A Study of Quantitative Precipitation Estimation Methods Based on S-Band Dual-Polarization Doppler Radar

Wen-Jian Zhu[1,2], Kun Zhao[1], Ben Jong-Dao Jou[3], Peng-Fei Zhang[4]

[1]Key laboratory of Mesoscale Severe Weather/MOE, School of Atmospheric Science, Nanjing University, Nanjing, China

[2]National Meteorology Center, Beijing, China

[3]Department of Atmospheric Science, National Taiwan University, Taipei, Taiwan

[4]Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma, Norman, Oklahoma

Outline

1. Motivation
2. Quantitative Precipitation Estimation (QPE) issues
3. Data & Methodology
4. Analysis & Discussion
5. Future work

Motivation

Heavy Rainfall，flash flood，casualties

Very Complicated on radar based QPE in terrain area

SoWMEX/TiMREX, Southwest Monsoon Experiment/Terrain influenced Monsoon Rainfall Experiment

How to do QPE over southern Taiwan area?

QPE issues

- Conventional Radar QPE

  M-P Distribution, WSR-88D,Error sources， Calibration with rain gauges

- Dual-Polarization Radar QPE

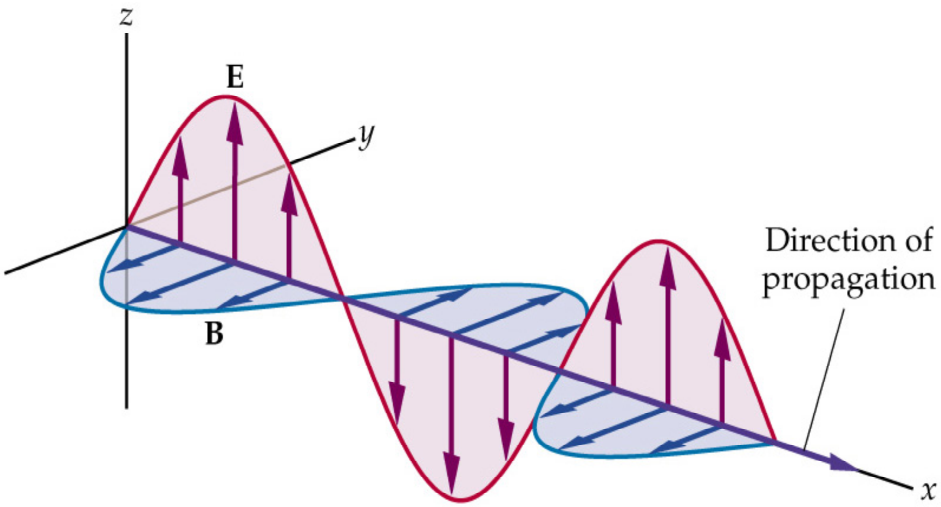
  Z_{DR} (raindrop size)，K_{DP} （immune to partial Beam Block and radar system bias）， combination of different measurements，Echo Classification

Some Measurements of Dual-Polarization Radar

- Horizontal reflectivity $\hat{Z}_h$
- Vertical reflectivity $\hat{Z}_v$
- Differential reflectivity $\hat{Z}_{DR}$
- Differential Phase ϕ_{DP}
- Specific Differential Phase $\boldsymbol{K_{DP}}$
- Correlation coefficient $\rho_{hv}(0)$

$$Z_{DR} = 10 \log \frac{Z_{hh}}{Z_{vv}}$$

$$K_{DP} = \frac{d\phi_{DP}}{dr}$$



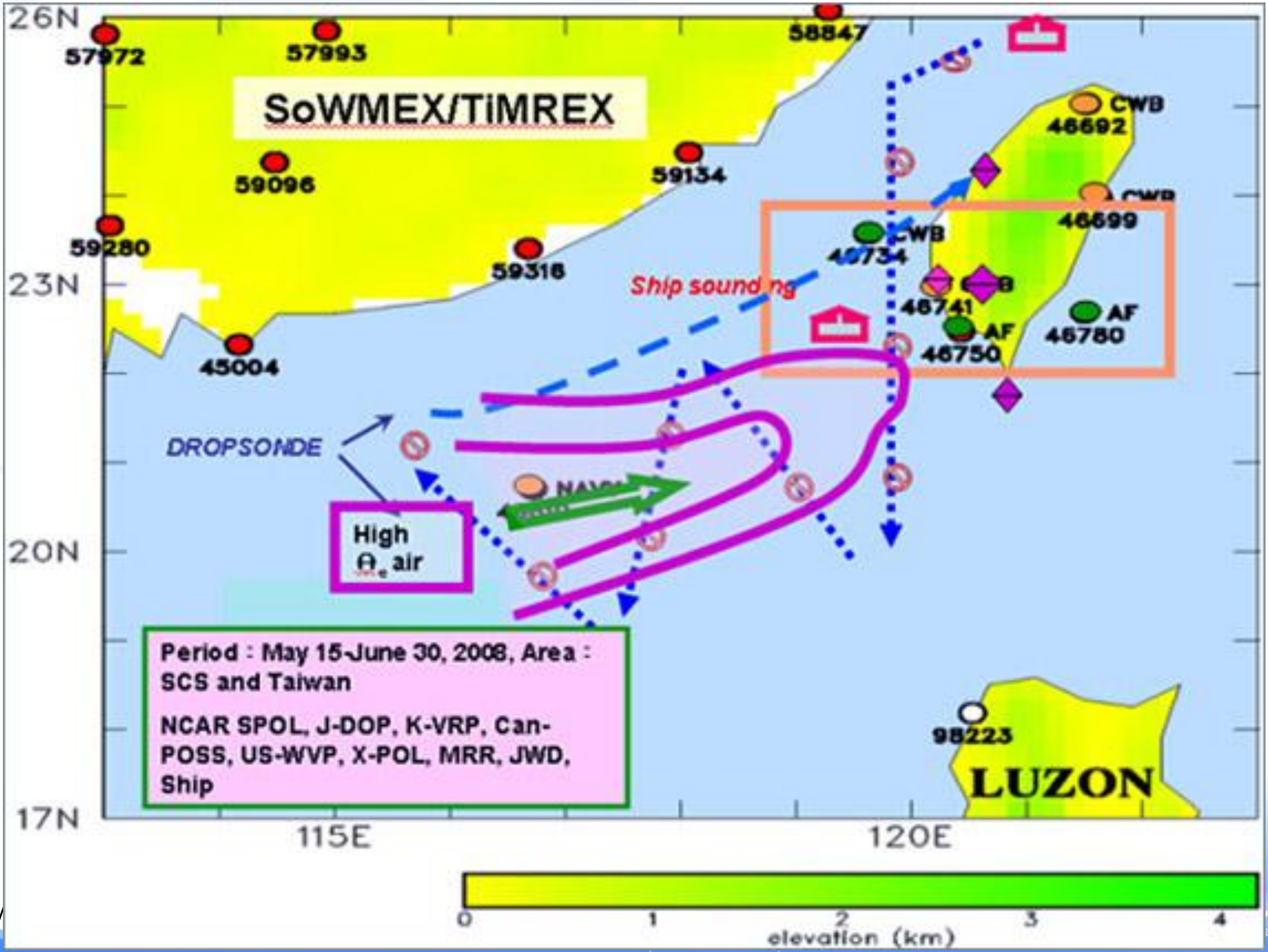
Radar measurements Error sources

- Z_H may be get biased due to radar calibration or partial beam blockage.

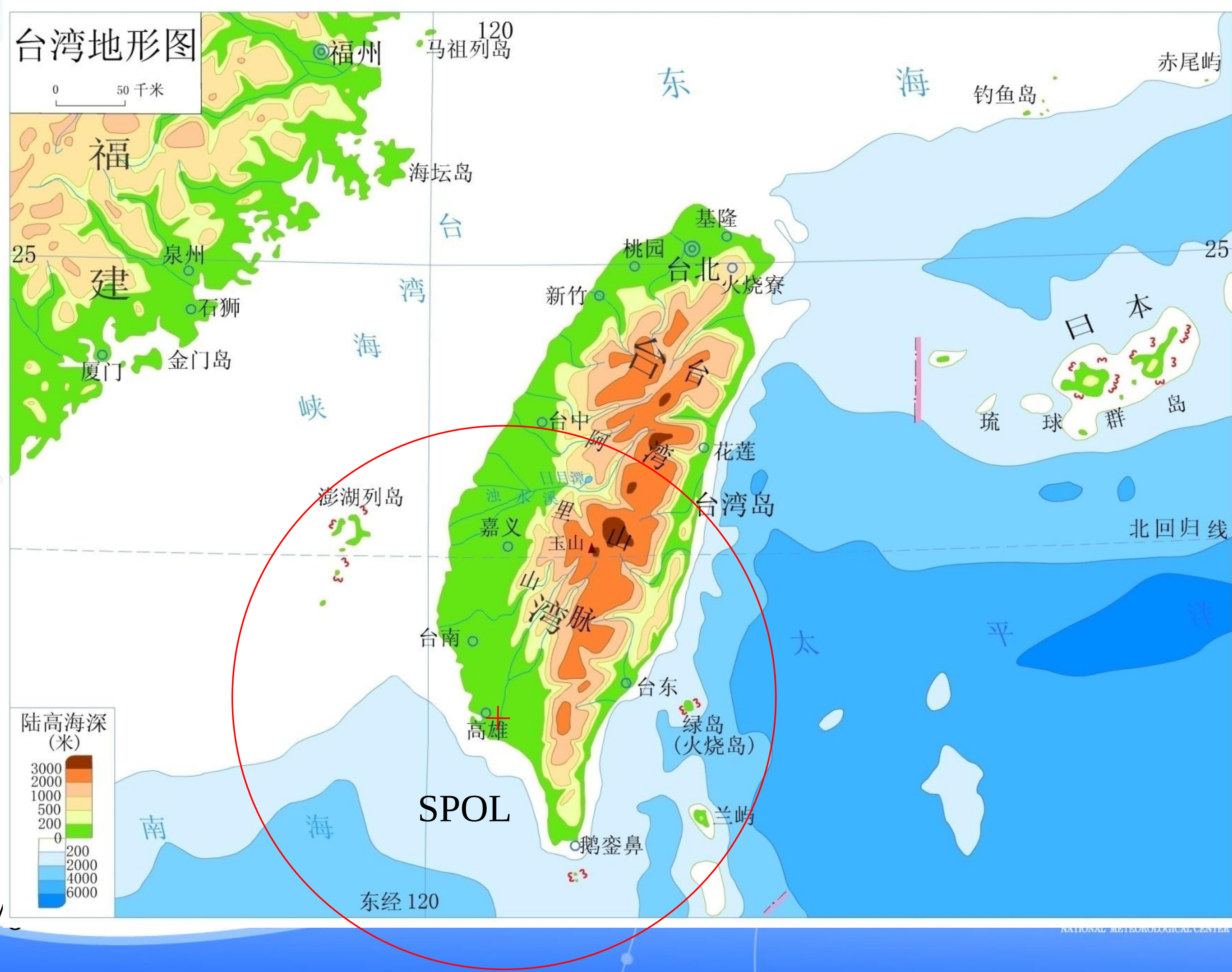
- Z_{DR} is sensitive of radar system bias or attenuation.

