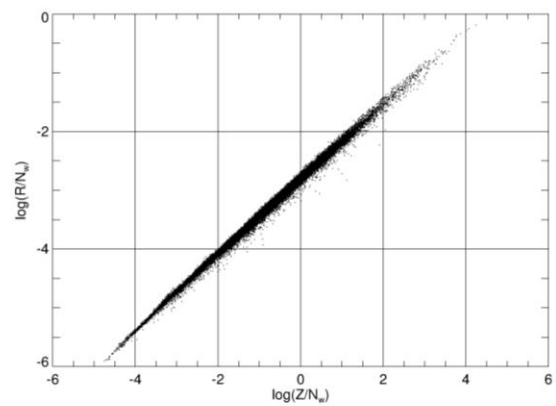
$$R(Z, Z_{DR}) = 1.42\,10^{-2} Z^{0.770} Z_{dr}^{-1.67}$$

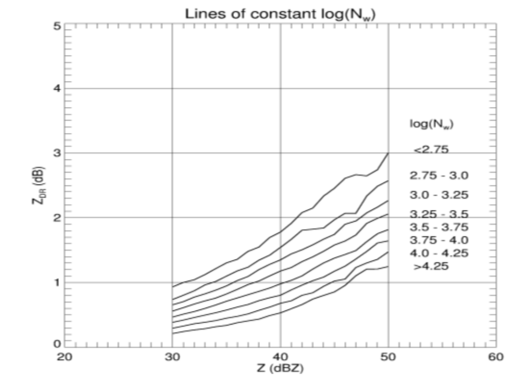
On the negative side, the risk is that more “aggressive” rainfall estimators are more prone to the errors in Zdr measurements

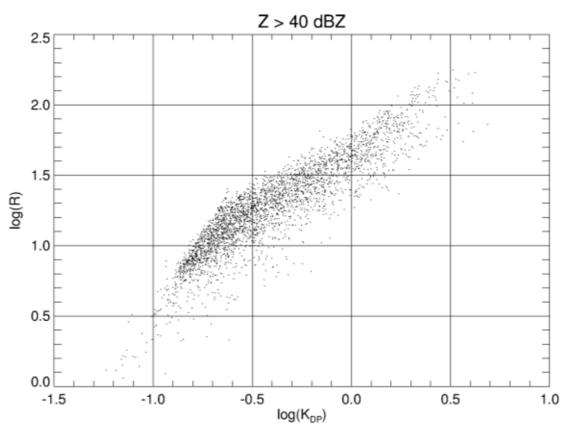
Two possible ways to optimize DP algorithm performance

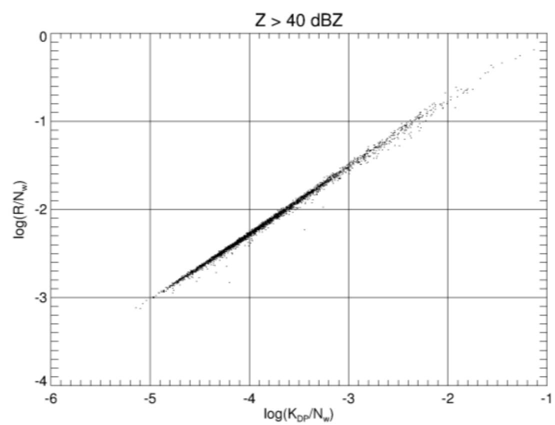
Strategy 2. Utilize normalized concentration of raindrops Nw











$$N_w = \frac{4^4}{\pi \rho_w} \frac{LWC}{D_m^4}$$

LWC is water content

D_m is mean volume diameter

Particular rain regime is characterized by a single value of N_w

N_w can be estimated from distributions of Z and Zdr within sufficiently large area

$$R(Z) = 1.57\,10^{-3} N_w^{0.365} Z^{0.635} \qquad R(K_{DP}) = 5.73 N_w^{0.240} K_{DP}^{0.760}$$

