Integrating Quantitative Precipitation Estimation Products Concurrently from S- and C-band Dual-polarimetric Radars over Norther Taiwan

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Atmosphere

Background
Drop Size Distribution (DSD) and QPE

1. **Radar-based QPE algorithms. [e.g., $Z = AR^b$, $R = aZ^bZ_{DR}^c$]**

2. Normalized gamma DSD [Willis 1984;Testud 2001].
   D_m: Mass-weighted Diameter; N_w: Normalized intercept

$$N(D)=N_w f(\mu)\left(\frac{D}{D_m}\right)^{\mu}\exp\left[-(3.67+\mu)\frac{D}{D_m}\right]$$

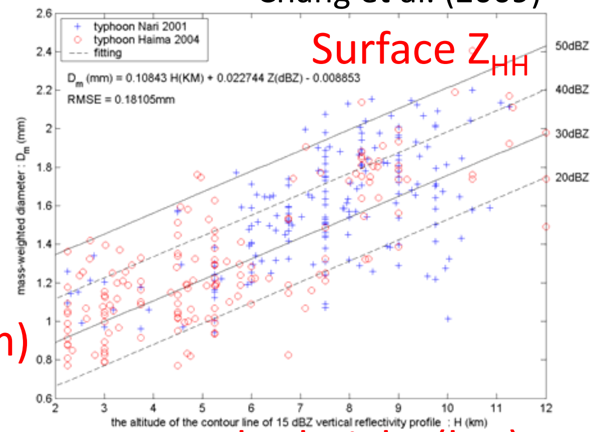
3. **Microphysical process:** condensation, collision-coalescence, break-up, aggregation, graupel melting, etc.

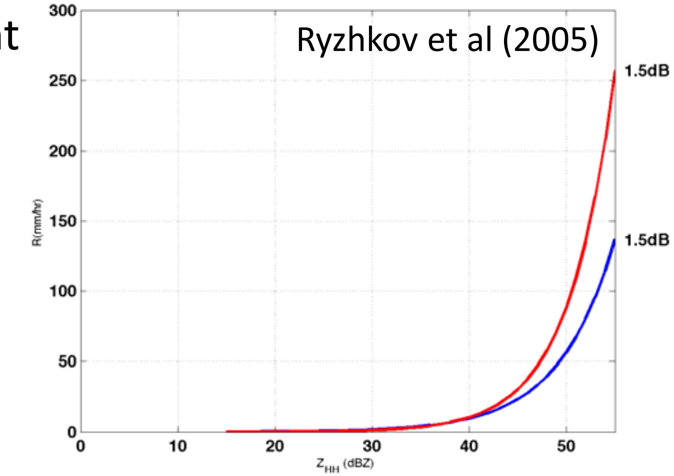
4. Uncertainty of $R(Z, Z_{DR})$ due to **DSD variability** at different climatological region.

Maritime type → $R(Z,Z_{DR}) = 0.0067(Z)^{0.927} (Z_{DR})^{-3.42}$

Continental type → $R(Z,Z_{DR}) = 0.0142(Z)^{0.770} (Z_{DR})^{-1.67}$

Chang et al. (2009)





Motivation

Pro. & Con. of S-/C-band dual-pol QPE

- The radar network of Taiwan will be configured with **14 S-/C-band + Doppler & dual-pol radars**. Combining the **advantages of C- & S-band polarimetric radar QPE** becomes an important issue.

		Reflectivity (Z_{HH})	Differential Reflectivity (Z_{DR})	Specific Differential Phase shift (K_{DP})
S	pro.			
	con.			
C	pro.			
	con.			

Motivation

The challenge of dual-pol QPE: S- or C-band?

❖ The weather radar network **S-/C-band Doppler/Dual-pol radars [9 → 14]**

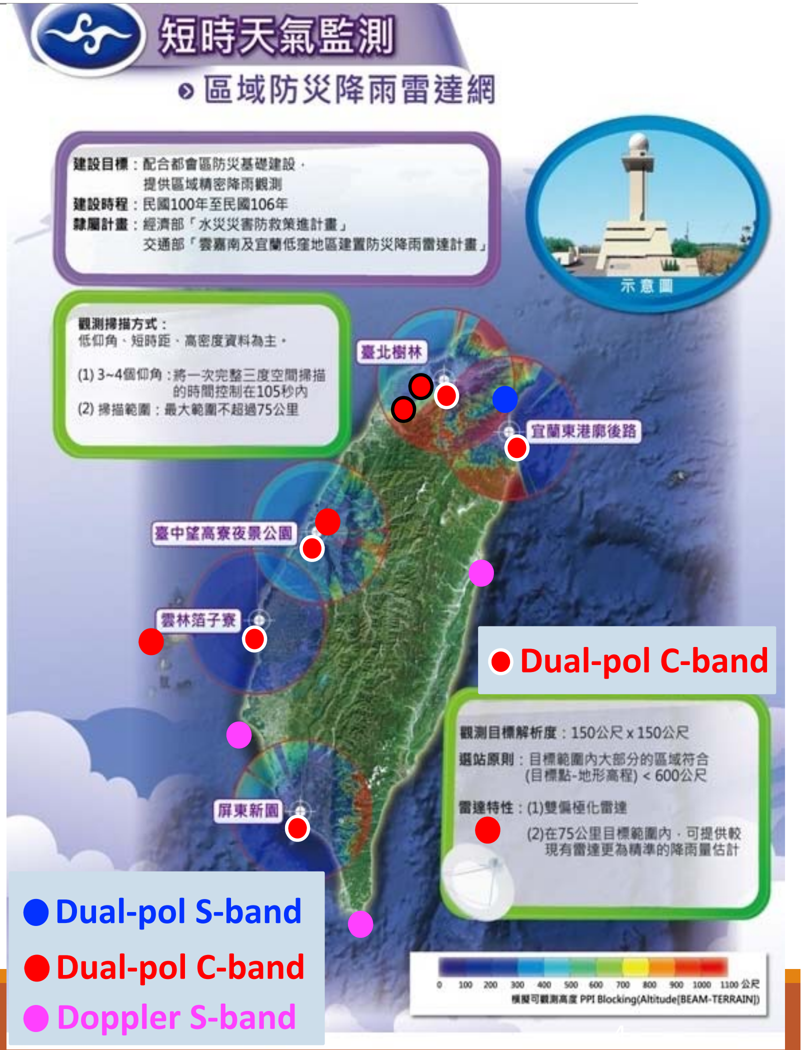
❖**DSD variations among diff. precipitation**

❖**DSD spatiotemporal variations**

❖**Diff. temporal resolution**

❖**Diff. QPEs.**

1. **QPE Coefficients of S-/C-band dual-pol radars.**
2. **The impact of QC procedures of S-/C-band radars in QPEs.**
3. **The performance of S-/C-band dual-pol QPE.**
4. **The integrations of S-/C-band QPEs.**



Seasonal dual-pol QPE

Seasonal dual-pol QPE from 8 years 2DVD

- **Disdrometric data**

  More than 8 years (2000-2007) NCU 2DVD disdrometer data at northern Taiwan.

  → 5 precipitation types (Chen and Chen 2003)

  → 6 mins DSDs

- **Rain rate relationships**

  → Obtain dual-pol measurements from DSDs: T-Martix

  Temperature : 20^0 C

  Wavelength : 10.7 / 5.3 cm

  Axis ratios : Bradnes et al. (2002)

  Chang et al. (2009) for typhoon cases

  → Obtain coefficients of: **[decision-tree QPE]**

  1. $R(Z_{HH})$ → $Z = aR^b$

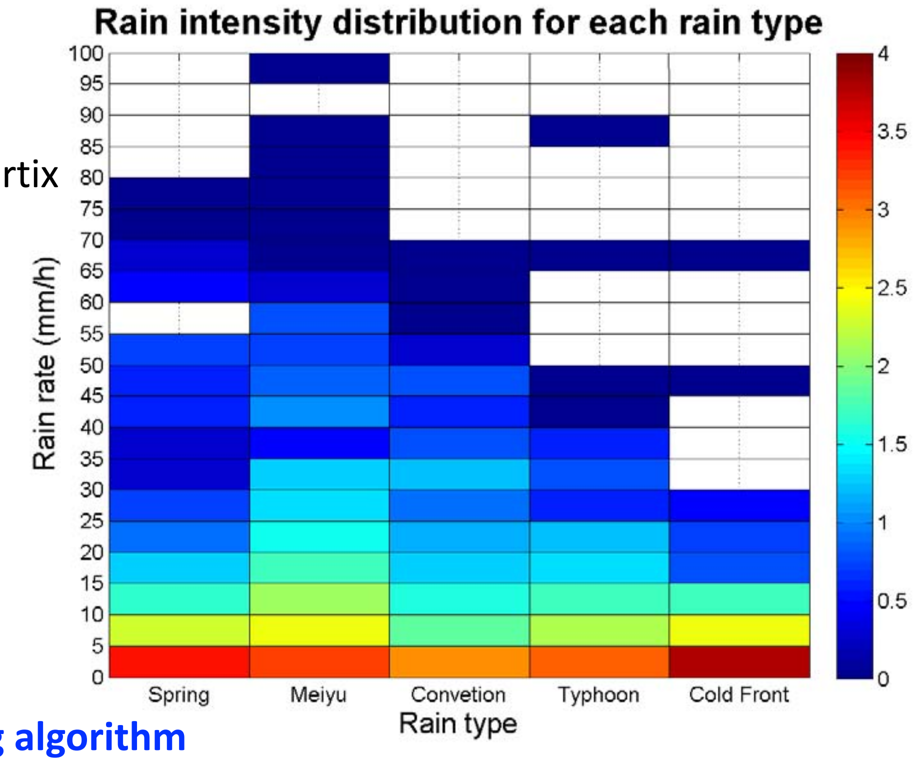
  2. $R(Z_{HH}, Z_{DR})$ → $R = aZ_{HH}^b Z_{DR}^c$

