P.229

A candidate of optimum rainfall estimation using polarimetric variables in Korea

Cheol-Hwan you[1], Dong-In Lee[2*], Mi-Young Kang[2], Jung-Tae Lee[2] , Sung-Ho Suh[2], Hyeon-Joon Kim[2] , Young-Su Bang[2] and Kyung-Yeub Nam[3]
[1] Atmospheric Environmental Research Institute, Pukyong National University, Busan, Korea
[2] Department of Environmental Atmospheric Sciences, Pukyong National University, Korea
[3] Radar Analysis Division, Korea Meteorological Administration, Korea

Weather Radar Center

Introduction

- There are three major agencies; Ministry of National Defense (MND), Ministry of Land, Infrastructure and Transportation (MOLIT), and Korea Meteorological Administration (KMA), which operate radars to monitor and forecast severe weather and flash flood operationally in Korea. For successful implementation of their radars for the purpose of operational uses, many researches on rainfall estimation, hydrometeor classification and DSDs retrieval are required.
- However, there are few studies on these polarimetric related issues except for getting relationships using long period disdrometer data and assessment of each relation after applying a very simple quality control for differential phase shift (2014). And the quality control and unfolding of Φ_{DP} for calculating K_{DP} were applied to the rainfall estimation (2014).
- This study discussed how to improve the accuracy of the rainfall estimation using all polarimetric variables with different raindrop shapes and get optimum rainfall algorithm for Korean S-band polarimetric radar.

Data and Methodology

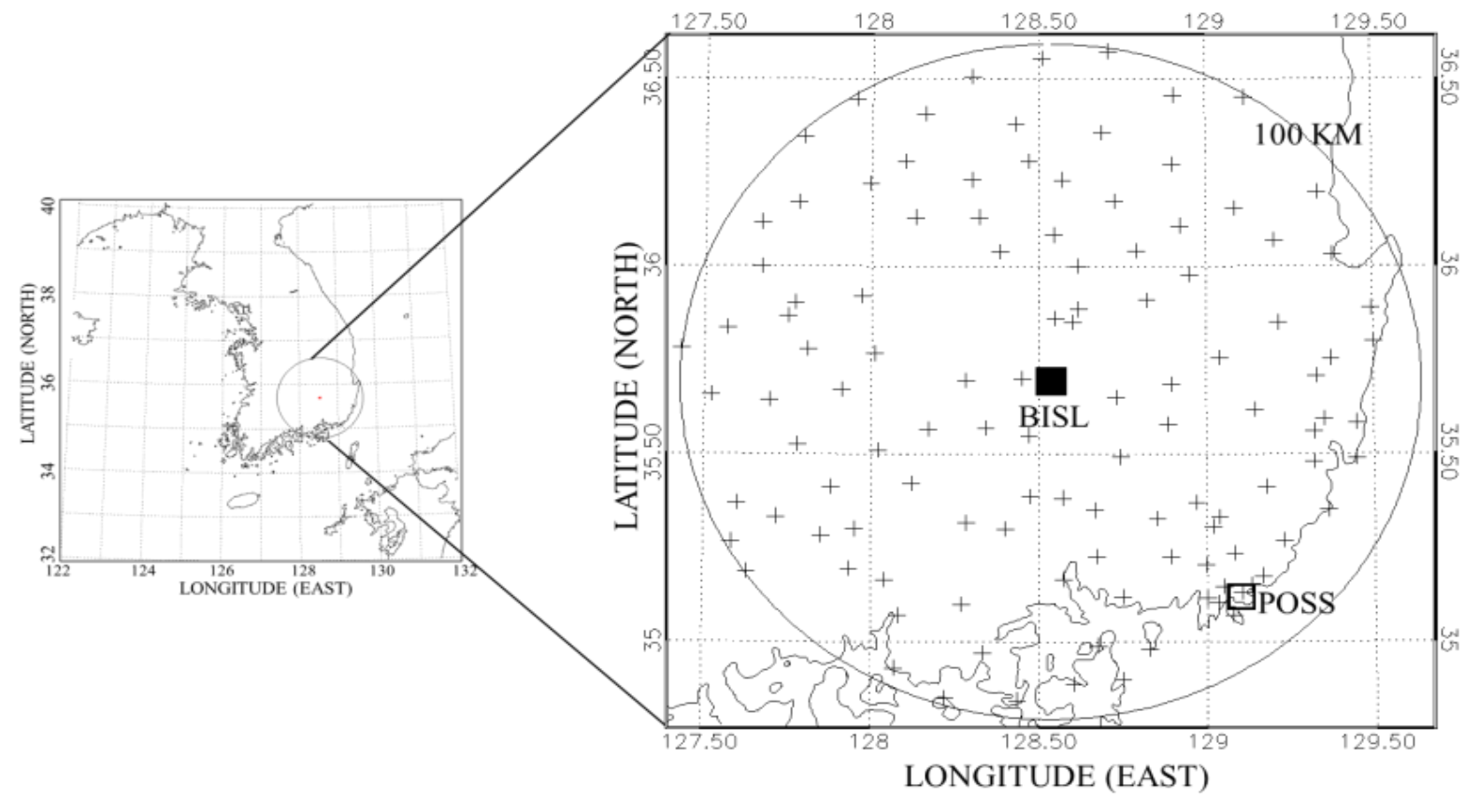


Figure 1. The location of a Bislsan radar (solid rectangle), a POSS disdrometer.