There is no direct dependence on local values of Zdr

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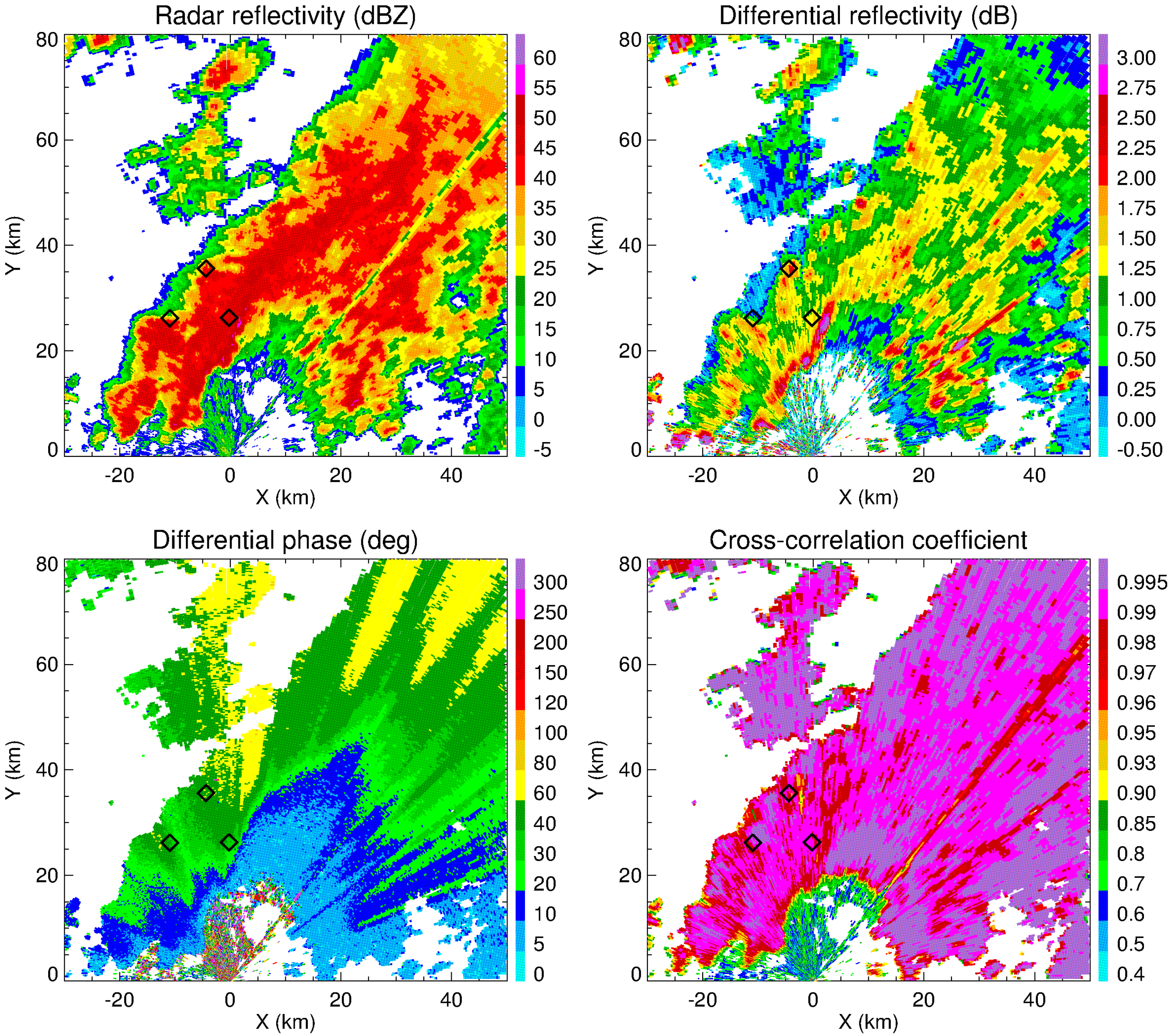
1202 Z

Flash flood in Oklahoma City on 06/14/2010

El = 1.4



Diamonds indicate locations of gages which received largest amount of rain during the hour 12 – 13 Z (63, 45, and 58 mm)