  3. $R(K_{DP})$: → $R = aK_{DP}^b$

  4. $R(K_{DP}, Z_{DR})$ → $R = aK_{DP}^b Z_{DR}^c$

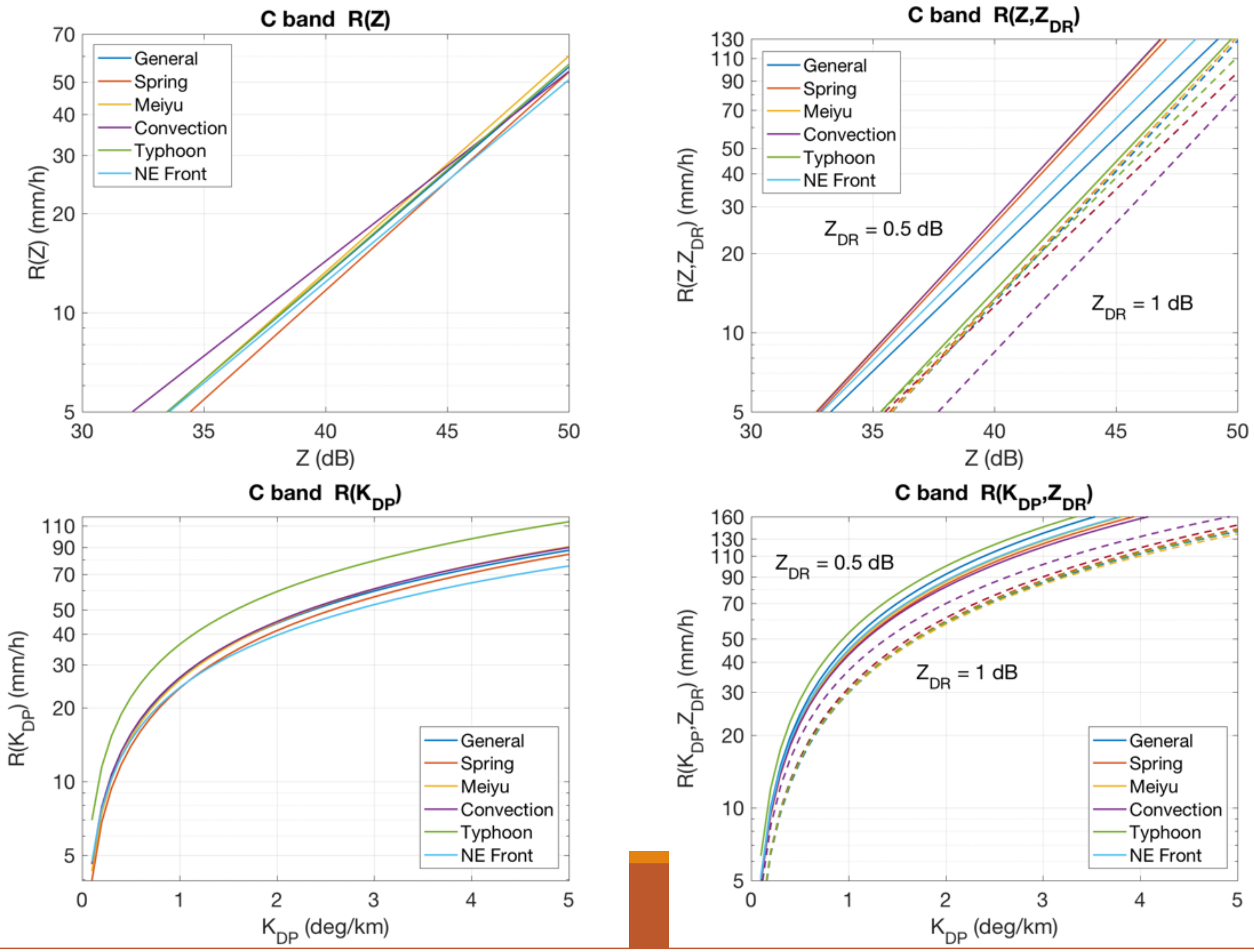
  Using Levenberg-Marquardt linear square fitting algorithm

  (1) Generalized coefficients, (2) seasonal-based coefficients.



Seasonal dual-pol QPE

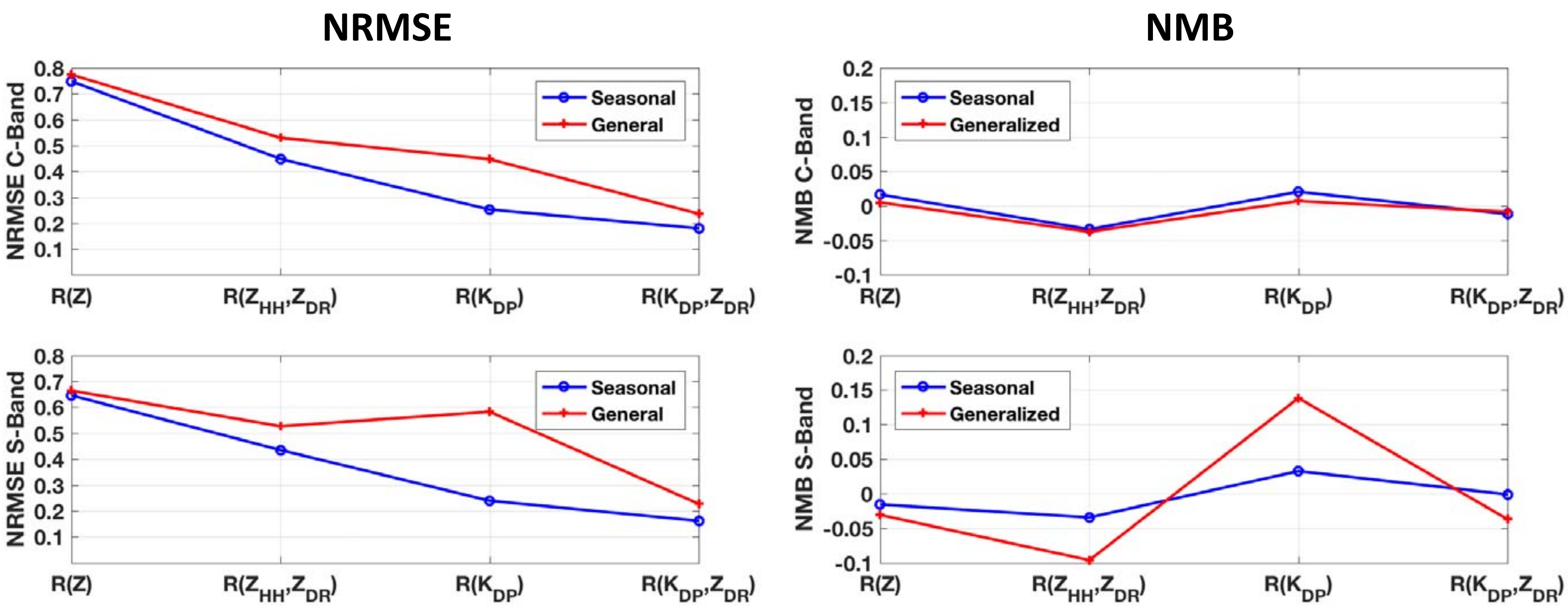
Seasonal dual-pol QPE from 8 years 2DVD



Seasonal dual-pol QPE

Seasonal dual-pol QPE from 8 years 2DVD

❖ **The NRMSEs and NMBs from seasonal-based coefficients are consistently lower than generalized coefficients.**



Seasonal dual-pol QPE

Seasonal dual-pol QPE from 8 years 2DVD

- **Cases from 2014/3-2015/8**
- **Hourly accumulated rainfall > 15mm in northern Taiwan basin area. → 18 events, 42 hours.**