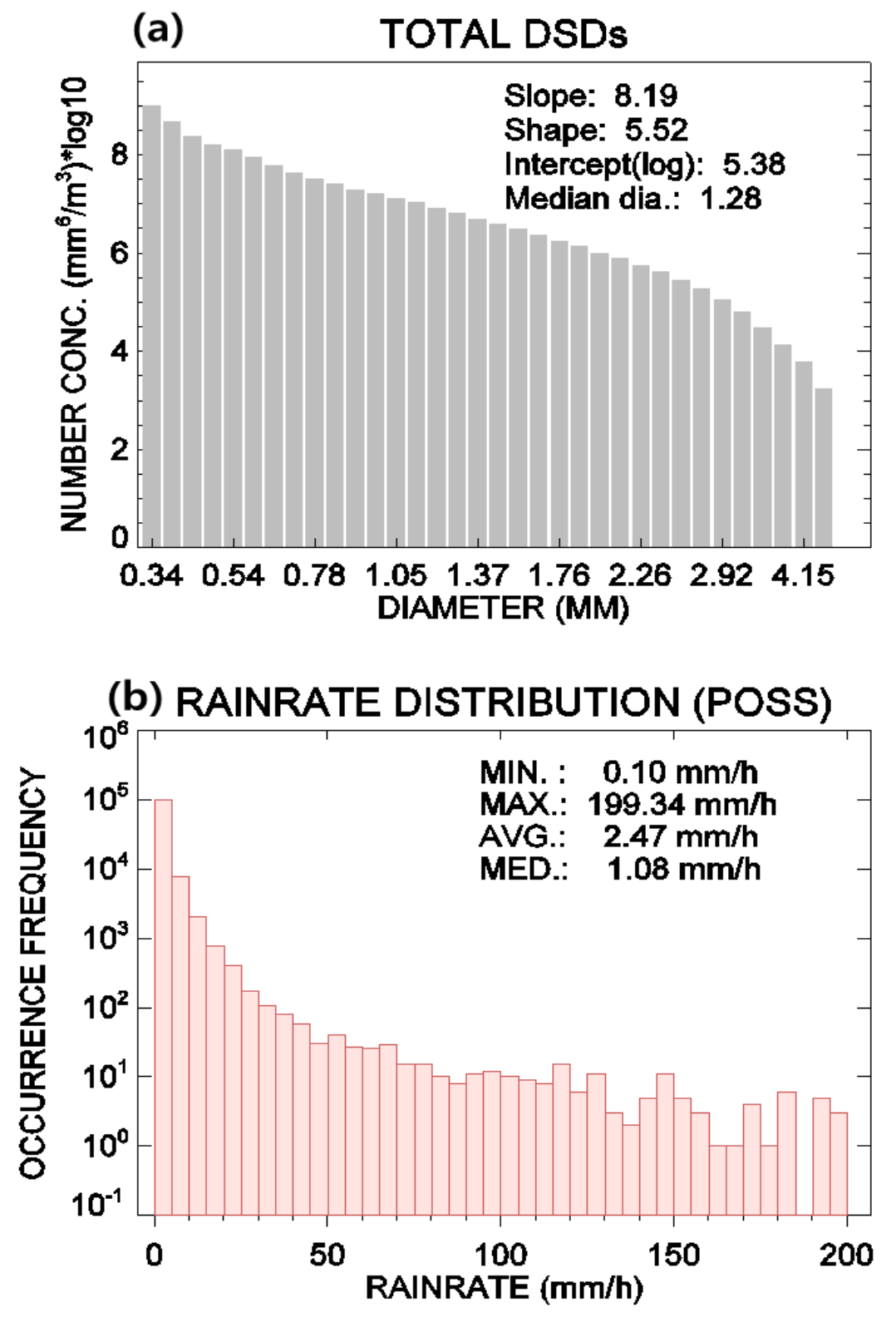


Figure 2. Histogram of (a) total number concentration and gamma parameters and (b) rain rate calculated using 114,105 samples.