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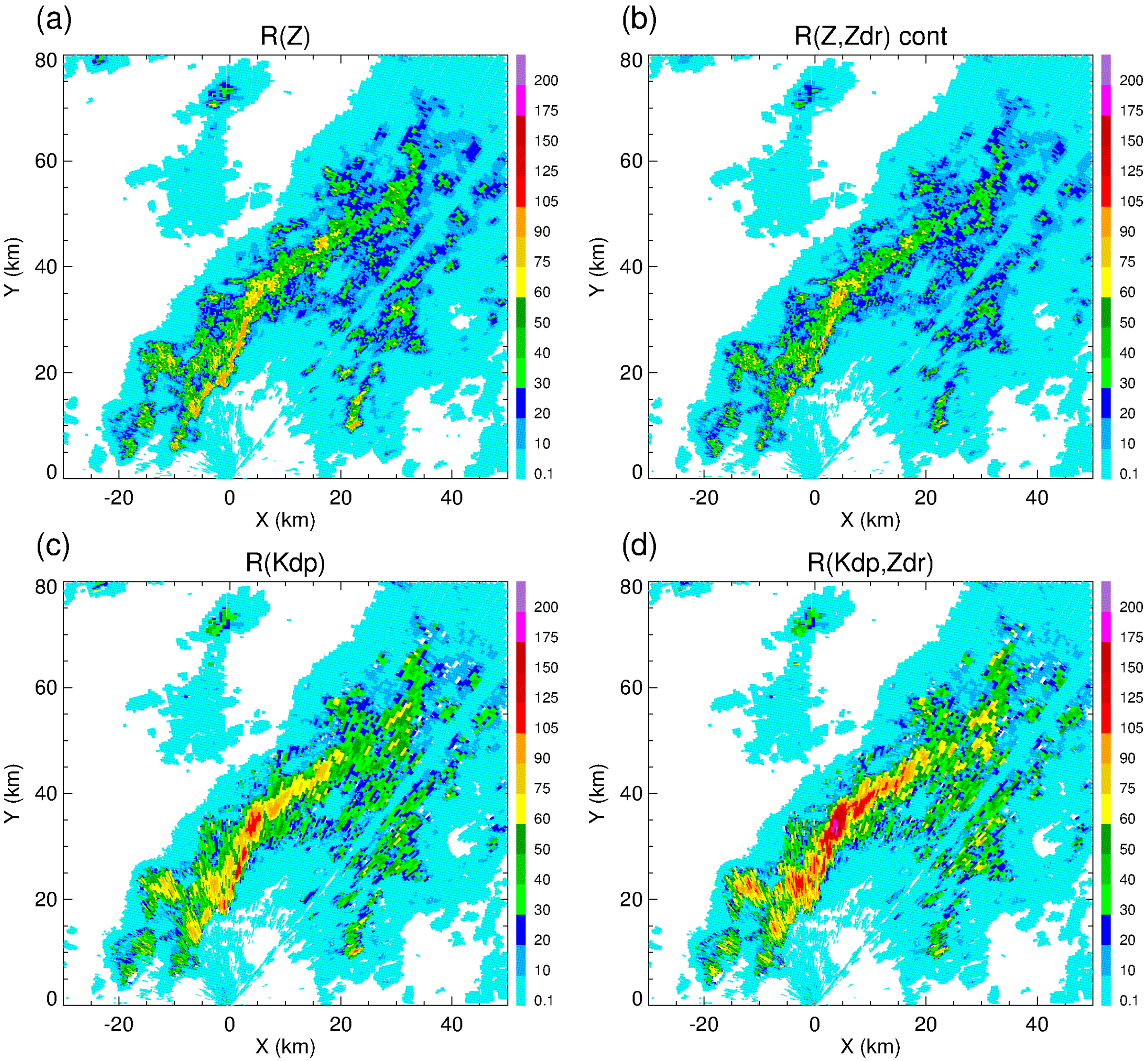
Fields of rain rates retrieved from different algorihtms

06/14/2010

1202 Z

El = 1.4



Both currently used relations R(Z) and R(Z,Zdr) underestimate rain

The R(Kdp) relation performs better but the R(Kdp,Zdr) relation yields highest rainfall in the best agreement with gages