- K_{DP} should be used carefully, the errors may be from calculation , smoothing along the radial, or backscattering phase difference.

Sketch map of SoWMEX/TiMREX

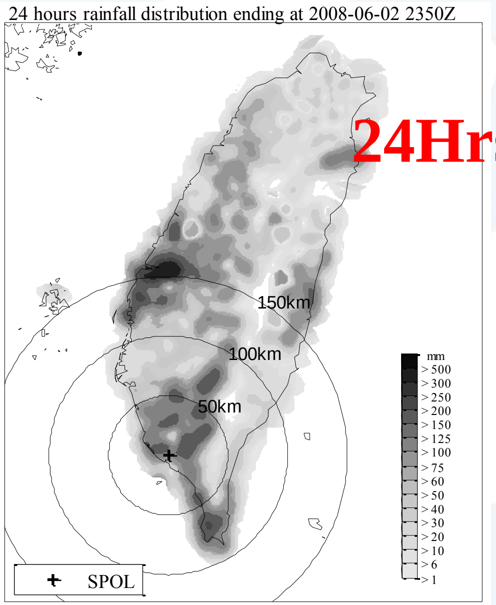


Taiwan terrain & S-pol location

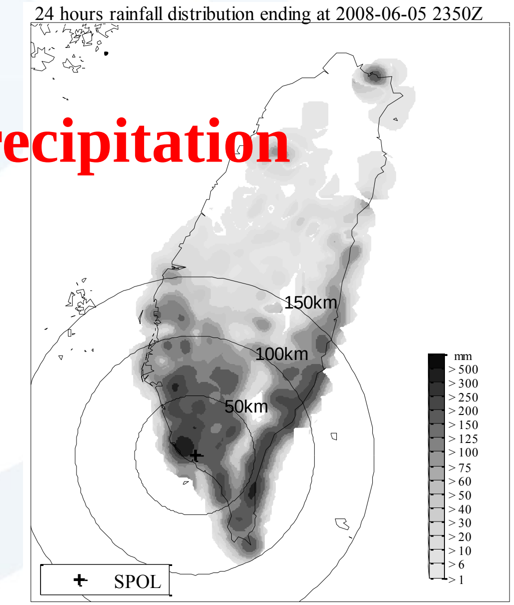


Three heavy rain cases

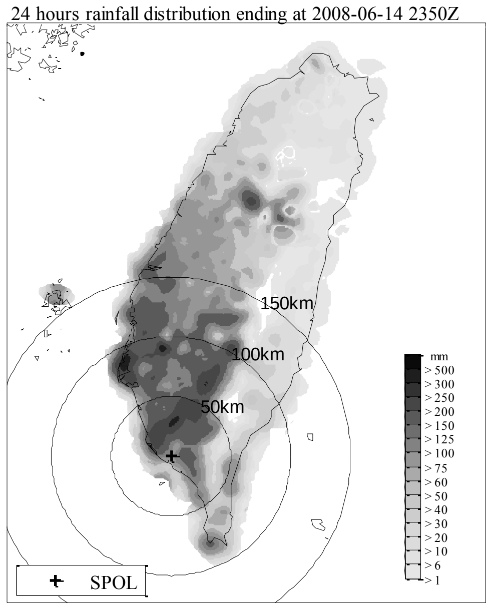
June 2



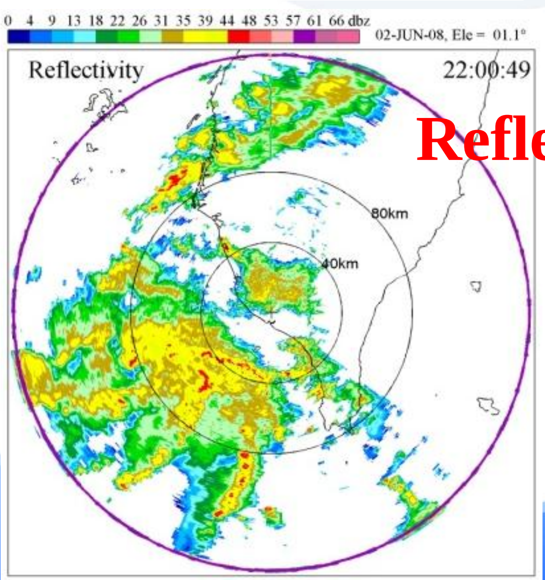
June 5

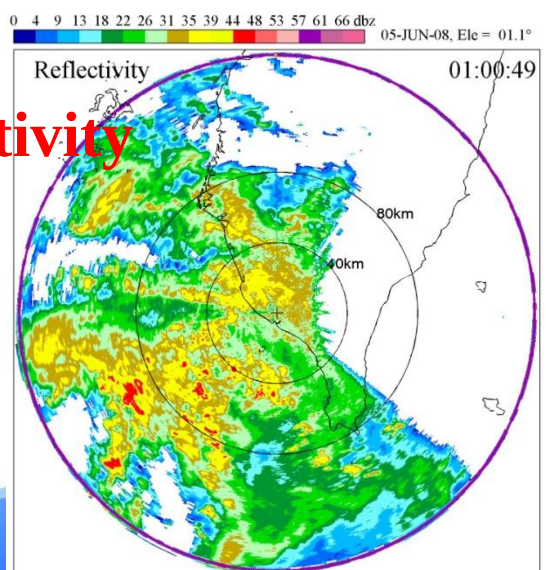


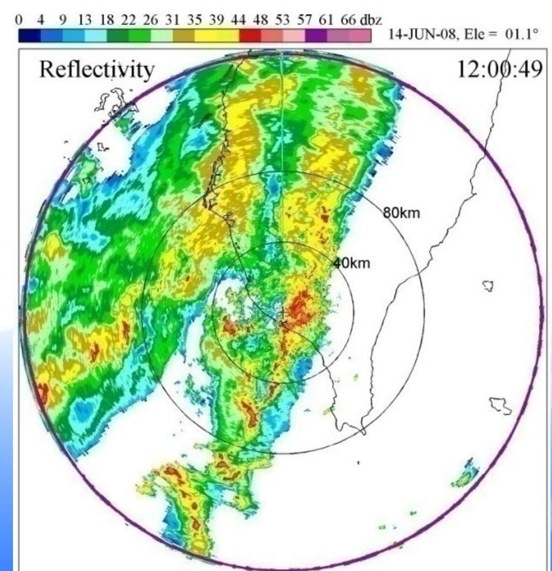
June 14



24Hrs precipitation







Reflectivity

Data source

- NCAR S-Pol radar data
- Raingauge data and sounding data from CWB(Central Weather Bureau,Taiwan)
- Three Cases duration:
- 200806 022100-200806 030000 (UTC)
- 200806 050100-200806 050300
- 200806 140200-200806 150000

Data quality

- Radar data:
- Observation Range: 150km
- Radial resolution 150m.
- Azimuthal resolution 0.75 degree.

- Raingauge data:
- Temporal resolution: 10minutes

Data Preprocess

Rules:

Reflectiviey Z_H< 53dBZ

0< Z_{DR} < 5dB

$\rho_{hv(0)} > 0.9$

QPE methods

- Totally 24 schemes, include 3 groups：
- Group 1, the conventional schemes：
- 1）WSR-88D $R_1(Z_H) = 0.017 * Z_H^{0.714}$
- 2）QPESUMs $R_2(Z_H) = 0.1213 * Z_H^{0.6061}$
- 3）Tropical rain $R_3(Z_H) = 0.0129 * Z_H^{0.8}$

here， Z_H is horizontal reflectivity，unit: mm^6m^{-3} ，
R is precipitation, $mm \cdot h^{-1}$

国家气象中心 NATIONAL METEOROLOGICAL CENTER

Group 2: the single Polarimetric methods

$R(K_{DP})=a|K_{DP}|^b sign(K_{DP})$

Scheme	a	b	DSD Assumption	From
4	50.7	0.85	Simulated DSD, equilibrium shape	BC(2001)
5	54.3	0.806	Measured DSD(FL), Brandes' shape	BZV(2002)
6	51.6	0.71	Simulated DSD, Goddard's shape	IB(2002)
7	44.0	0.822	Measured DSD(OK), equilibrium shape	NSSL
8	50.3	0.812	Measured DSD(OK), Bringi's shape	NSSL
9	45.3	0.786	Measured DSD(OK), Brandes' shape	NSSL
10	52.2	0.875	Measured DSD(OK), linear (β=0.052)	NSSL