QC on PPI

↓

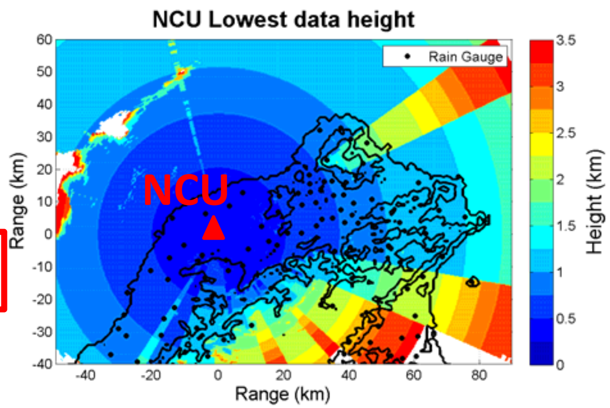
QPEs from QCed PPI

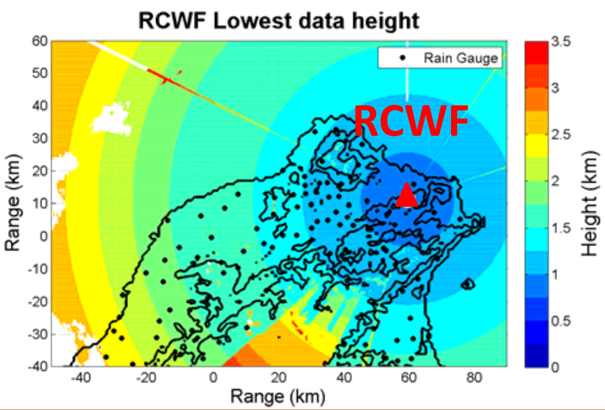
↓

PPI to CAPPI QPEs

↓

Lowest CAPPI QPEs



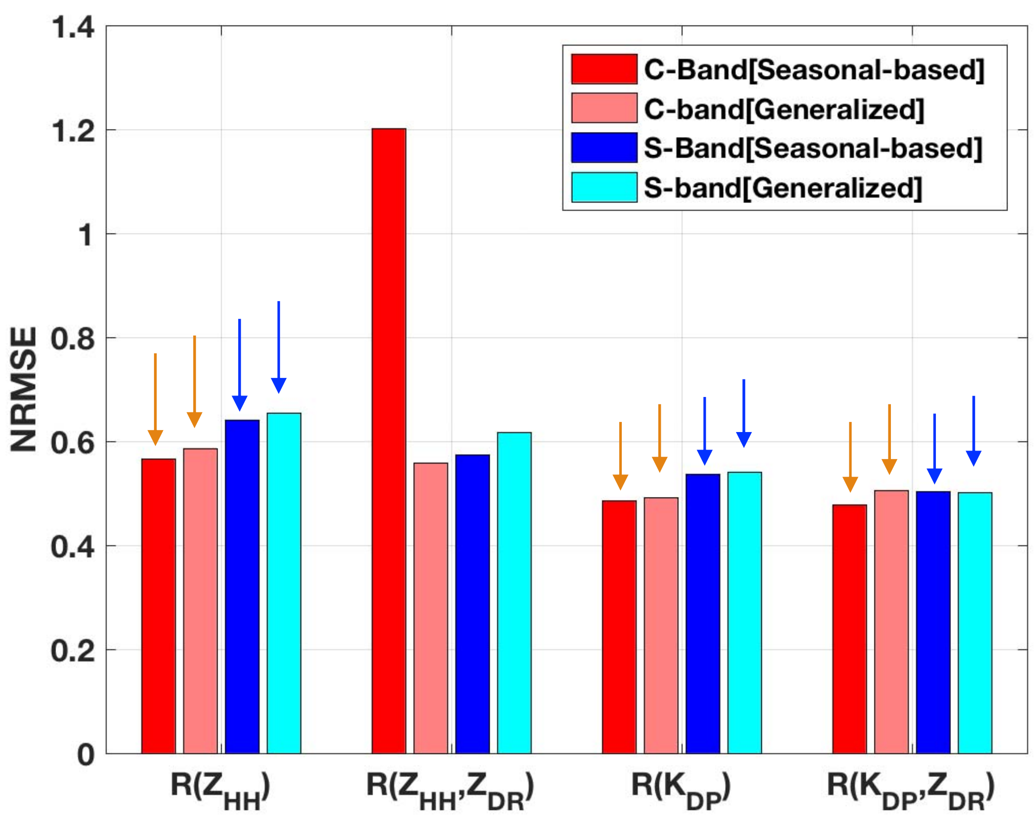


[yy/mm/dd/(h)]	Max. Hourly / Accum. R	Scan Time	
		NCU	RCWF
140426 (1h)	60	6:40	5:50
140505 (2h)	20 / 33	6:40	5:50
140509 (2h)	23.5 / 35	6:40	5:50
140515 (1h)	57.5	6:40	5:50
140520 (3h)	26 / 50	6:40	5:50
140521 (2h)	38 / 52.5	6:40	5:50
140529 (6h)	56.5 / 115	6:40	5:50
140605 (6h)	46 / 135.5	6:40	5:50
140607 (1h)	35	6:40	5:50
140731 (1h)	48.5	10:00	5:50
140813 (1h)	36.5	10:00	5:50
140819 (3h)	71.5 / 92.5	10:00	5:50
150224 (4h)	29.5 / 58.5	10:00	5:50
150512 (2h)	41.5 / 50.5	10:00	5:50
150522 (2h)	19.5 / 28	10:00	5:50
150606 (2h)	37 / 45.5	10:00	5:50
150614 (2h)	103.5 / 167	10:00 12:30	5:50
150723 (2h)	74 / 80	10:00 12:30	5:50

Seasonal dual-pol QPE

Seasonal and generalized dual-pol QPE coefficients

- **Seasonal-based coefficients perform better than generalized coefficients.**
- **Except R(Z_{HH} , Z_{DR}) in C-band, due to other issue (e.g., att. effect in Z_{DR})**



QC procedures & dual-pol QPE

Bias QC procedures for S-/C-band dual-pol

Less than 50% of power blockage

PBB problem
① Terrain height

⇩

RCWF : RH=0.8 ; Std=15
NCU : RH=0.85 ; Std=20

Filter out non-weather signal
① Remove circle area near radar
② RH + Std of ΦDP

⇩

Next presentation
陳如瑜小姐

9-points smoothing

PHI action
① ΦDP Unfold
② ΦDP Filter and smooth
③ KDP calculation and smooth

⇩

Correction
① ΦDP-based Att. correction
② Z bias (self-consistency)
③ ZDR system bias (statistic)

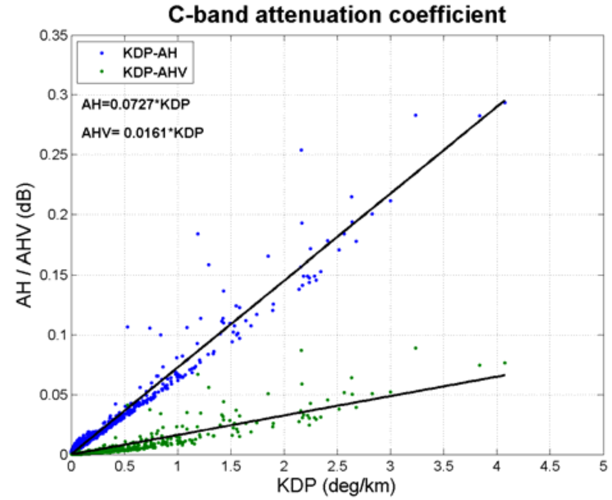
⇩

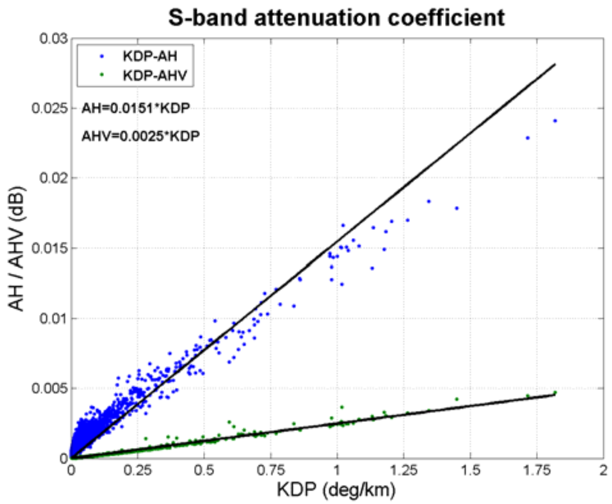
ZDR 9-points smooth

$$\Phi_{DP} = 2\int K_{DP}dx = 2\int a\,Z^{b}dx$$

$$\Phi'_{DP} = 2\int K'_{DP}\,dx = 2\int a\,Z^{b}_{obs}dx$$

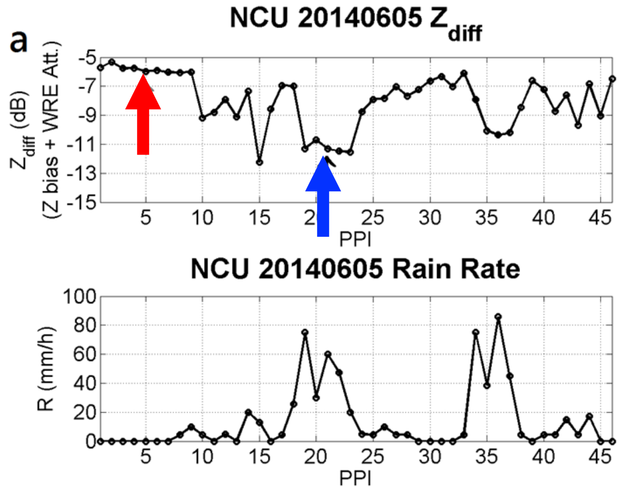
$$Z_{bias}(dB) = 10 \times \frac{1}{b} \times log_{10}(\Delta\Phi'_{DP}/\Delta\Phi_{DP})$$