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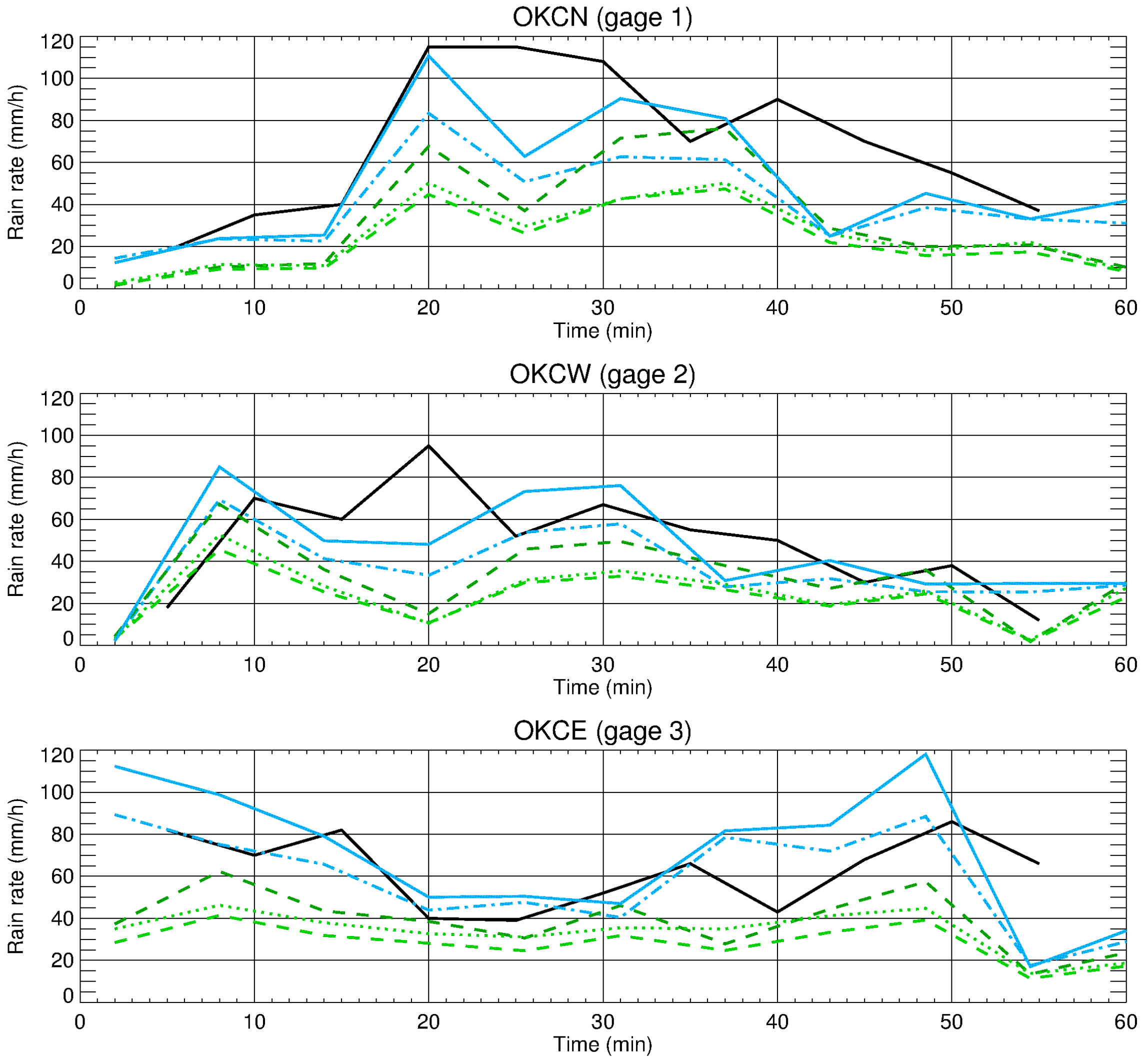
Comparison with gages

06/14/2010, 12 – 13 Z



gage
R(Z)
R(Z,Zdr) cont
R(Z,Zdr) trop
R(Kdp)
R(Kdp,Zdr)