$R(Z,Z_{DR})=aZ^bZ_{dr}^c$

Scheme	a	b	c	DSD Assumption	From
11	$6.70*10^{-3}$	0.927	-3.43	Simulated DSD, equilibrium shape	BC(2001)
12	$7.46*10^{-3}$	0.945	-4.76	Measured DSD(FL), Brandes' shape	BZV(2002)
13	$7.11*10^{-3}$	1.0	***	Simulated DSD, Goddard's shape	IB(2002)
14	$1.42*10^{-2}$	0.770	-1.67	Measured DSD(OK), equilibrium shape	NSSL
15	$1.59*10^{-2}$	0.737	-1.03	Measured DSD(OK), Bringi's shape	NSSL
16	$1.49*10^{-2}$	0.752	-1.24	Measured DSD(OK), Brandes' shape	NSSL
17	$1.41*10^{-2}$	0.802	-3.43	Measured DSD(OK), linear (β=0.052)	NSSL

$R(K_{DP},Z_{DR})=a|K_{DP}|^bZ_{dr}^c sign(K_{DP})$

Scheme	a	b	c	DSD Assumption	From
18	90.8	0.93	-1.69	Simulated DSD, equilibrium shape	BC(2001)
19	136	0.968	-2.86	Measured DSD(FL), Brandes' shape	BZV(2002)
20	52.9	0.852	0.53	Measured DSD(OK), equilibrium shape	NSSL
21	63.3	0.851	-0.72	Measured DSD(OK), Bringi's shape	NSSL
22	68.6	0.915	-1.01	Measured DSD(OK), linear (β=0.052)	NSSL

From
Ryzhkov 2005

Group 3. the Synthesis schemes

- Schem 23： Bringi et al. （2002）：

$$R(mm\cdot hr^{-1}) = \begin{cases} R_1(Z_H) & R_1(Z_H) \le 20mm\cdot hr^{-1} \\ R(Z_H, Z_{dr}) & 20mm\cdot hr^{-1} \le R_1(Z_H) \le 70mm\cdot hr^{-1} \\ R_1(K_{DP}) & R_1(Z_H) > 70mm\cdot hr^{-1} \end{cases}$$

here,

$$R(Z_H, Z_{DR}) = 0.0159 * Z_H^{0.737} * Z_{dr}^{-0.103}$$

The same as scheme 15

$$R_1(K_{DP}) = 40.56 * |K_{DP}|^{0.866} * sign(K_{DP})$$

from Ryzhkov 2003

Group 3. the Synthesis schemes

- Scheme 24： Ryzhkov (2005) :

$$R(mm \cdot hr^{-1}) = \begin{cases} R_1(Z_H)/f_1(Z_{DR}) & R_1(Z_H) \le 6mm \cdot hr^{-1} \\ R_2(K_{DP})/f_2(Z_{DR}) & 6mm \cdot hr^{-1} \le R_1(Z_H) \le 50mm \cdot hr^{-1} \\ R_2(K_{DP}) & R_1(Z_H) > 50mm \cdot hr^{-1} \end{cases}$$

here,

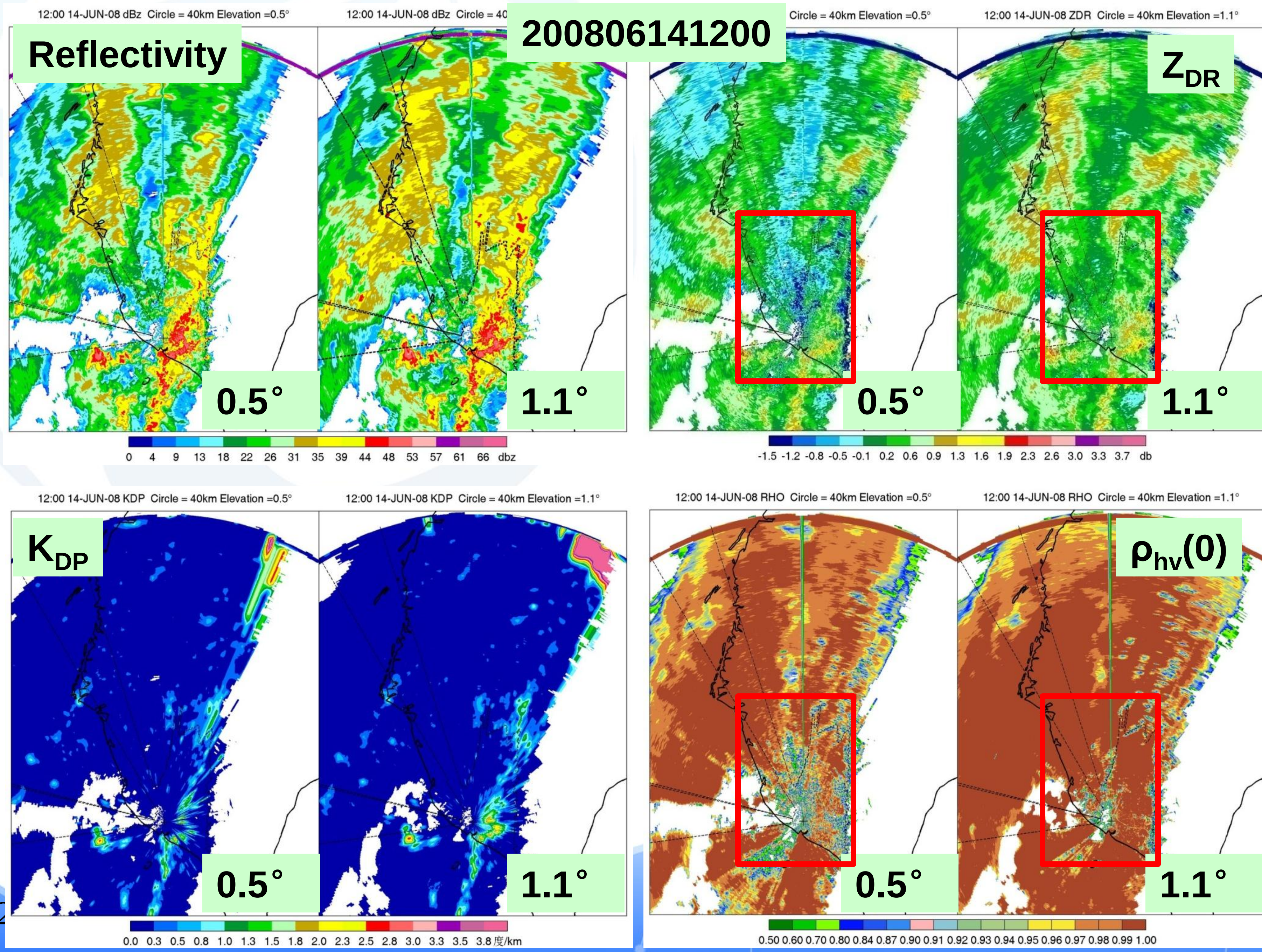
$$R_2(K_{DP}) = 44.0*|K_{DP}|^{0.822} *sign(K_{DP})$$

⇨ The same as scheme 7

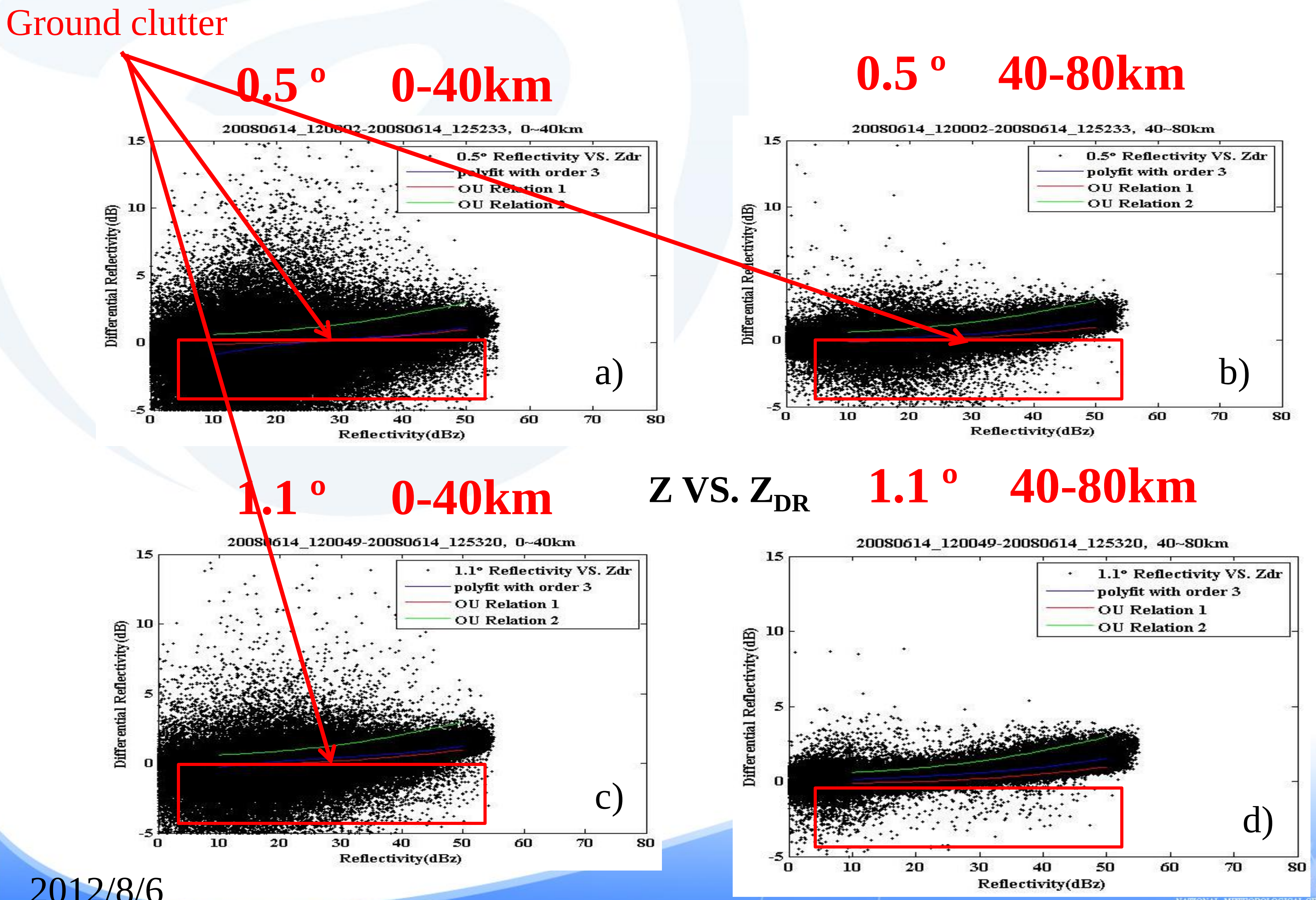
$$f_1(Z_{DR}) = 0.4 + 5.0*|Z_{dr} - 1|^{1.3}$$