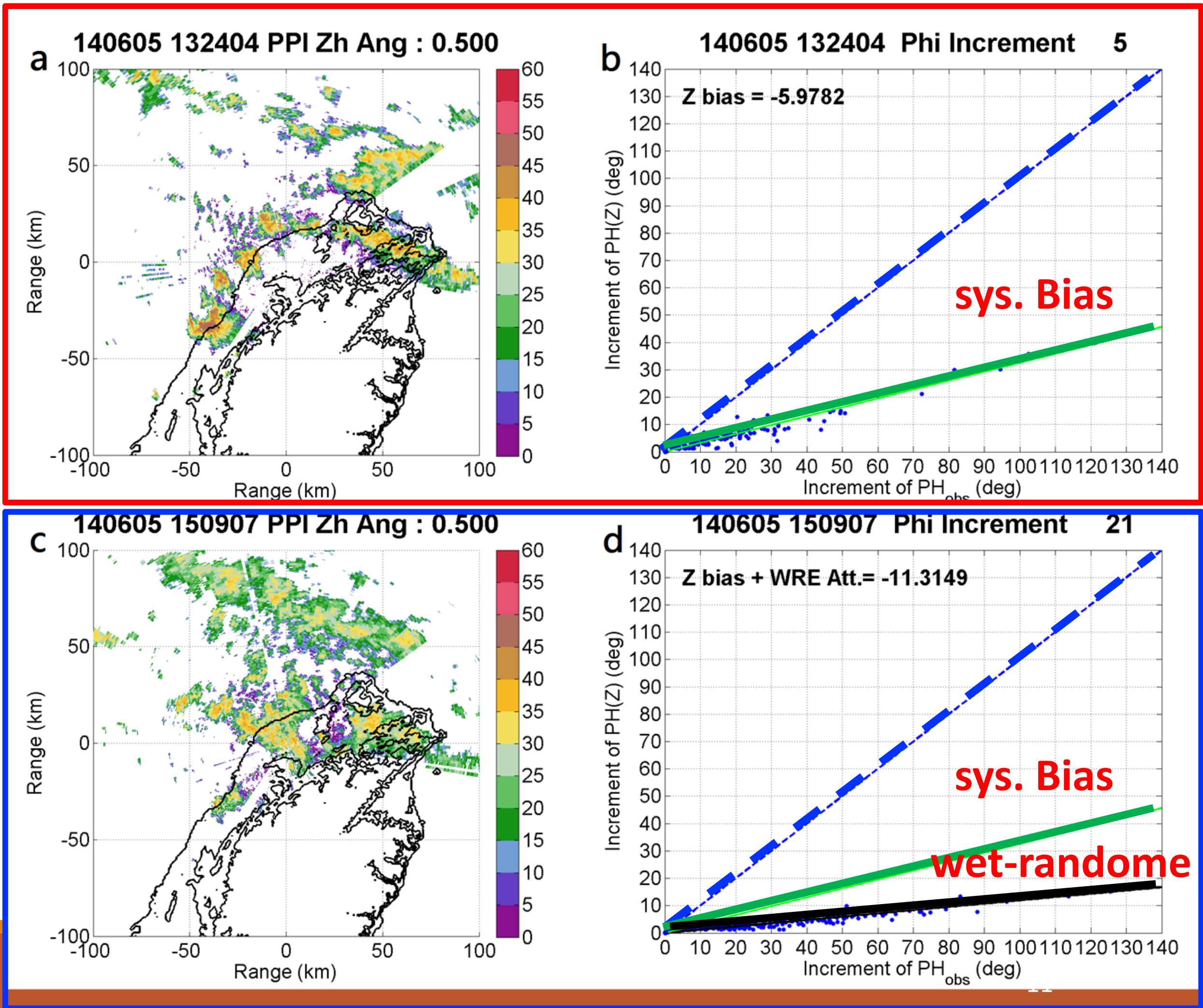
QC procedures & dual-pol QPE

Bias QC procedures for S-/C-band dual-pol



$Z_{HH}^{True} = Z_{HH}^{obs}$ + Bias + att.

$Z_{DR}^{True} = Z_{DR}^{obs}$ + Bias + att.



QC procedures dual-pol QPE

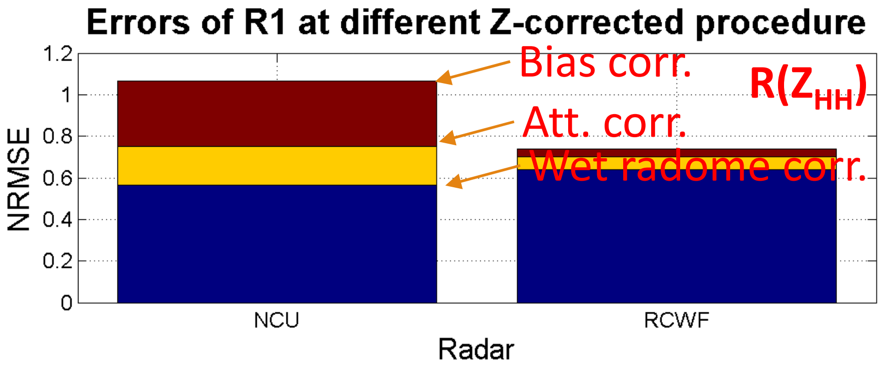
Bias QC procedures for S-/C-band dual-pol

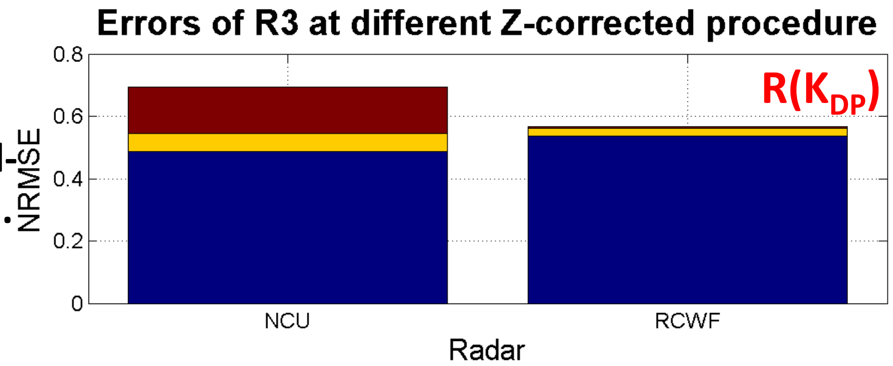
- Z bias : NCU → -6dB
  RCWF → -1.7dB

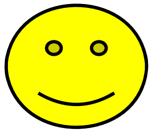
Bias → Att. Cor.

Att. Cor. → wet radome Cor.

- **The wet-randome effect in S-band can not be ignored.**
- **The severe att. & wet-randome of C-band dual-pol measurements can be corrected fairly well.**
- **Comparable S/C-band QPE after applying proper QC procedures.**

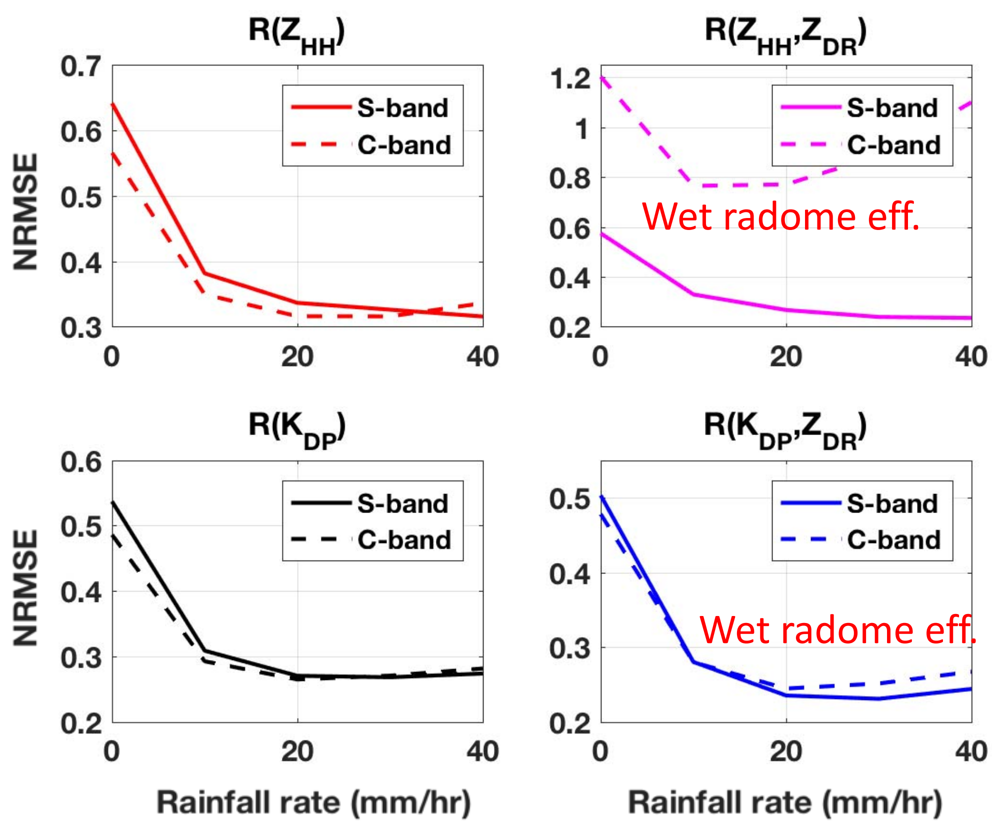






Comparison of S/C dual-pol QPE

Comparison among the same QPE: diff. frequency



$R(Z_{HH})$:
C-band performance better.

$R(Z_{HH}, Z_{DR})$:
S-band → performance better.
C-band → suffered from att. effect.