Analysis of 3 gages with maximal rain total

Algorithm	R(Z)	R(Kdp)	R(Kdp,Zdr)
Bias	-50.1%	-20.5%	-2.8%

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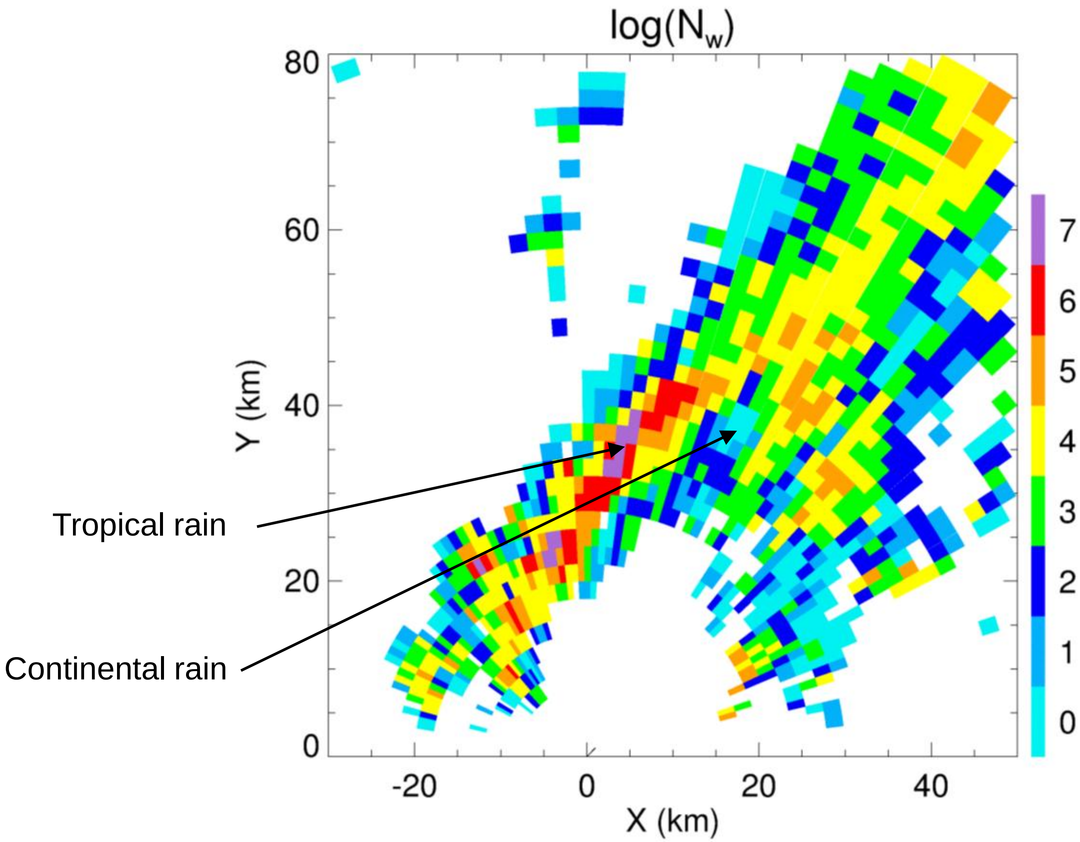
Field of retrieved N_w



Resolution 2 km x 2

Log(N_w)