- Polarimetric variables were calculated using T-matrix scattering techniques derived by Waterman (1971) and later developed further by Mishchenko et al. (1996). To get the variables using DSDs, six rain drop shape assumptions were used.
- The distribution of canting angles of rain drops is Gaussian with a mean of 0° and a standard deviation of 7°, which have been recently determined by Huang et al. (2008).

Drop shape assumptions

$$\frac{b}{a}=\begin{cases}1.0 & 0\le D\le 0.3\ mm\\ 1.03-0.062\mathrm{D} & \mathrm{D}\ge 0.3\ \mathrm{mm},\end{cases}$$ DS1, Pruppacher and Beard (1970)

$$\frac{b}{a}=1.0048+0.500057D-0.02628D^2+0.003682D^3-0.0001677D^4$$ DS2, Beard and Chuang(1987)

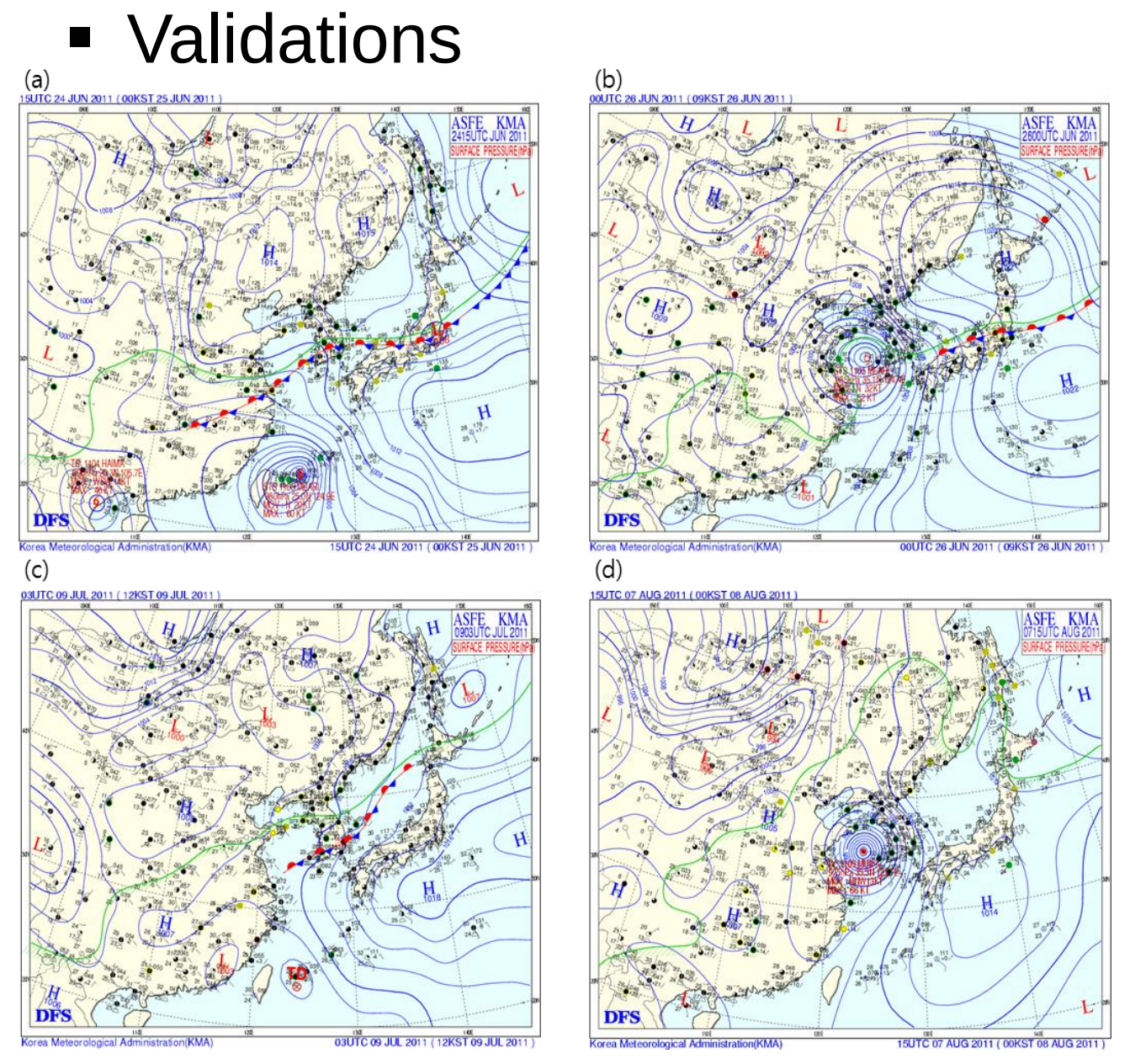
$$\frac{b}{a}=1.012-0.01445D-0.01028D^2$$ DS3, Andsager et al.(1999)