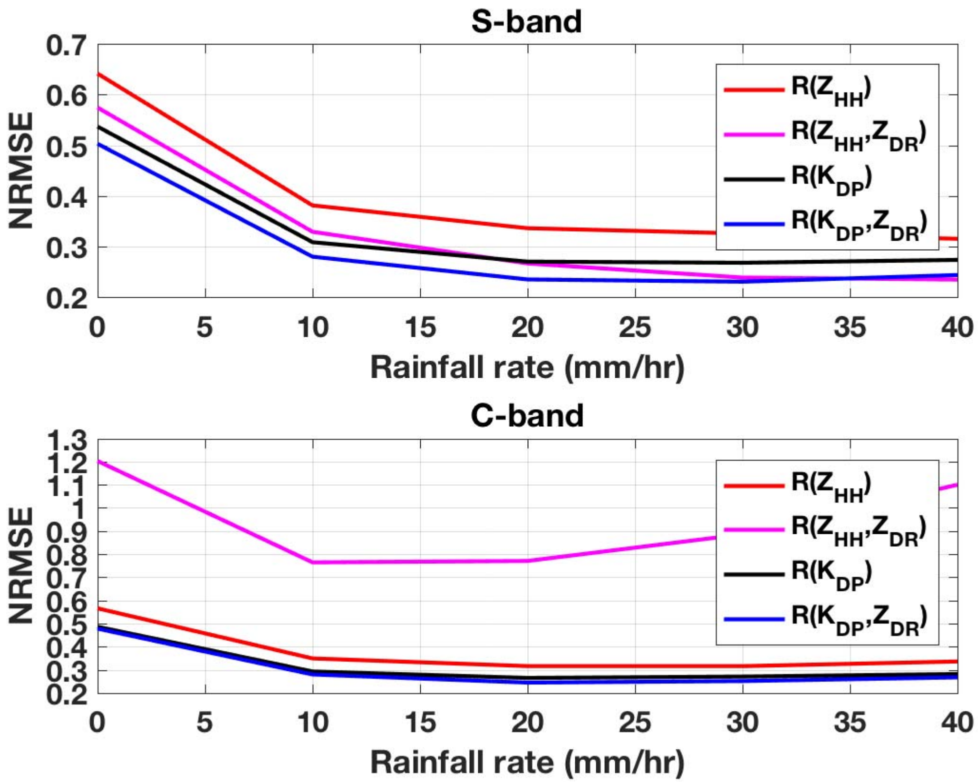
$R(K_{DP})$:
R < 30 mm/hr → C-band is better
R > 30 mm/hr → S-band is better
(Z_{HH} att. effect)

$R(K_{DP}, Z_{DR})$:
R < 10 mm/hr → C-band is better
R > 10 mm/hr → S-band is better
(Z_{DR} att. effect)

❖ **Comparable performance of S/C dual-pol QPEs.**

Comparison of S/C dual-pol QPE

Comparison among diff. QPEs: same frequency



$R(Z_{HH})$:
The worse.

$R(Z_{HH}, Z_{DR})$:
S-band → comparable to $R(K_{DP}, Z_{DR})$.
C-band → suffered from att. effect (Z_{DR}).

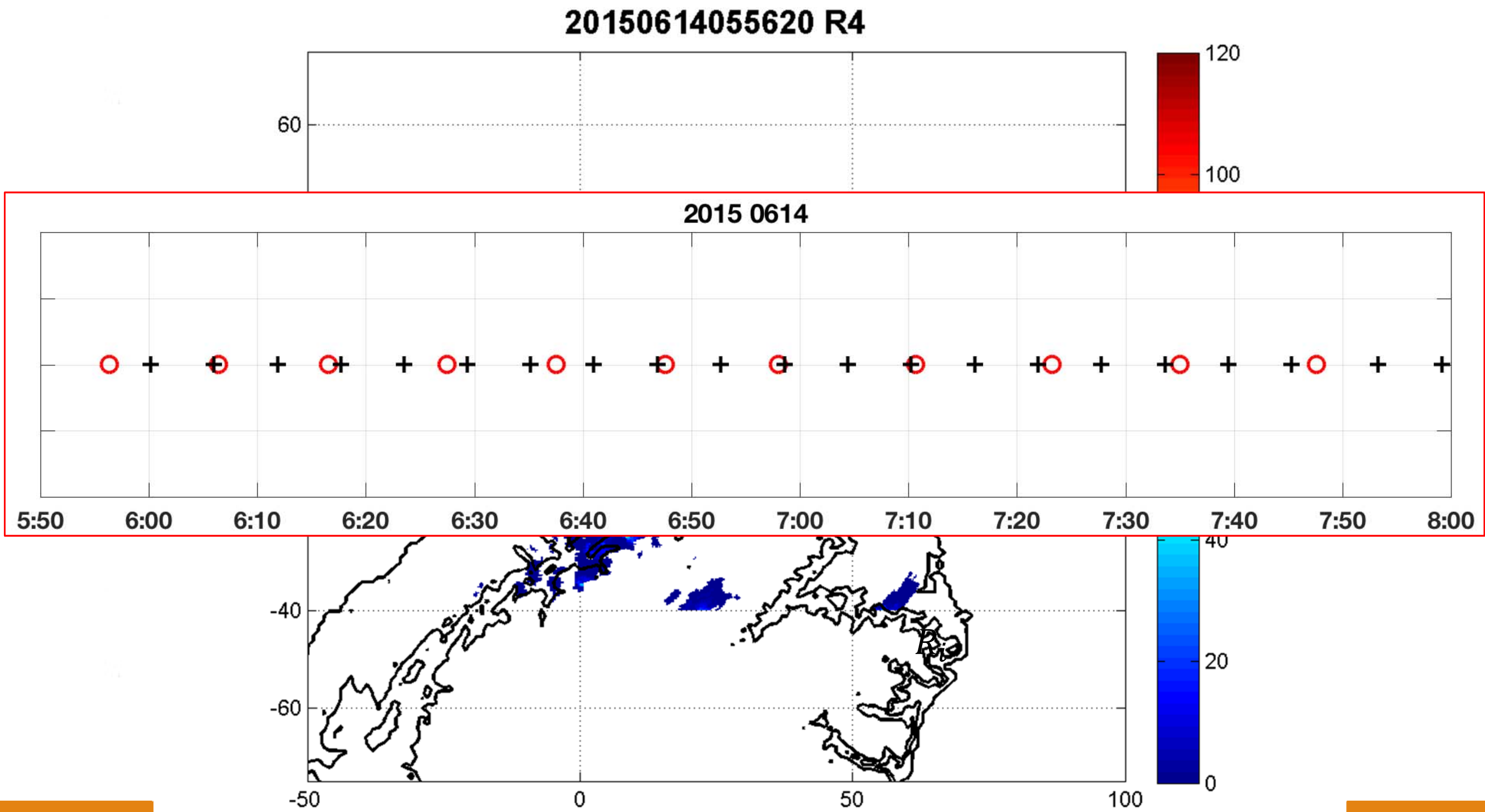
$R(K_{DP})$:
2nd best QPE.

$R(K_{DP}, Z_{DR})$:
The best QPE.