> 4.25

4 – 4.25

3.75 – 4

3.5 – 3.75

3.25 – 3.5

3 – 3.25

2.75 - 3

< 2.75

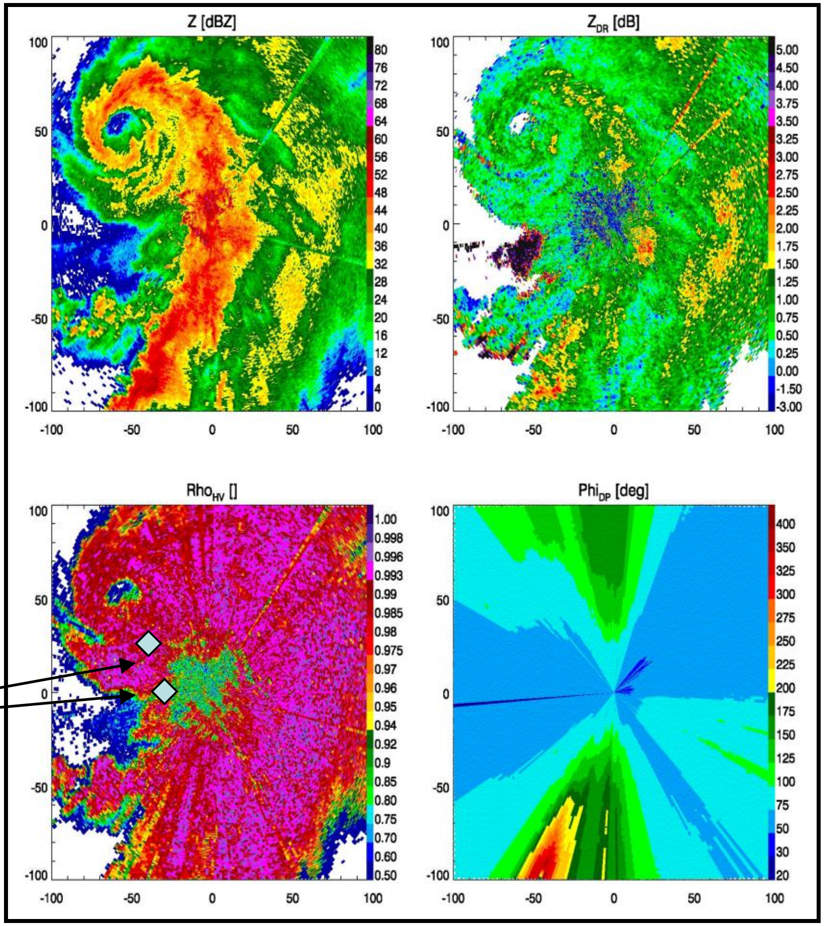
Retrieving and displaying N_W can be beneficial because

(1) Rain regime / type is directly displayed

(2) Possible errors in Zdr calibration and noise correction can be visually monitored since N_w is very sensitive to artifacts in Zdr

Remnants of hurricane Erin (08/19/2007)