$$\frac{b}{a}=0.9951+0.025D-0.03644D^2+0.005303D^3-0.0002492D^4$$ DS4, Brandes et al. (1999)

$$\frac{b}{a}=\begin{cases}1.0 & D\le 0.7\ mm\\ 1.173-0.5165\mathrm{D}+0.4698D^2-0.1317D^3-0.0085D^3 & 0.7<\mathrm{D}\le 1.5\ \mathrm{mm}\\ 1.065-0.0625\mathrm{D}-0.00399D^2-0.000766D^3-0.0004095D^4 & \mathrm{D}>1.5\ \mathrm{mm},\end{cases}$$ DS5, combined Beard and Kubesh (1991) and Thurai et al. (2007)

$$\frac{b}{a}=\begin{cases}1.0 & D\le 1.0\ mm\\ 1.075-0.065\mathrm{D}-0.0036D^2+0.0004D^3 & \mathrm{D}>1.0\ \mathrm{mm},\end{cases}$$ DS6, Goddard et al. (2005)

Validations



Period	Sources
2011. 6. 25. 0900 LST ~ 6. 26. 1400 LST	Changma front and typhoon
2011. 7. 09. 0000 LST ~ 7. 10. 2200 LST	Changma front
2011. 8. 07. 1800 LST ~ 8. 08. 0300 LST	Typhoon

$$\mathrm{NE}=\frac{\frac{1}{N}\sum_{i=1}^{N}\left(\left|R_{R,i}-R_{G,i}\right|\right)}{\overline{R_G}}\qquad \mathrm{RMSE}=\left[\frac{1}{N}\sum_{i=1}^{N}\left(R_{R,i}-R_{G,i}\right)^2\right]^{1/2}$$

$$\mathrm{CC}=\frac{\sum_{i=1}^{N}\left(R_{R,i}-\overline{R_R}\right)\left(R_{G,i}-\overline{R_G}\right)}{\left[\sum_{i=1}^{N}\left(R_{R,i}-\overline{R_R}\right)^2\right]^{1/2}\left[\sum_{i=1}^{N}\left(R_{G,i}-\overline{R_G}\right)^2\right]^{1/2}}$$

Figure 3. The surface weather chart (a) 0000 LST June 25, (b) 0900 LST June 26, (c), 1200 LST July 9, and (d) 0000 LST August 8 in 2011.