$$f_2(Z_{DR}) = 0.4 + 3.5*|Z_{dr} - 1|^{1.7}$$

} From Fulton et al 1999

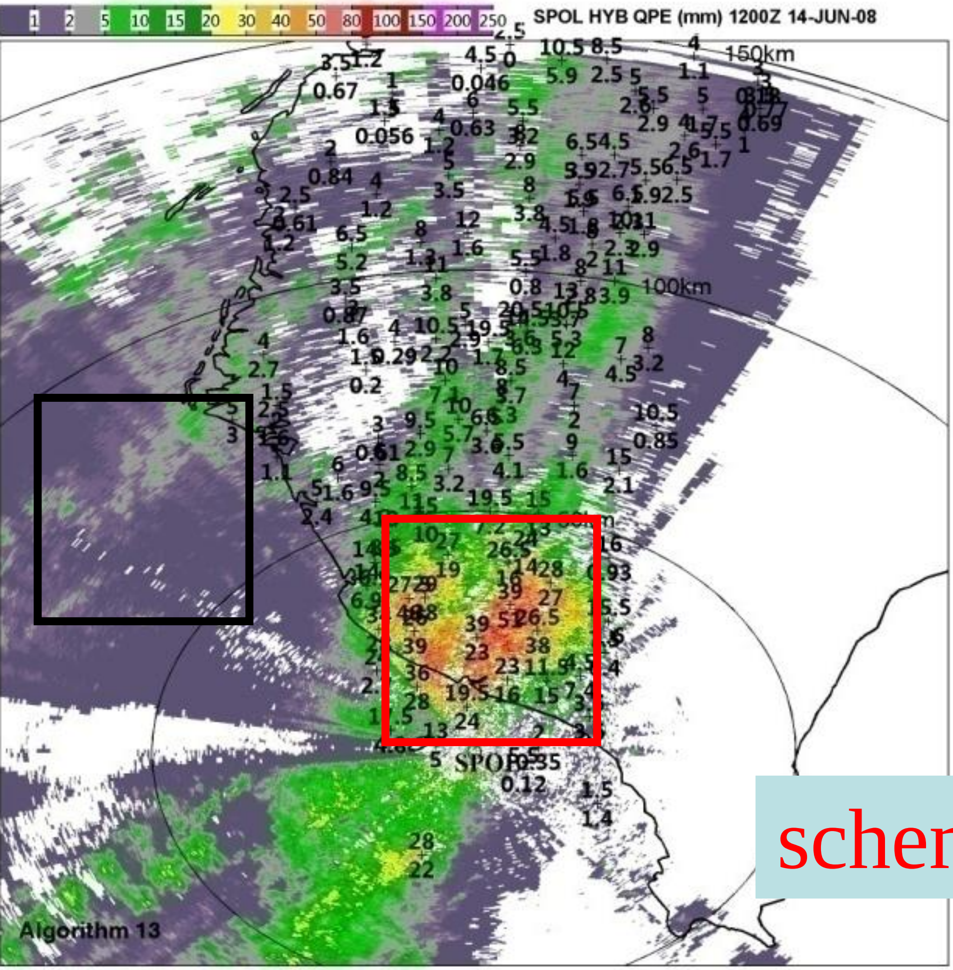

200806141200
12:00 14-JUN-08 dBz Circle = 40km Elevation =0.5°
12:00 14-JUN-08 dBz Circle = 40
Reflectivity
0.5°
1.1°
0 4 9 13 18 22 26 31 35 39 44 48 53 57 61 66 dbz
Circle = 40km Elevation =0.5°
12:00 14-JUN-08 ZDR Circle = 40km Elevation =1.1°
ZDR
0.5°
1.1°
-1.5 -1.2 -0.8 -0.5 -0.1 0.2 0.6 0.9 1.3 1.6 1.9 2.3 2.6 3.0 3.3 3.7 db
12:00 14-JUN-08 KDP Circle = 40km Elevation =0.5°
12:00 14-JUN-08 KDP Circle = 40km Elevation =1.1°
KDP
0.5°
1.1°
0.0 0.3 0.5 0.8 1.0 1.3 1.5 1.8 2.0 2.3 2.5 2.8 3.0 3.3 3.5 3.8 度/km
12:00 14-JUN-08 RHO Circle = 40km Elevation =0.5°
12:00 14-JUN-08 RHO Circle = 40km Elevation =1.1°
ρhv(0)
0.5°
1.1°
0.50 0.60 0.70 0.80 0.84 0.87 0.90 0.91 0.92 0.93 0.94 0.95 0.96 0.97 0.98 0.99 1.00