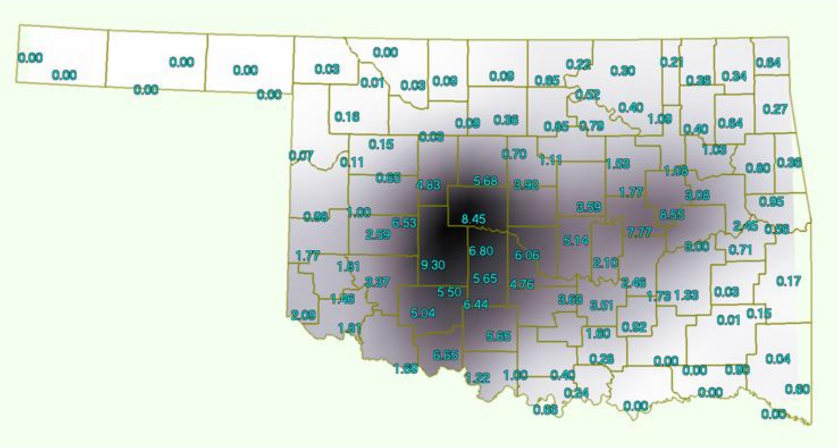
1003 UTC



Gage locations

Highest hourly gage accumulations are

86.1 mm and 69.4 mm

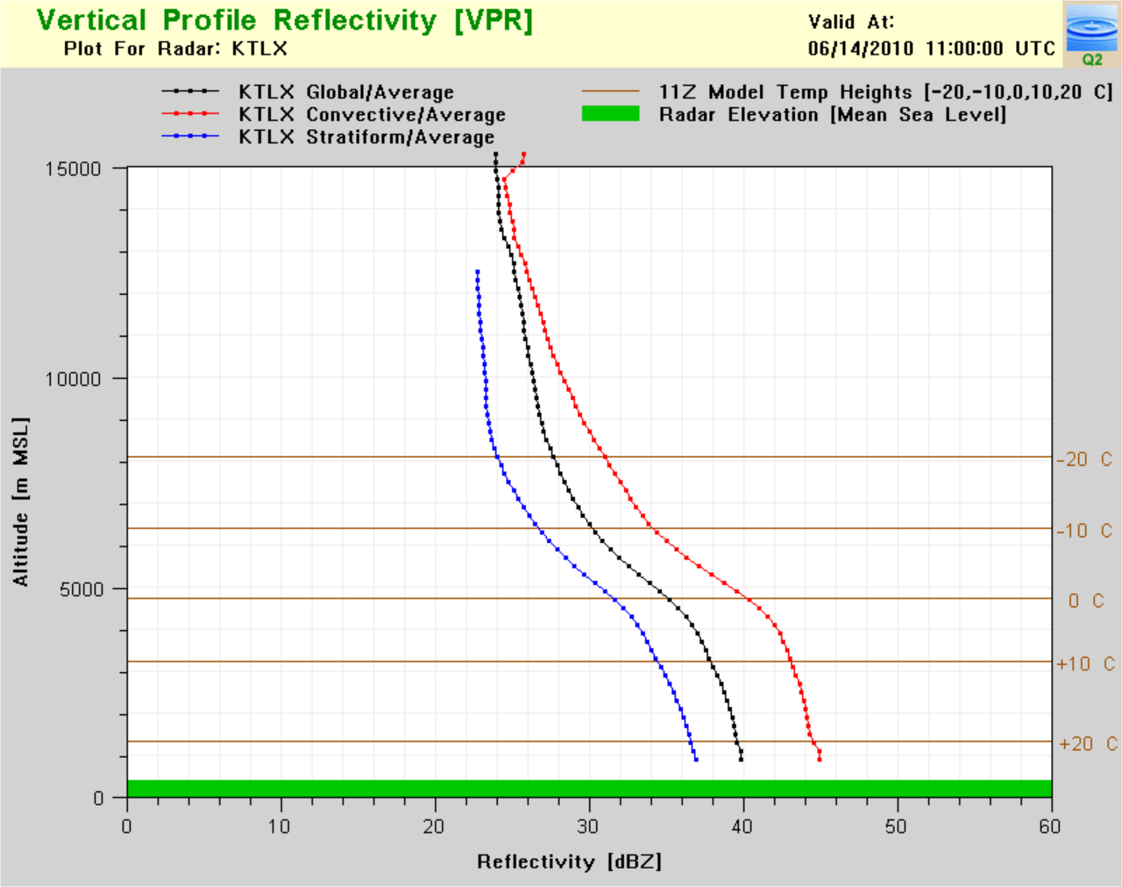


07 – 08 Z

Algorithms	R(Z)	R(Kdp)	R(Kdp,Zdr)	R(Z,Zdr)
Biases	-28.9%	-31.2%	-8.9%	14.5%

Results are similar to the 06/14/2010 case and are consistent with findings by Petersen (1999) for the famous flash flood event in Fort Collins, CO on 08//27/1997 when the R(Kdp,Zdr) relation performed best

Another reason for rainfall underestimation of precipitation in tropical rain is rapid decrease of precipitation rate with height



This may require implementation of VPR based on vertical profile of reflectivity

Conclusions

Persistent underestimation of rainfall by the polarimetric WSR-88D during the system test is partially attributed to (a) the problems with data quality (miscalibration of Zdr and overcensoring due to compromised cross-correlation coefficient) and (b) rainfall algorithm which is not optimized for tropical rain.

The problem with absolute Zdr calibration is tough but solvable

The issue with CC censoring is relatively easy to fix

Utilization of Kdp combined with Zdr for heavy rain definitely helps to reduce the negative bias in estimation of heavy tropical rain, and the corresponding change in the algorithm is easy to implement

Additional testing and validation is required to establish if the suggested change in the QPE algorithm does not adversely affect the quality of estimation of continental rain

Utilization of VPR technique may further improve the accuracy of tropical rain estimation

A new technique based on the use of normalized drop concentration Nw may show promise and needs to be explored