Results

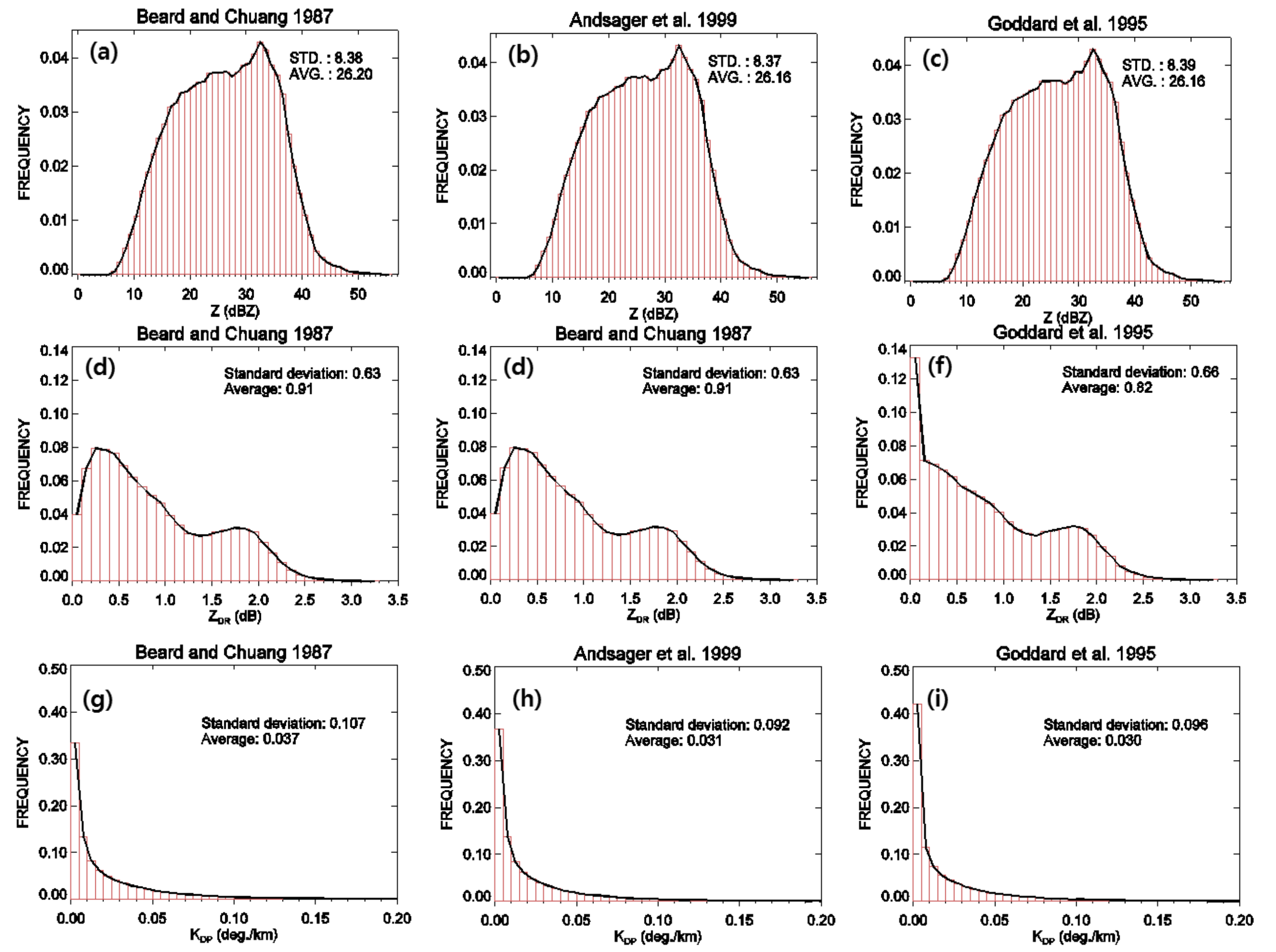


Figure 4. The occurrence frequency of (a) Z with DS1, (b) Z with DS3 , (c) Z with DS6, (d) Z_{DR} with DS1, (e) Z_{DR} with DS3, (f) Z_{DR} with DS6, (g) K_{DP} with DS1, (h) K_{DP} with DS3, and (i) K_{DP} with DS6.

Table 2. The rainfall relations of R(Z), R(Z_{DR}), R(K_{DP}), R(Z,Z_{DR}), and R(K_{DP}, Z_{DR}) with different raindrop shape assumptions.

DS	R(Z)	R(Z_{DR})	R(K_{DP})	R(Z,Z_{DR})	R(K_{DP},Z_{DR})
DS1	$R=0.0273Z^{0.60}$	$R=0.29Z_{DR}^{5.27}$	$R=44.5K_{DP}^{0.942}$	$R=0.016Z^{0.889}Z_{DR}^{-4.94}$	$R=53.7K_{DP}^{0.857}Z_{DR}^{-1.48}$
DS2	$R=0.0277Z^{0.59}$	$R=0.38Z_{DR}^{4.87}$	$R=53.3K_{DP}^{0.913}$	$R=0.014Z^{0.852}Z_{DR}^{-4.08}$	$R=75.2.7K_{DP}^{0.855}Z_{DR}^{-1.98}$
DS3	$R=0.0277Z^{0.60}$	$R=0.42Z_{DR}^{4.98}$	$R=61.5K_{DP}^{0.908}$	$R=0.015Z^{0.818}Z_{DR}^{-3.72}$	$R=82.2K_{DP}^{0.855}Z_{DR}^{-1.98}$
DS4	$R=0.0277Z^{0.60}$	$R=0.41Z_{DR}^{4.98}$	$R=59.9K_{DP}^{0.896}$	$R=0.014Z^{0.844}Z_{DR}^{-4.06}$	$R=67.4K_{DP}^{0.785}Z_{DR}^{-2.13}$
DS5	$R=0.0277Z^{0.60}$	$R=0.40Z_{DR}^{5.03}$	$R=56.2K_{DP}^{0.897}$	$R=0.013Z^{0.861}Z_{DR}^{-4.3}$	$R=84.7K_{DP}^{0.840}Z_{DR}^{-2.38}$
DS6	$R=0.0280Z^{0.59}$	$R=0.43Z_{DR}^{4.69}$	$R=56.3K_{DP}^{0.857}$	$R=0.013Z^{0.857}Z_{DR}^{-4.0}$	$R=15.0K_{DP}^{0.483}Z_{DR}^{-0.77}$