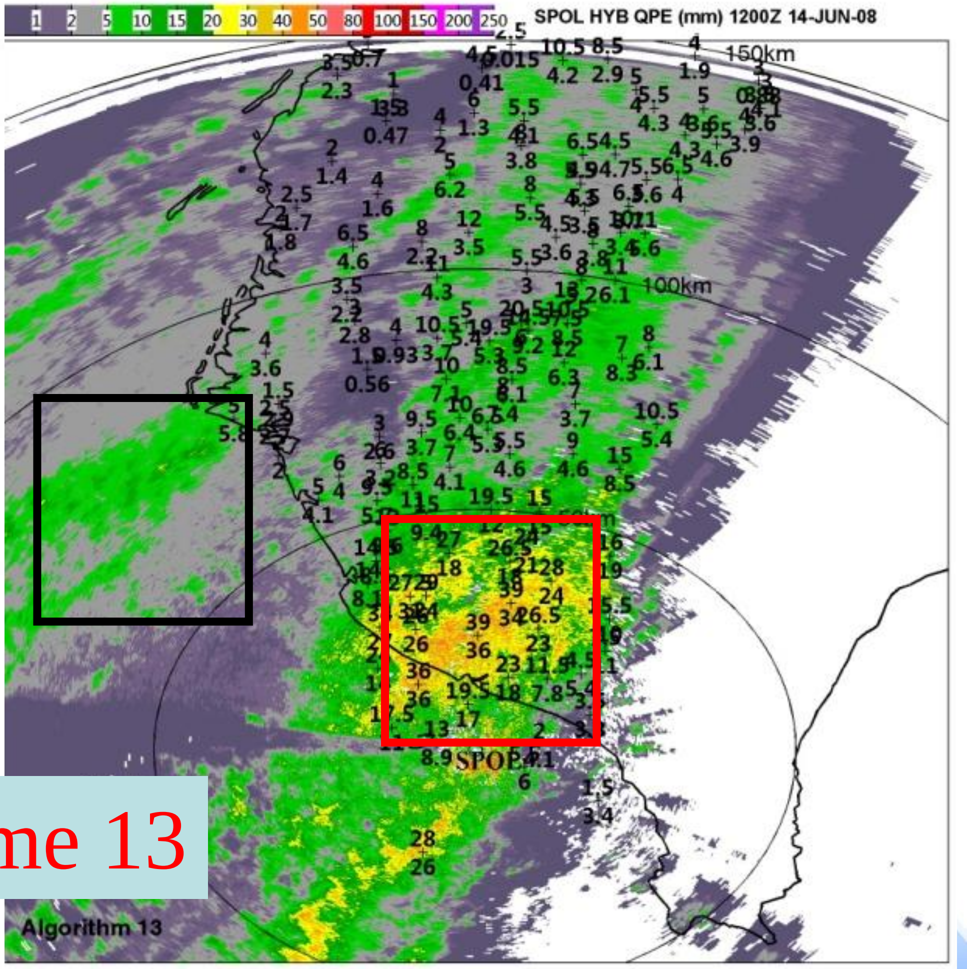
Polarimetric measurements statistics



Radar estimation & Gauge observation

20080614 1100-1200UTC





scheme 13

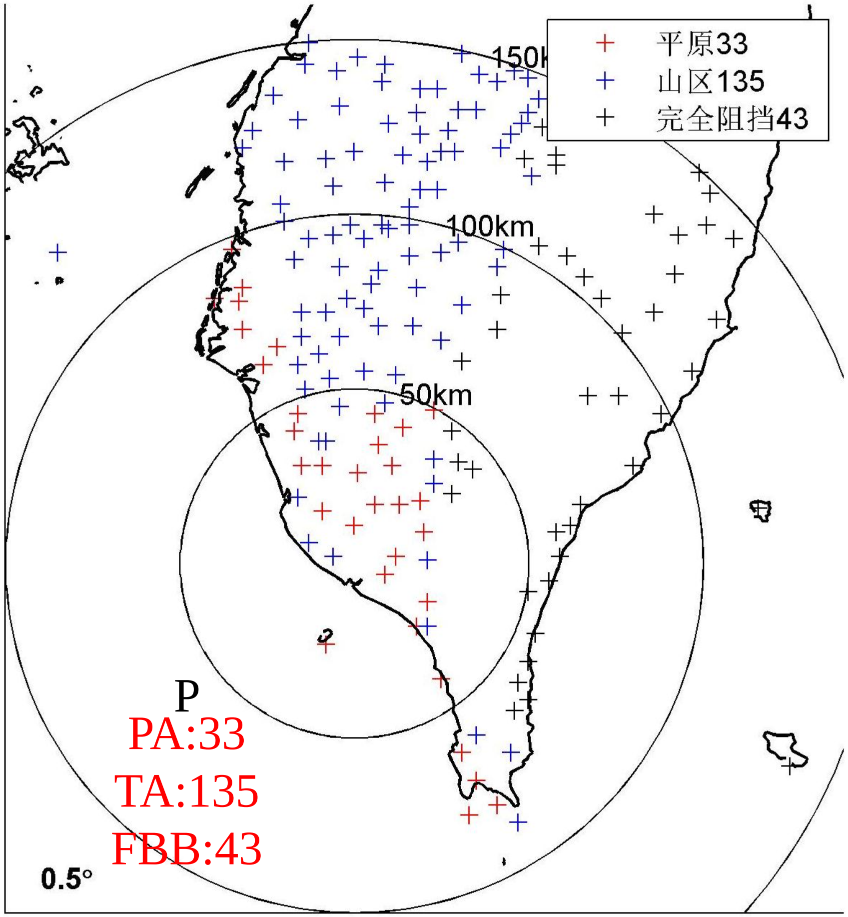
0.5 degree elevation

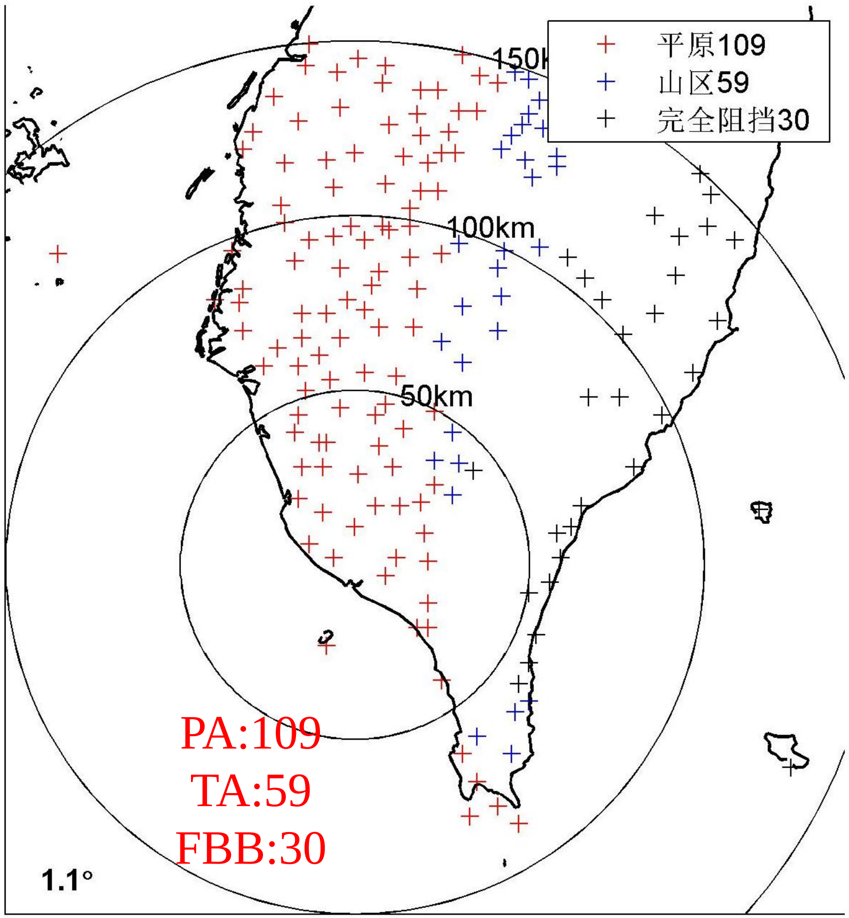
1.1 degree elevation

Different areas

- Non-beam blockage -> plain area(PA)
- Partial beam blockage->terrain area(TA)
- Full beam blockage->undetectable(FBB)