❖ **$R(K_{DP}, Z_{DR})$ out performs other dual-pol QPEs.**

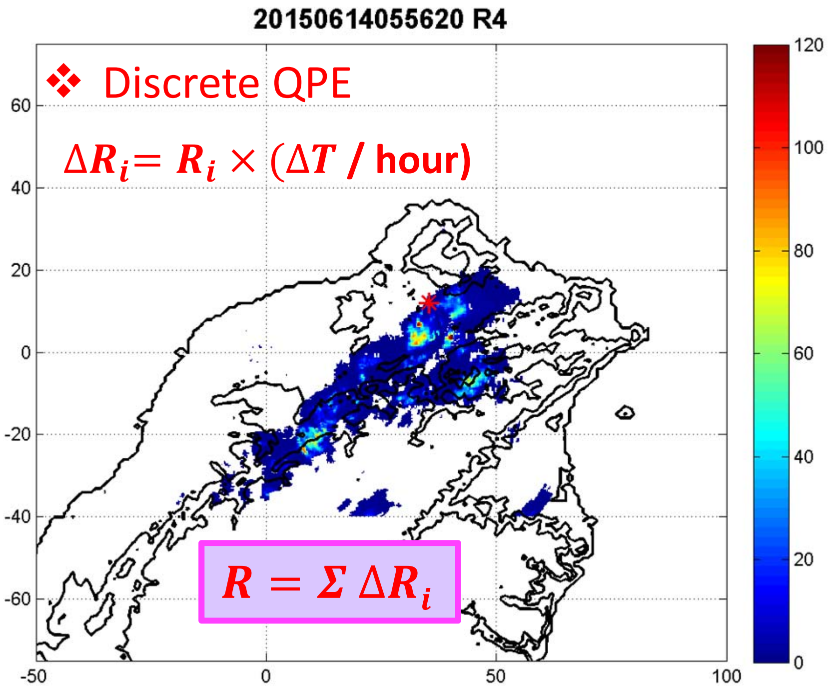
Integrating S/C dual-pol QPEs

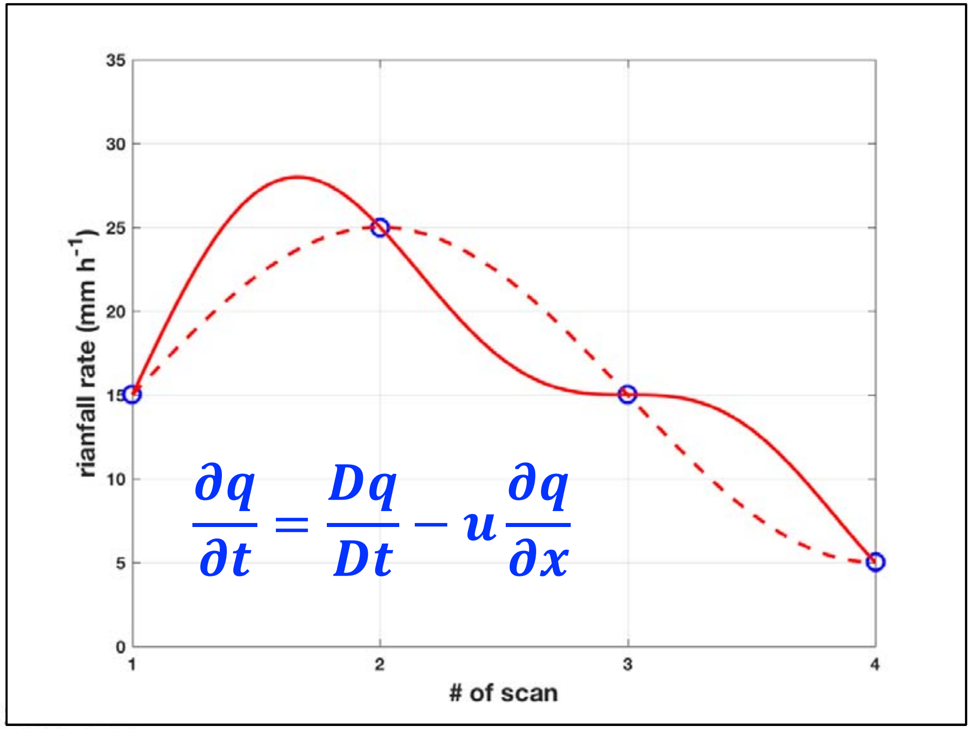
Discrete QPE

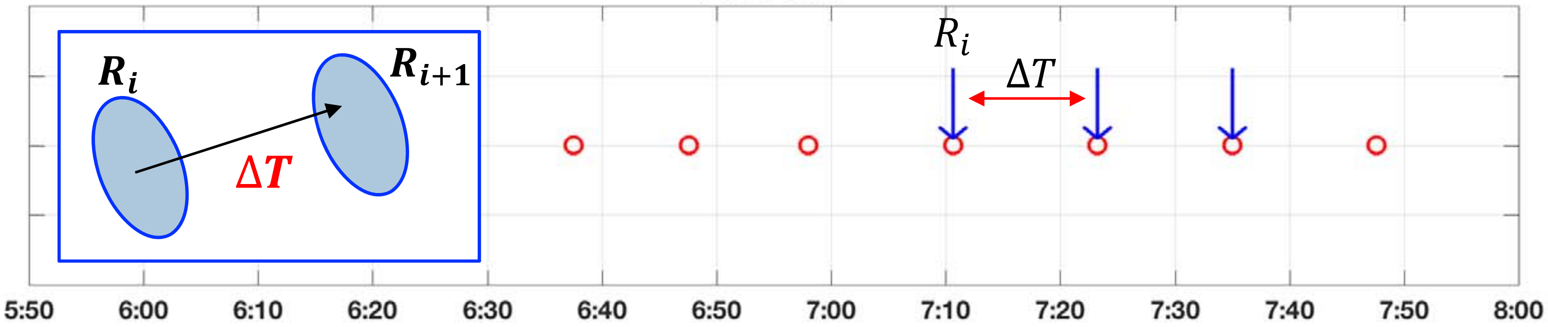


Integrating S/C dual-pol QPEs

Discrete QPE

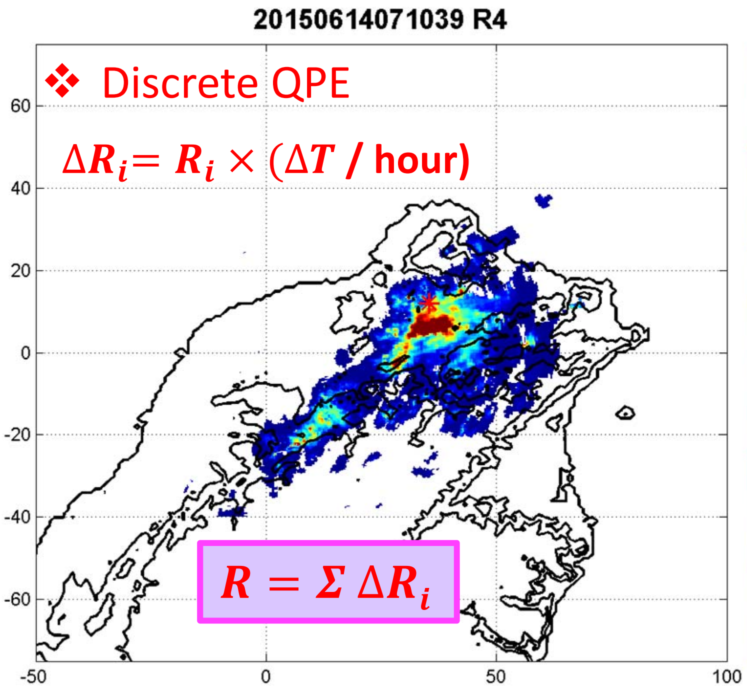


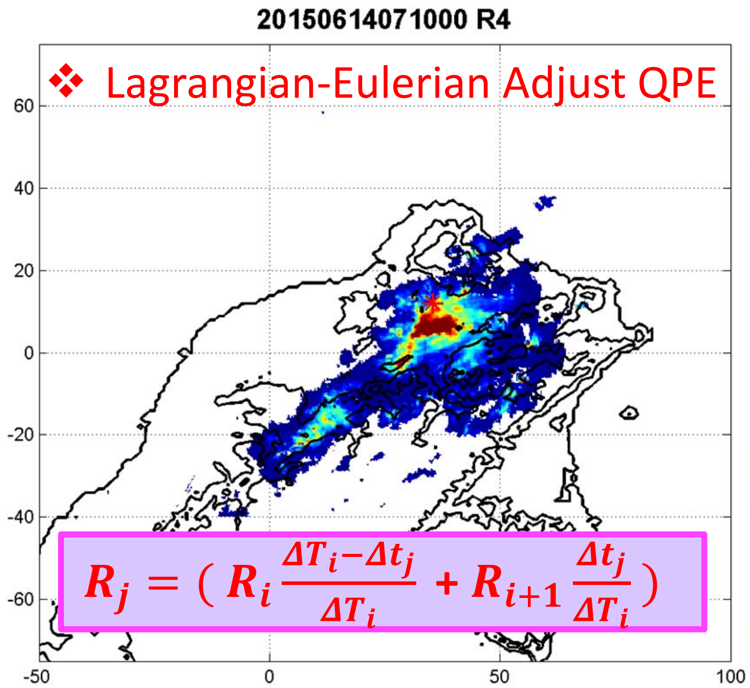


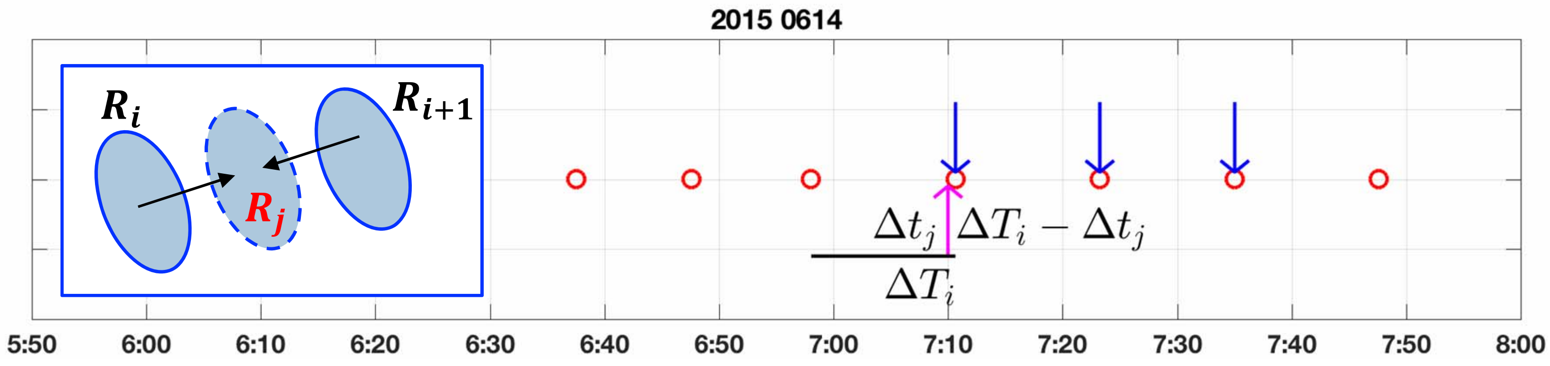


Integrating S/C dual-pol QPEs

Lagrangian-Evoluation Adjust (LEA) QPE

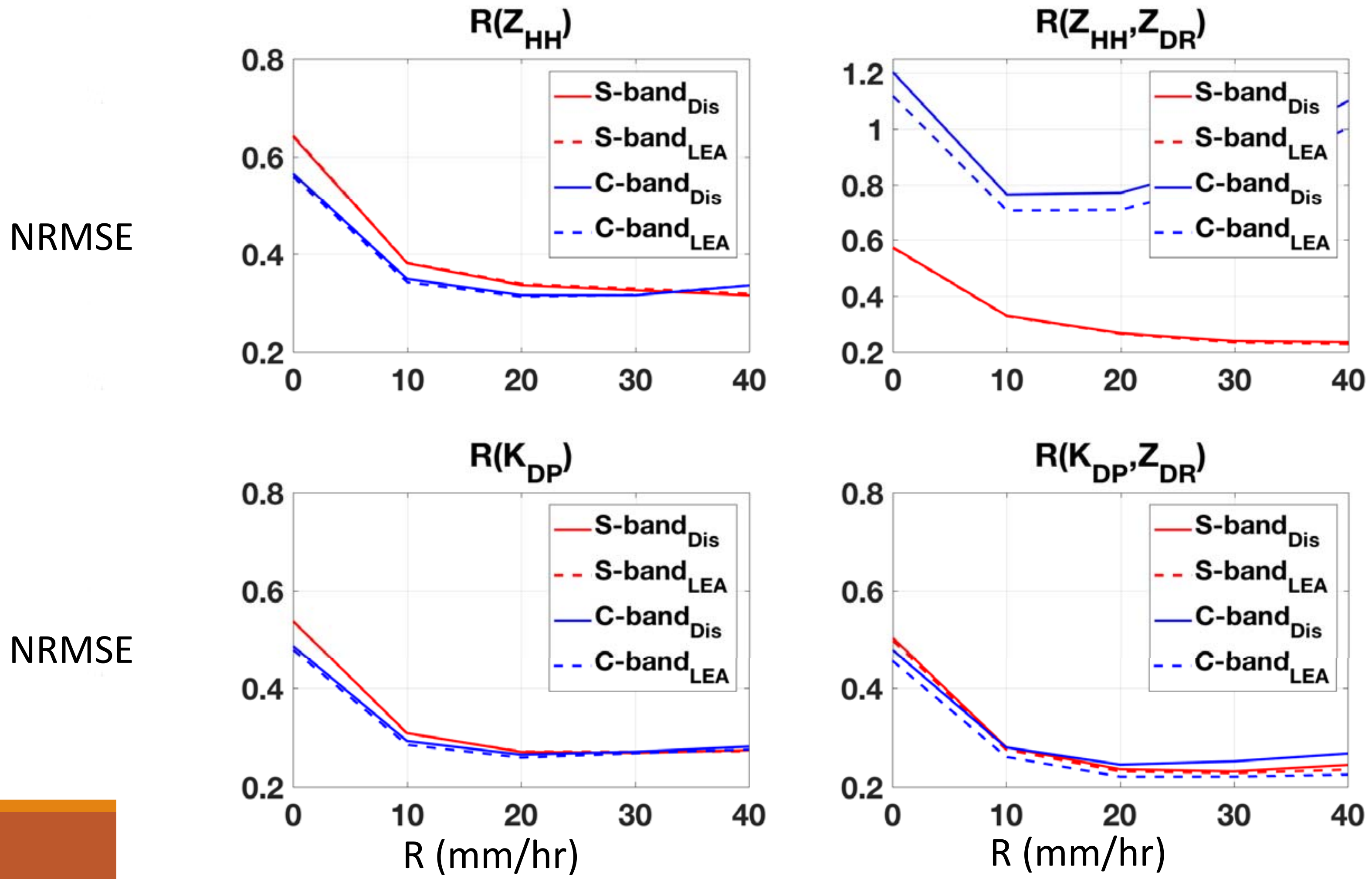






Integrating S/C dual-pol QPEs

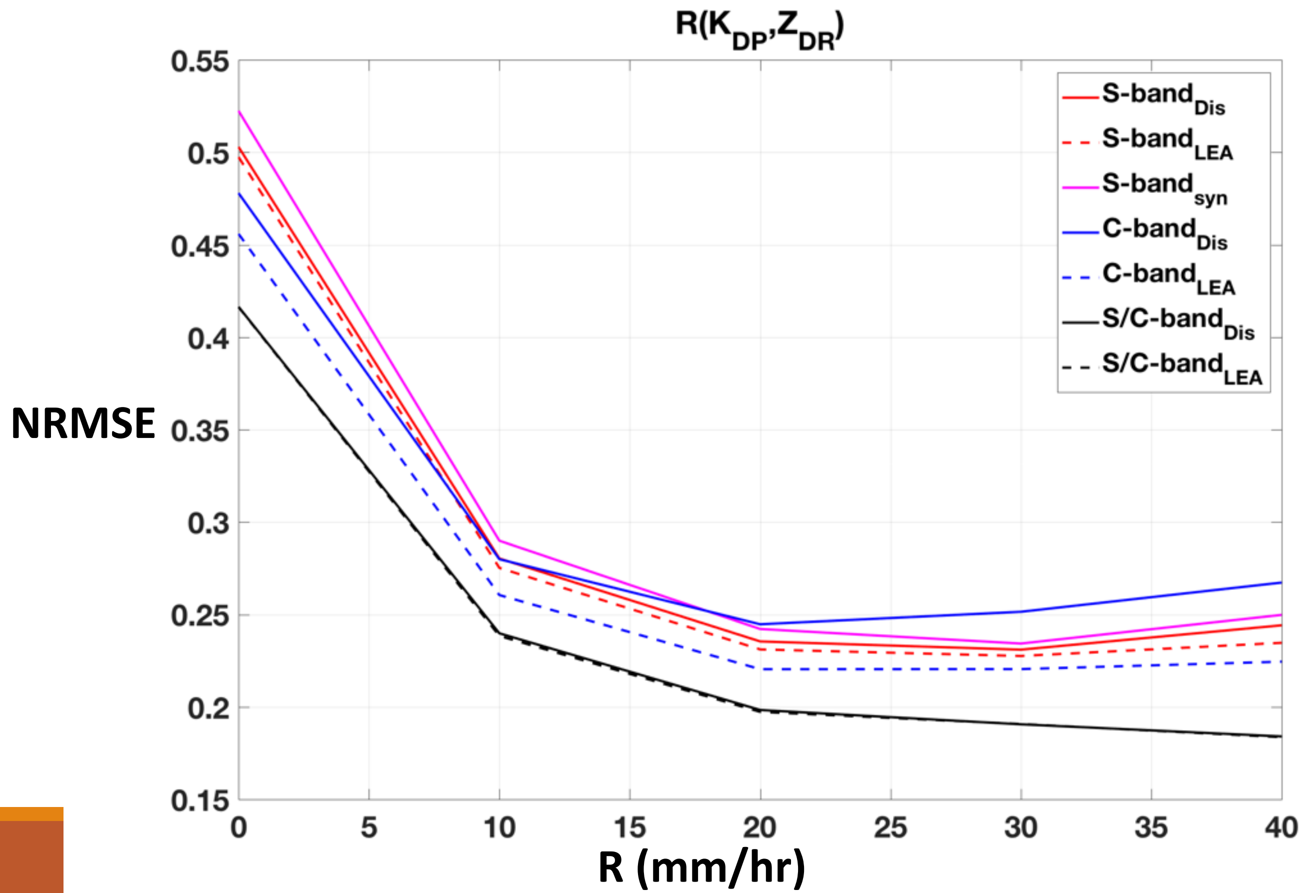
Comparison of discrete & LEA QPEs



Integrating S/C dual-pol QPEs

Combining S/C dual-pol QPEs

- The benefit from LEA is pronounced when ΔT is large, but diminishing with decreasing of ΔT.
- Combining S/C dual-pol QPEs further reduce the NRMSE.



Summary

- The seasonal-based coefficient QPEs are slightly better than generalized coefficient QPEs.
  - ❖ After applying proper QC procedures, the S- and C-band QPEs are comparable.
- Even K_{DP}-based QPEs from S-band radar need attenuation and web-randome effects correction.
  - ❖ The K_{DP}-based QPEs have less NRMSE than Z_{HH}-based QPEs.
  - ❖ Z_{DR} can further reduce the NRMSE, except the C-band due to the wet-randome effect.
- $R(K_{DP}, Z_{DR})$ outperformance other dual-pol QPEs.
- The NRMSE of discrete QPEs can be further reduced by applying Lagrangian-Evoluation Adjust. Combining S/C dual-pol QPEs provides the lowest NRMSE by capturing DSD variation.