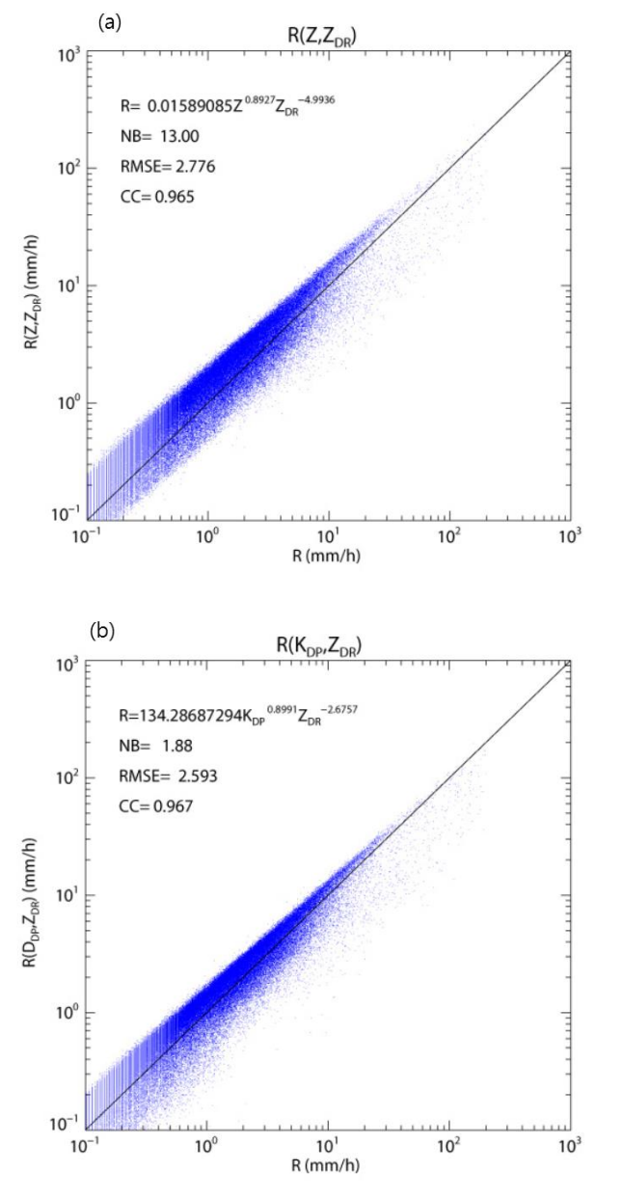


Table 3. The correlation coefficients and RMSEs (mm) of rainfall obtained by rainfall relations and DSDs. The CC means cross correlation.

DS	R(Z)		R(Z_{DR})		R(K_{DP})		R(Z,Z_{DR})		R(K_{DP},Z_{DR})	
	CC	RMSE	CC	RMSE	CC	RMSE	CC	RMSE	CC	RMSE
DS1	0.913	4.705	0.572	6.241	0.875	3.030	0.964	2.965	0.951	3.313
DS2	0.913	4.709	0.569	6.248	0.861	3.198	0.956	3.272	0.956	3.222
DS3	0.914	4.704	0.562	6.261	0.861	3.178	0.949	3.523	0.960	3.151
DS4	0.913	4.706	0.569	6.249	0.828	3.549	0.954	3.334	0.931	3.882
DS5	0.913	4.706	0.572	6.243	0.849	3.326	0.957	3.210	0.950	3.348
DS6	0.913	4.713	0.572	6.244	0.795	3.828	0.956	3.239	0.814	5.412

Figure 6. The scatter plots of rainfall obtained by DSDs and (a) R(Z,Z_{DR}) and (b) R(K_{DP},Z_{DR}) using Z for DS3, Z_{DR} for DS1, and K_{DP} for DS3.