Plain area and terrain area gauges distribution



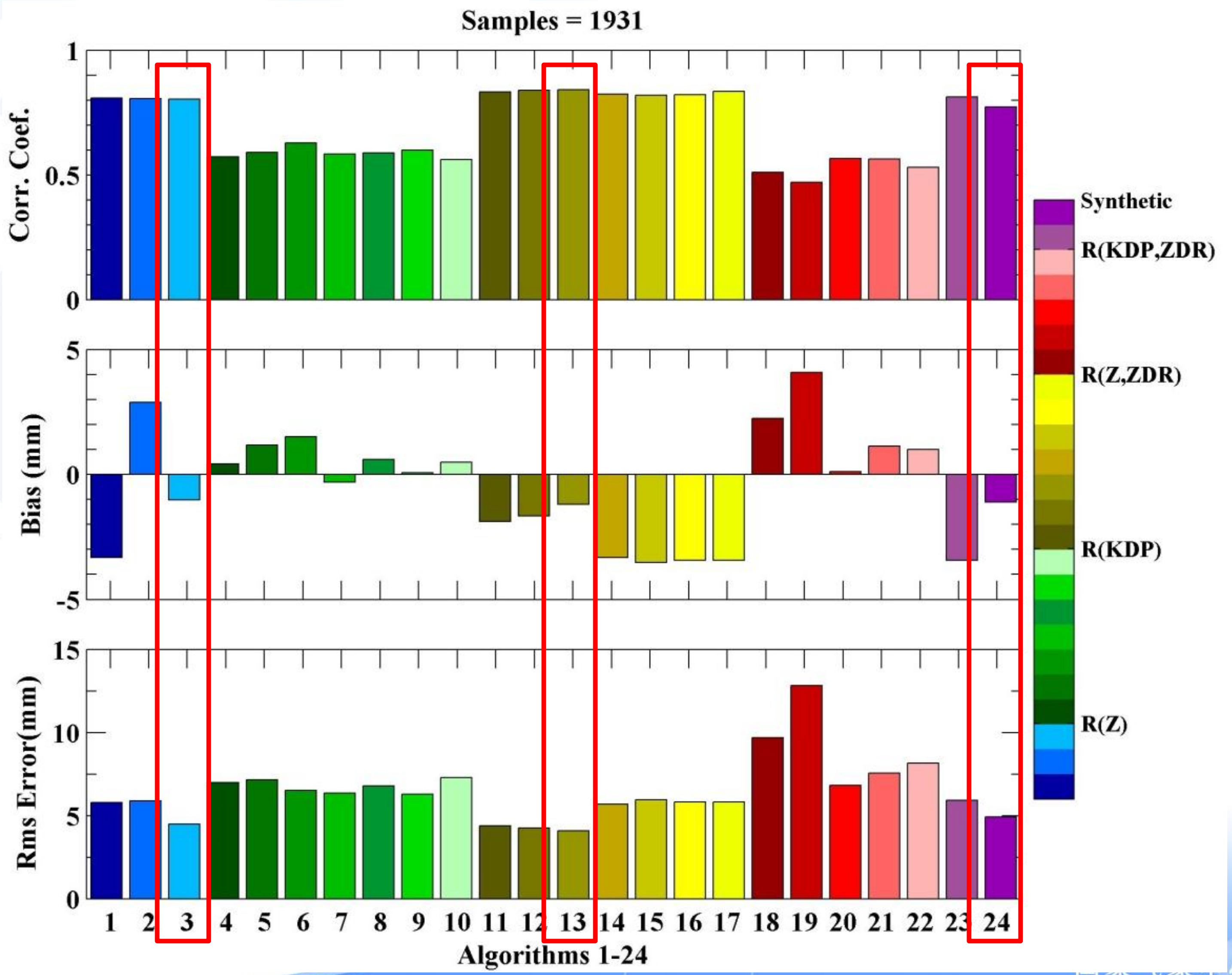


Statistics on 1.1 degree elevation in the plain area

Correlation cofficient

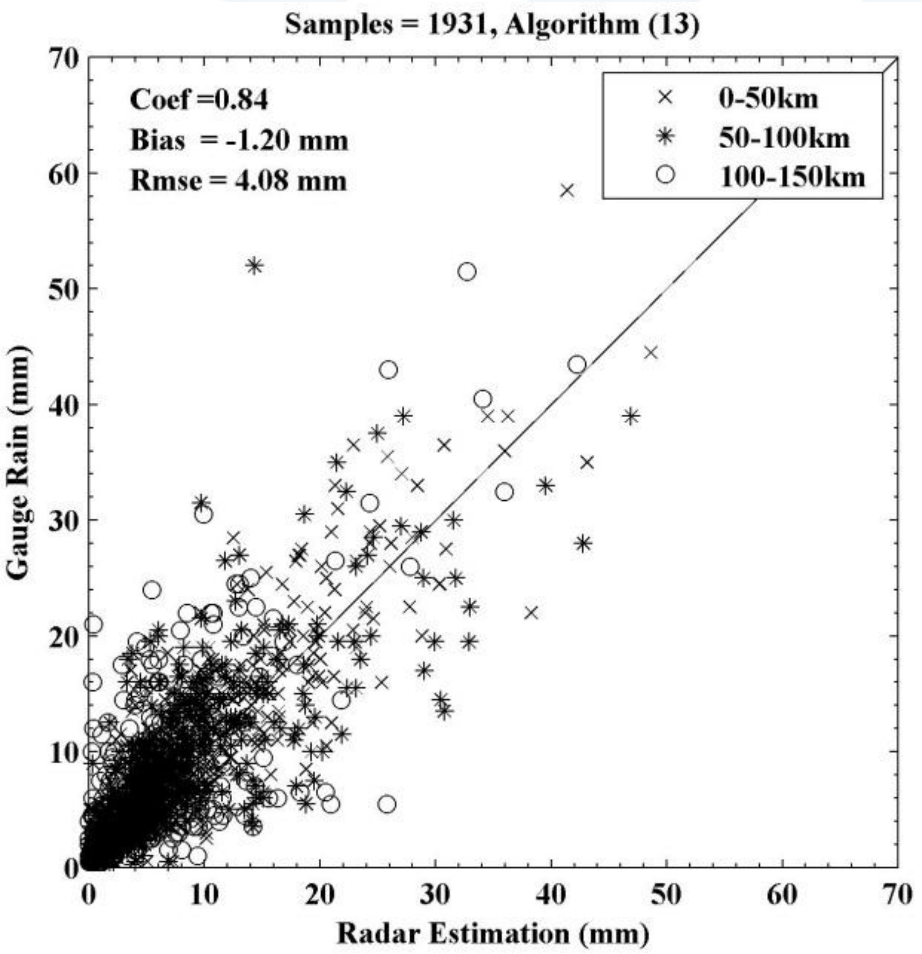
Bias

RMSE

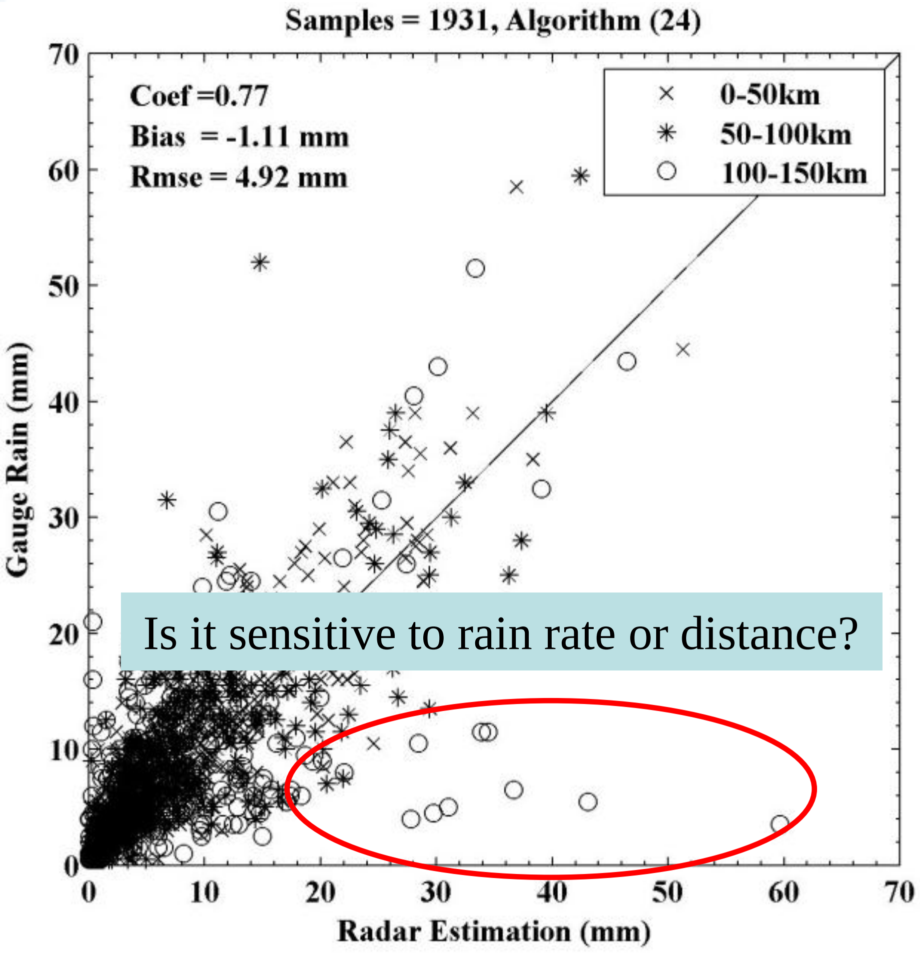


Radar estimations VS. gauge observation on 1.1 degree elevation in the plain area

Scheme 13



Scheme 24

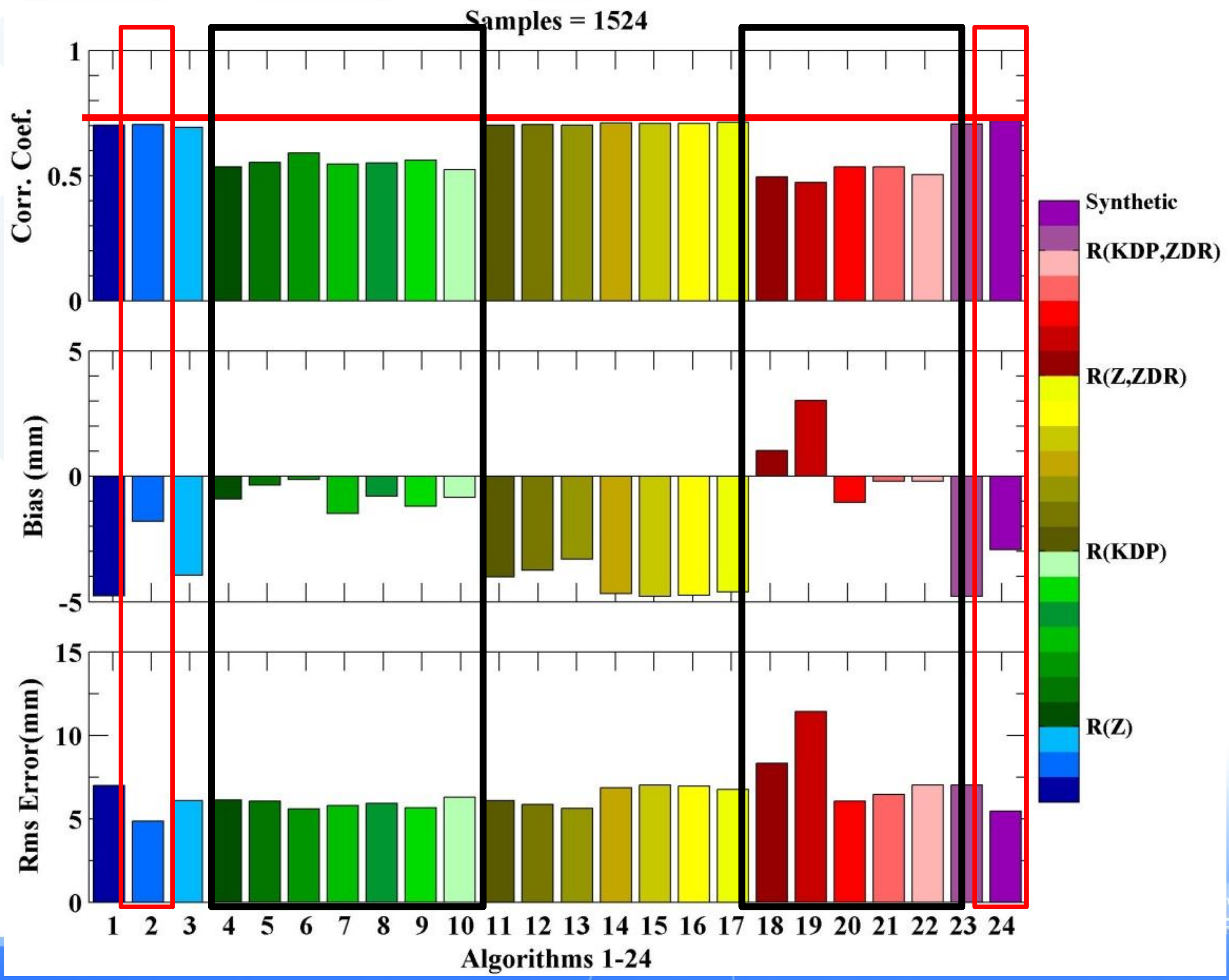


Statistics on 0.5 degree elevation in the terrain area(before PBB correction)