Thanks

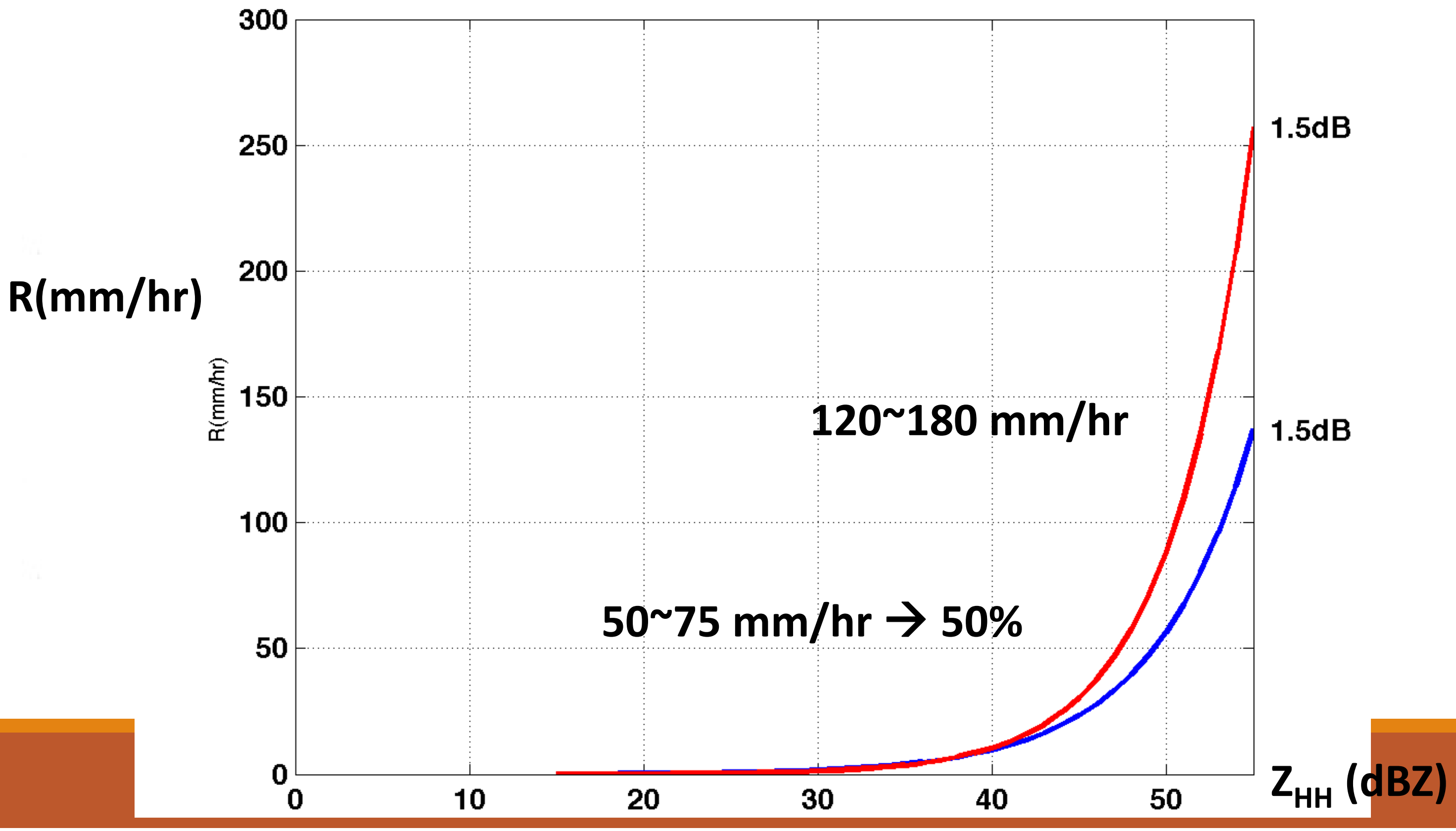
Background

The challenge of dual-pol QPE: DSD variability

- **Ryzhkov et al. (2005): Uncertainty of $R(Z_{HH}, Z_{DR})$ due to DSD variability.**

  Maritime type → $R(Z,Z_{DR}) = 0.0067(Z)^{0.927} (Z_{DR})^{-3.42}$

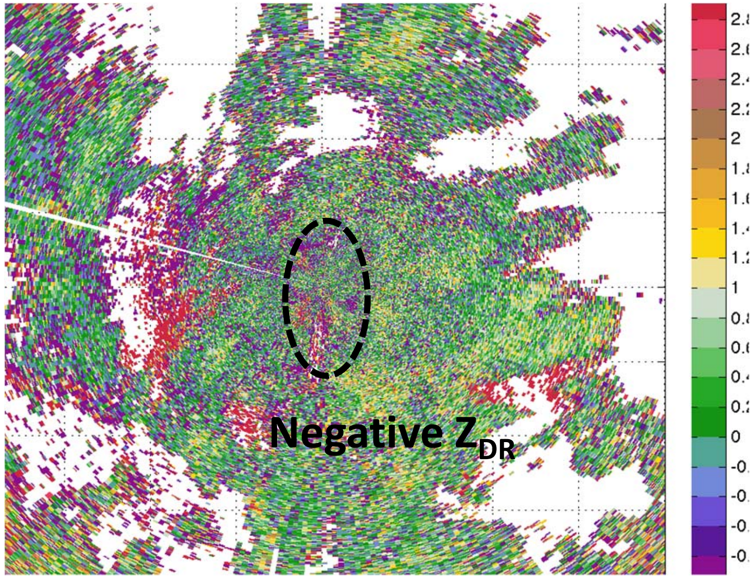
  Continental type → $R(Z,Z_{DR}) = 0.0142(Z)^{0.770} (Z_{DR})^{-1.67}$

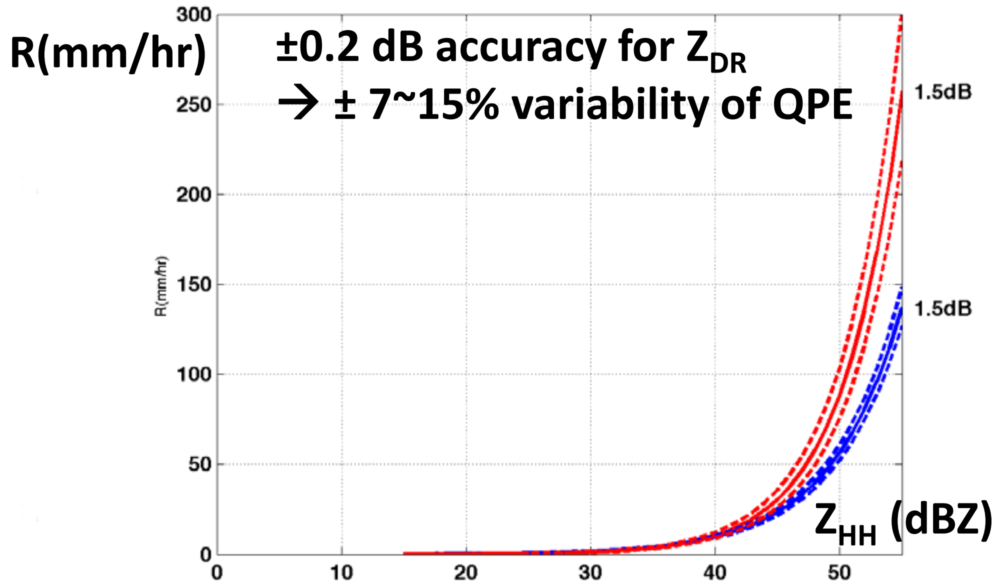


Background

The challenge of dual-pol QPE: data quality

- **Bringi and Chandrasekar (2001): Uncertainty due to observation error.**
  - → **System bias from calibrations**
  - → **Noisy measurement (e.g., low sampling number)**
  - → **Wet-radome Effect**
  - → **Partial beam blockage (PBB) + Interference from ground target**



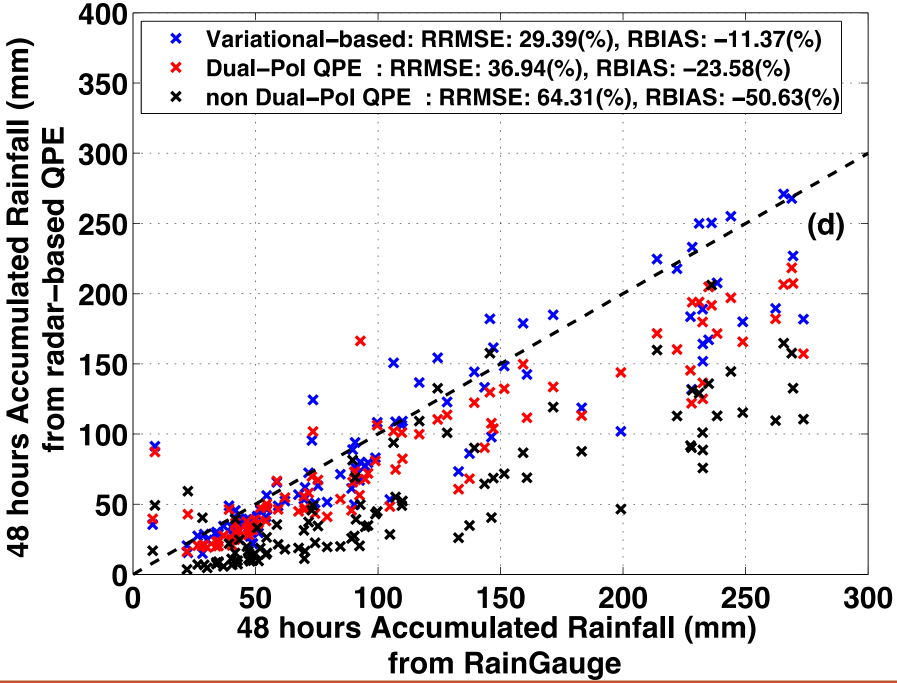


Background

The challenge of dual-pol QPE: Var.-based QPE

From Chang et al (2016)

- **The variational-based QPE consistently outperforms $Z(Z_{HH},Z_{DR})$ QPE.**
- **The variational-based QPE is less vulnerable to observational error (0.2 ~ 0.5 dB).**
- **The variational-based QPE retrieved more accurate rainfall estimation than dual-pol QPE despite both algorithms used the dual-pol measurements from KFTG.**
- **20~30% improvements.**



	RRMSE (mm)	RBIAS (mm)
Variational-base	29.4%	-11.4%
Dual-pol	36.9%	-23.6%
Non dual-pol	64.3%	-50.6%

Seasonal dual-pol QPE

Seasonal and generalized dual-pol QPE coefficients

- **Seasonal-based coefficients perform better than generalized coefficients.**
- **Except $R(Z_{HH}, Z_{DR})$ in C-band, due to other issue (e.g., att. effect in Z_{DR})**

$R(Z_{HH})$ → $Z = aR^b$

$R(Z_{HH}, Z_{DR})$ → $Z_{DR} > 0$: $R = aZ_{HH}^b Z_{DR}^c$
else : $R(Z_{HH})$

$R(K_{DP})$: → $K_{DP} > 0.5$: $R = aK_{DP}^b$
else : $R(Z_{HH})$

$R(K_{DP}, Z_{DR})$ → $K_{DP} > 0.5$ & $Z_{DR} > 0$: $R = aK_{DP}^b Z_{DR}^c$
else : $R(Z_{HH})$