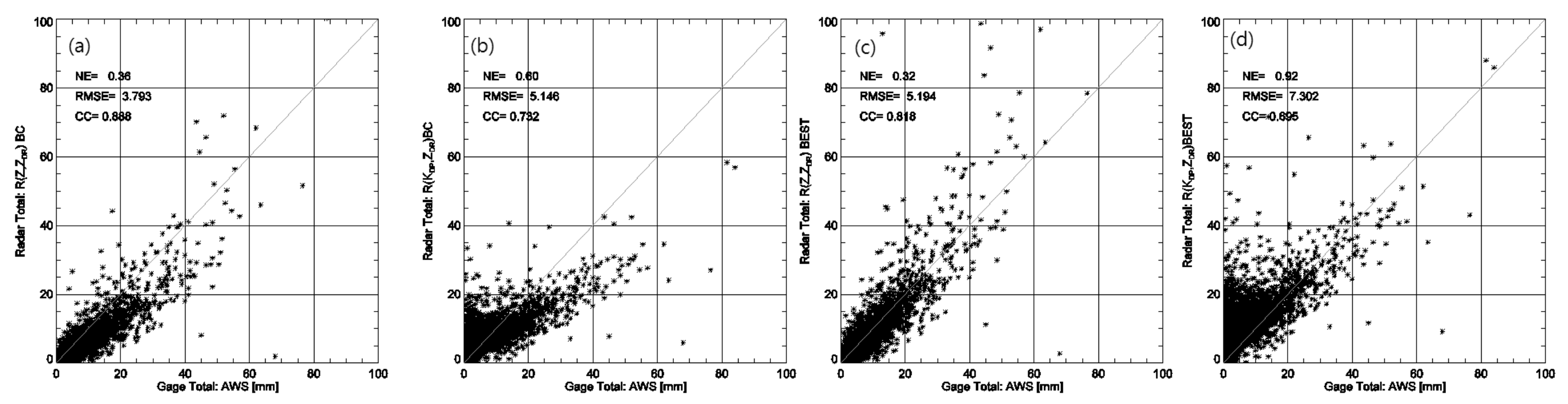


Figure 7. The scatter plot of rainfall from gage and (a) R(Z,Z_{DR}), (b) R(K_{DP},Z_{DR}) with single raindrop axis ratio relation, (c) R(Z,Z_{DR}), and (d) R(K_{DP}, Z_{DR}) with two raindrop axis ratio relation.

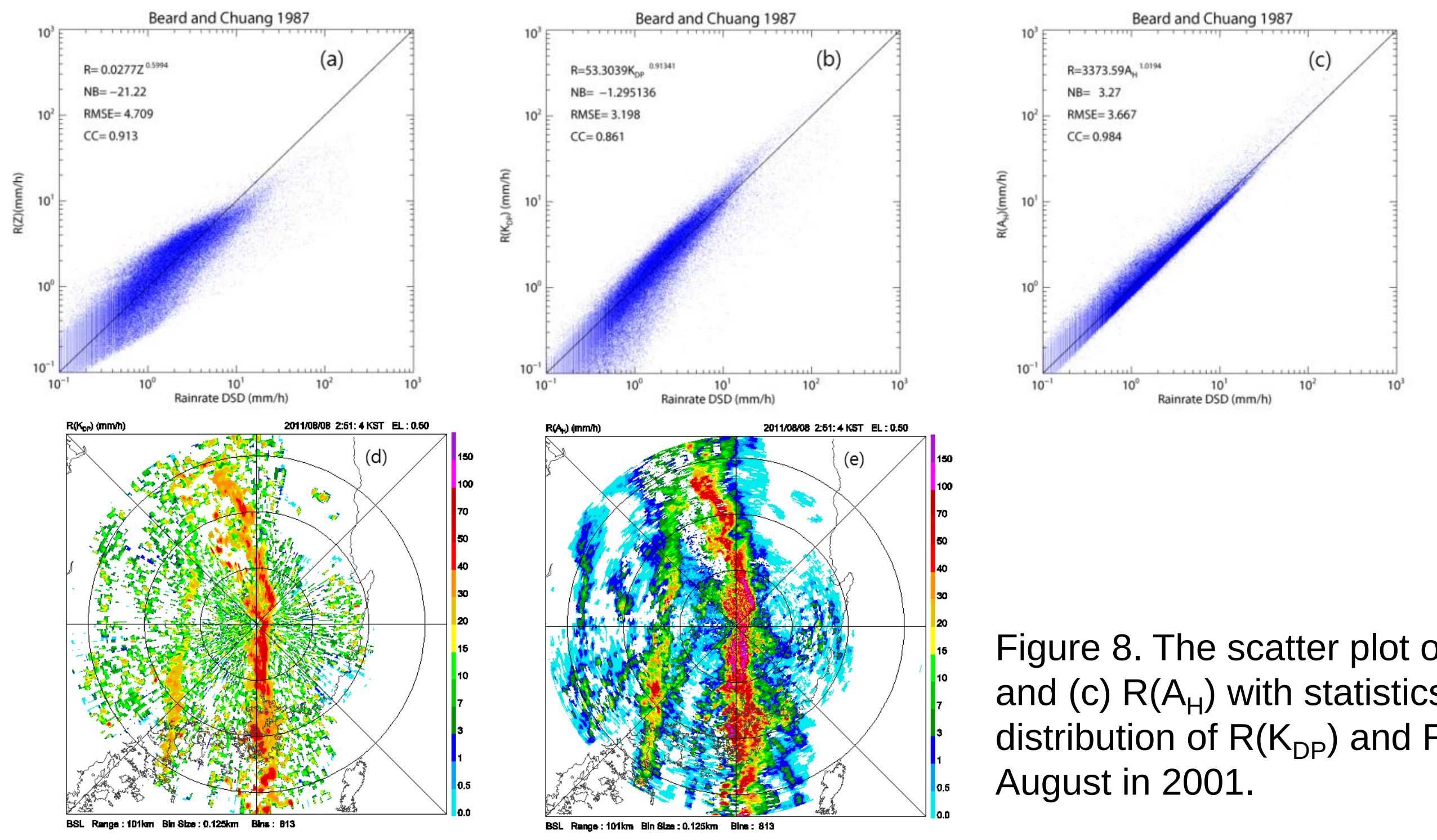


Figure 8. The scatter plot of (a) R(Z), (b) R(K_{DP}), and (c) R(A_H) with statistics and the rainfall distribution of R(K_{DP}) and R(A_H) at 0251 KST on 8th August in 2001.