Correlation cofficient

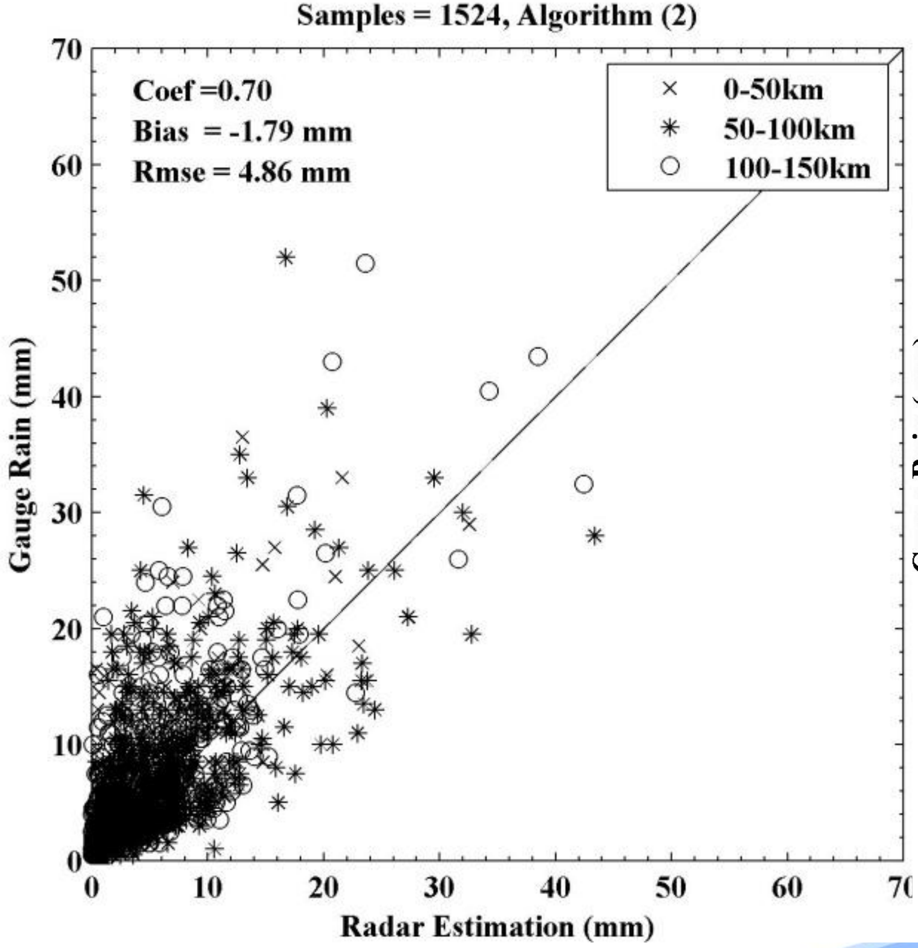
Bias

RMSE

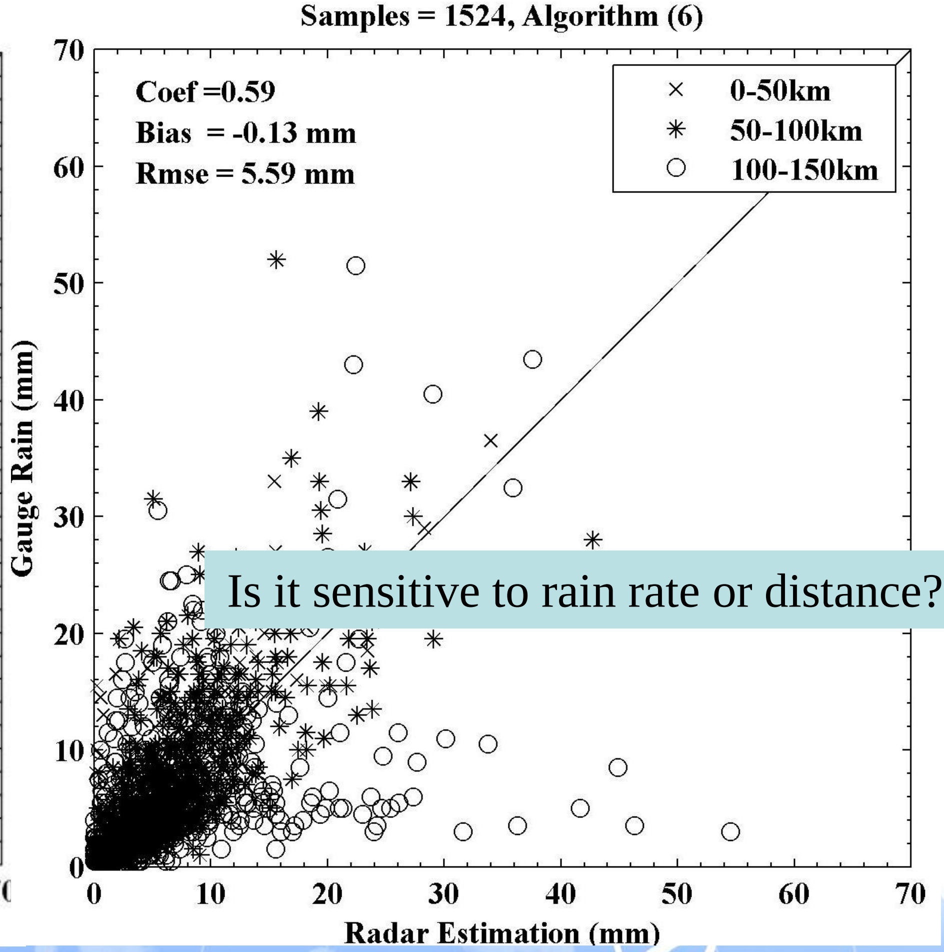


Radar estimation VS. gauge observation on 1.1 degree elevation in the terrain area(before PBB correction)

Scheme 2



Scheme 6



Is it sensitive to rain rate or distance?

Partial beam blockage correction (PBB correction)

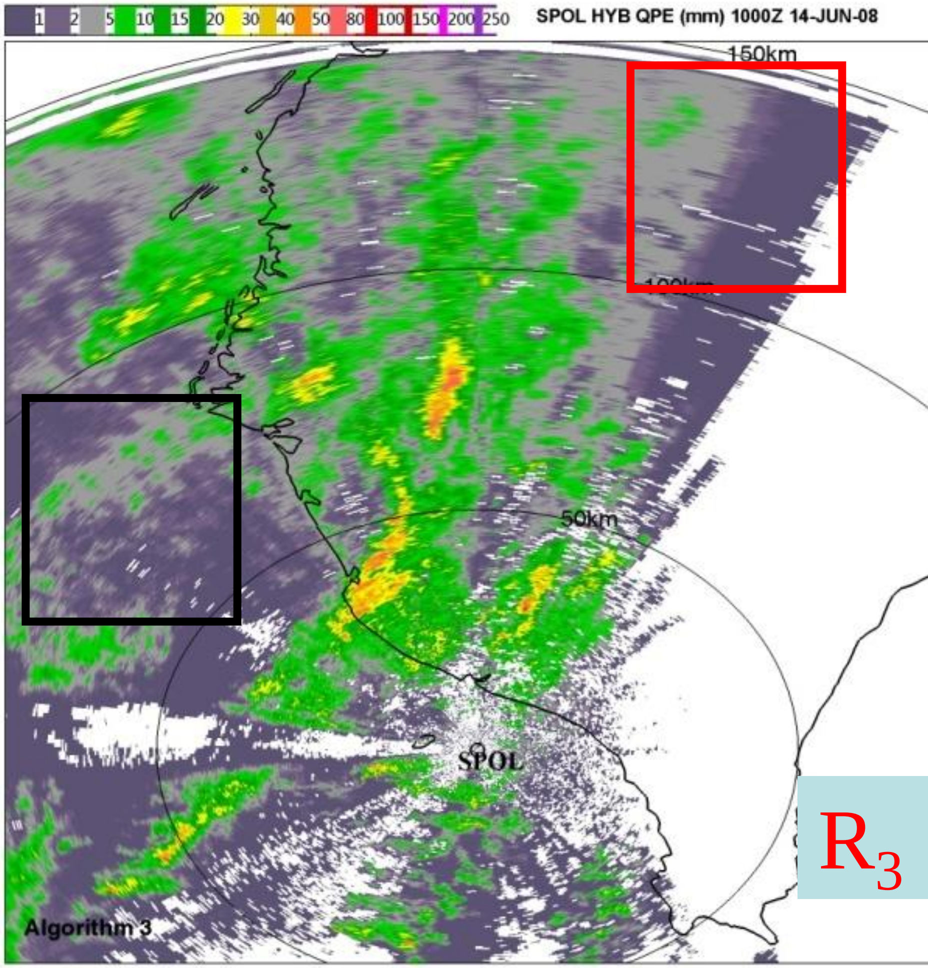
Equation:

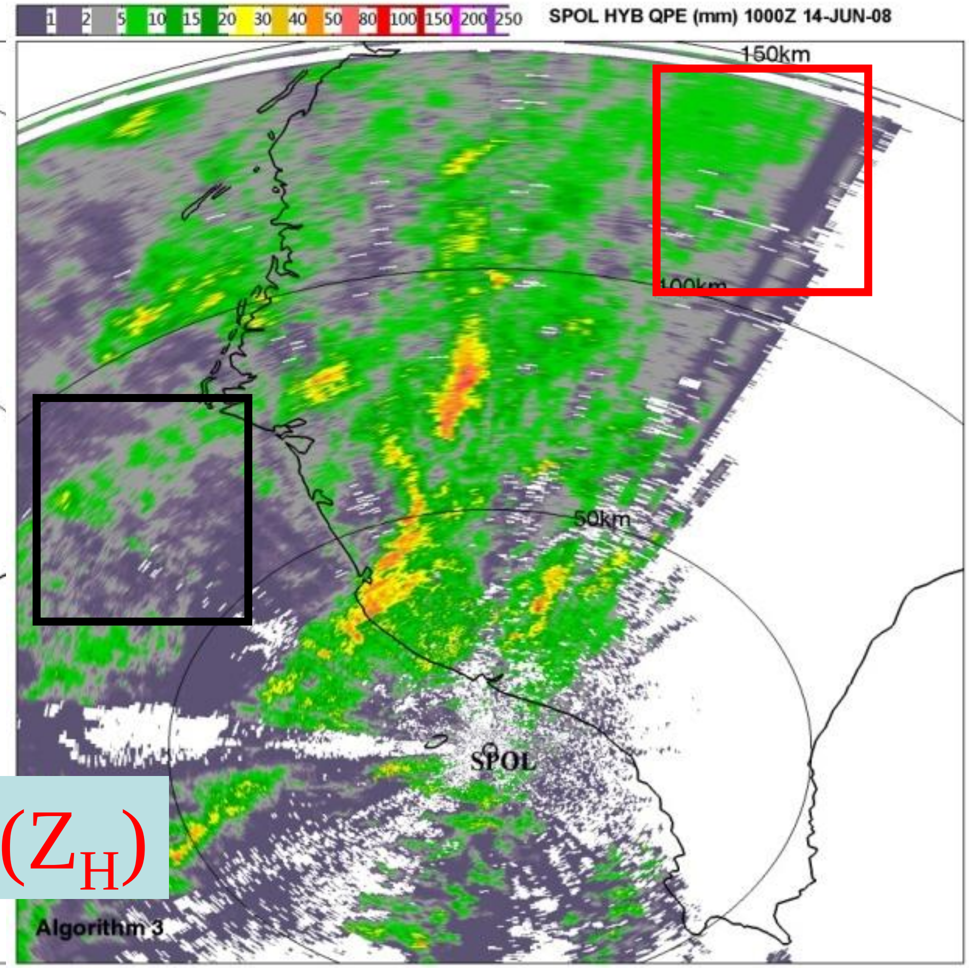
$$Z_{bcg}(i,j) = Z - 10 \times a \log 10(0.5 \times \tanh(0.0277 \times (50.0 - BB(i,j) \times 100.0)) + 0.5)$$

Here, ***i,j*** correspond to azimuth and radial， ***Z*** indicate the originate reflectivity values， BB is beam blockage, less than 1， $\boldsymbol{Z_{bcg}}$ is the reflectivity values after PBB correction.

Radar estimation before and after PBB correction

20080614 1100-1200UTC 0.5 degree elevation



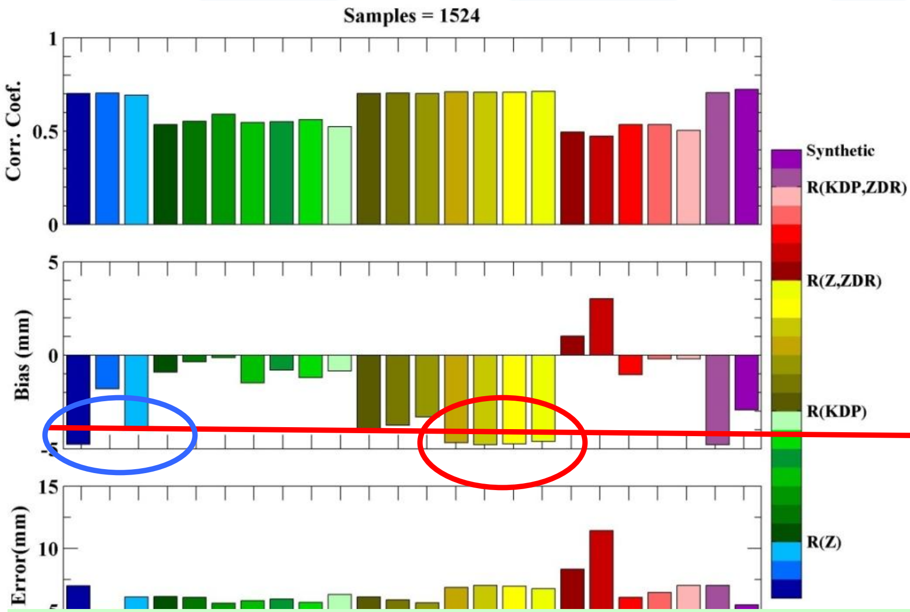


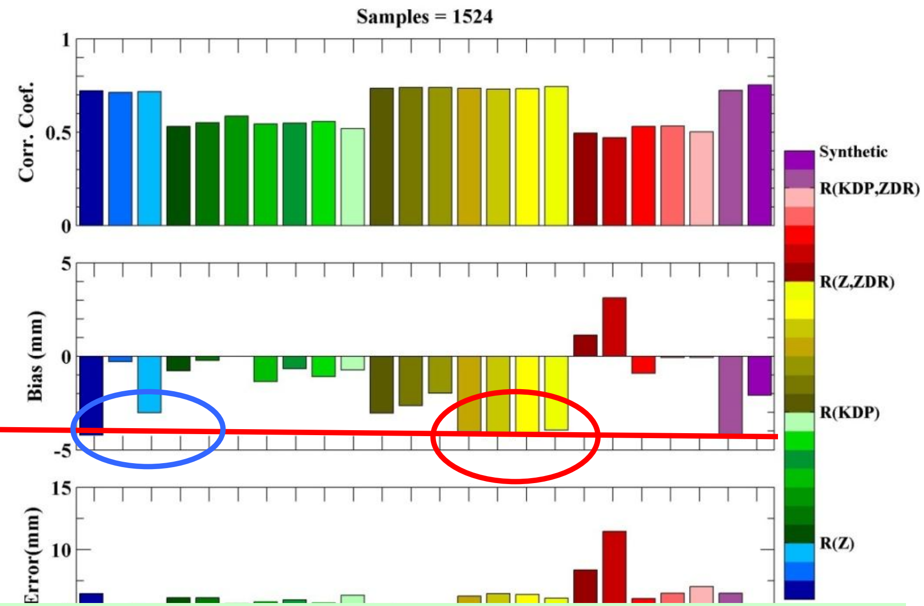
$R_3\ (Z_H)$

before PBB correction

after PBB correction

Statistics on 0.5 degree elevation before and after PBB





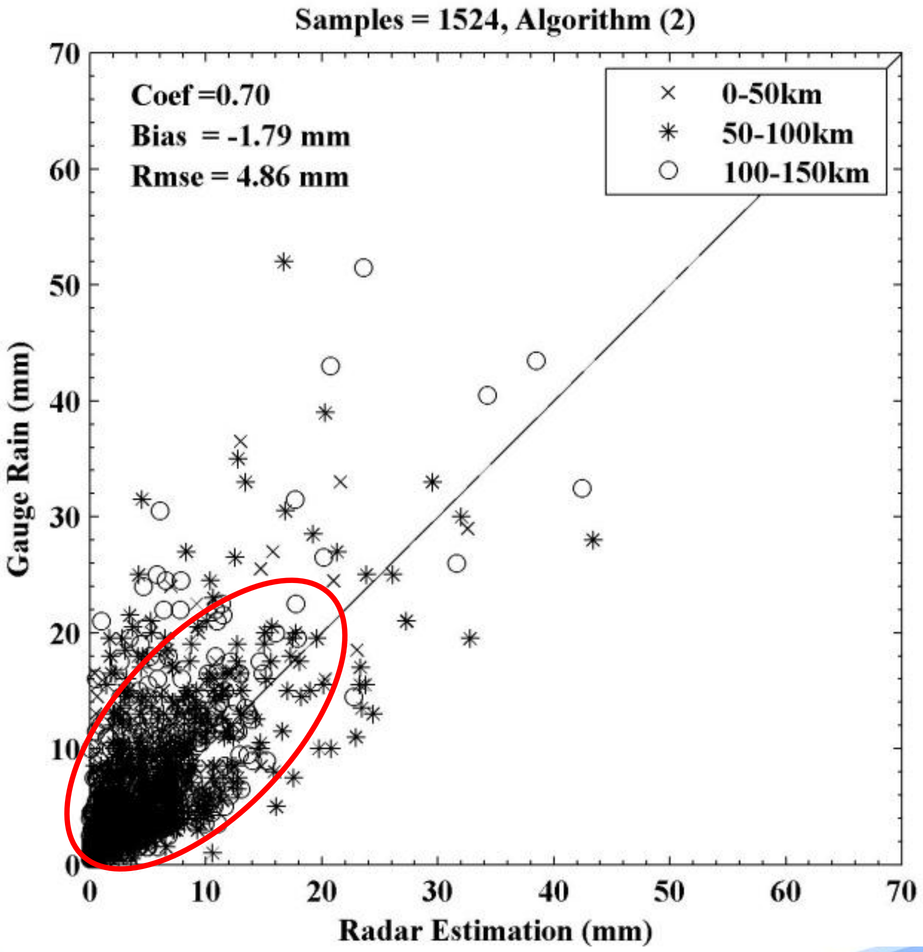
After PBB correction, the average bias of the schemes which using Z_H get a reduction of 30%

Before PBB

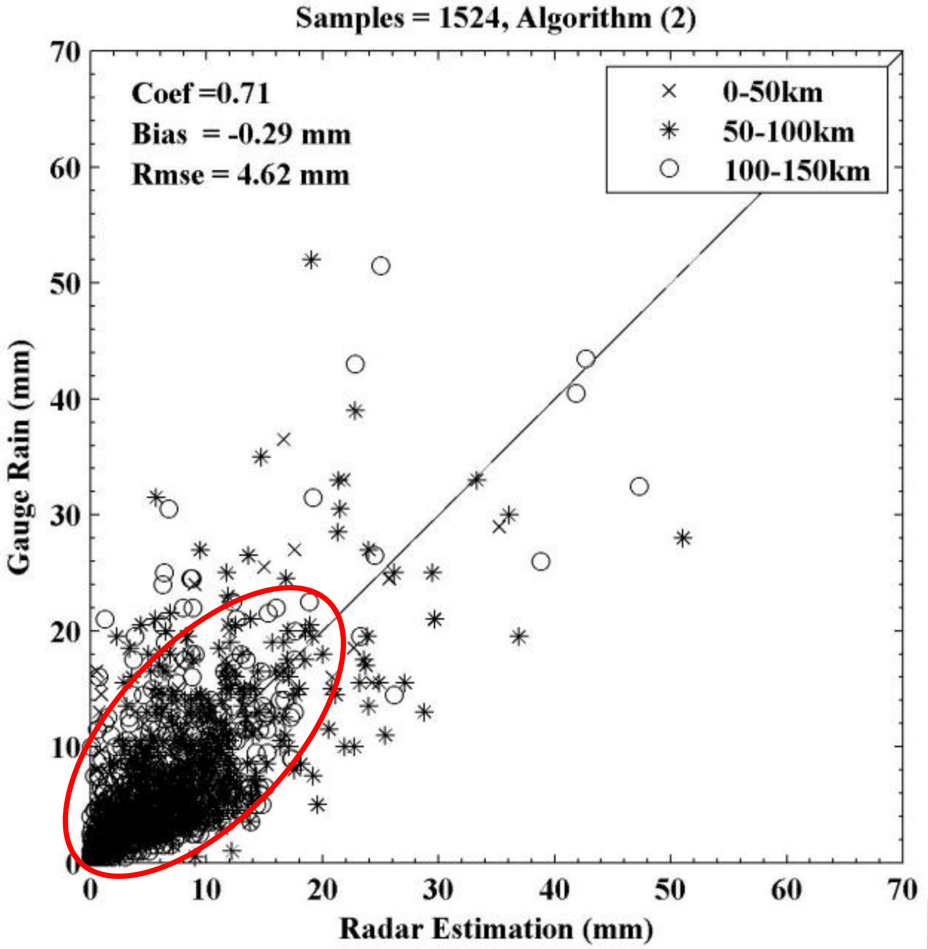
After PBB

Radar estimation VS. gauge observation on 0.5 degree elevation in the terrain area(before and after PBB)

scheme2 before PBB



scheme2 after PBB



conclusion

1) The measurements on the lowest tilt get severely contaminated by the ground clutter around radar.

2) In the plain area, when using 1.1 degree to estimated rainfall, the $R(Z,Z_{DR})$ scheme13 developed by Illingworth and Blackman(2002), the tropical scheme, and the synthetic scheme 24developed by Ryzhkov(2005) perform relatively better.

3) In the terrain area, when using 0.5 degree to estimate rainfall, $R(K_{DP})$ schemes and $R(K_{DP},Z_{DR})$ schemes perform better than R(Z)、$R(Z,Z_{DR})$ schemes and synthetic schemes 23,24 within the observation range of 100km.

4） The rain rate, distance and beam blockage does affect the QPE precision.

5） Over the southern Taiwan area, the measurements of 1.1 degree elevation is more robust to estimate rainfall, simultaneously, scheme 13 or 24 is recommended.

Future work

- Retrieval the drop size distribution using polarimetric measurements, try to make clear the physical mechanism during the heavy rainfall。
- Using the echo classification technique to divide the observation into different particles, thus, various algorithms would be used to estimate rainfall.

Thanks！