$$\mathrm{R}=0.014Z^{0.852}{Z_{DR}}^{-4.08}\qquad 0<Rainfall<5\ mm\ h^{-1}$$

$$\mathrm{R}=82.2{K_{DP}}^{0.855}{Z_{DR}}^{-1.98}\qquad 5<Rainfall<30\ mm\ h^{-1}$$

$$\mathrm{R}=61.5{K_{DP}}^{0.908}\qquad 30\ mmh^{-1}<Rainfall$$

➢ First optimum rainfall algorithm with rainfall rate in Korea

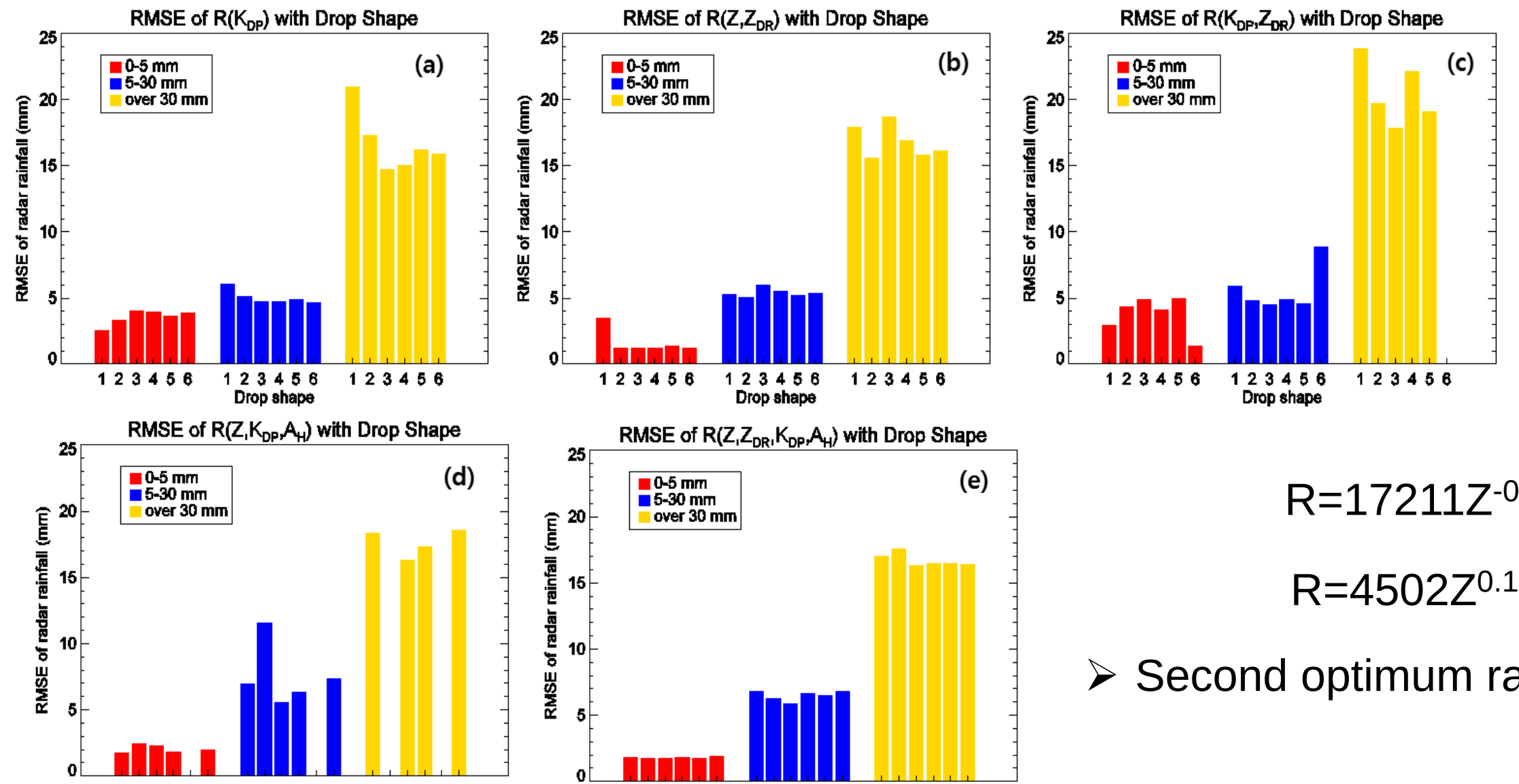


Figure 10. The RMSEs of (a) R(K_{DP}), (b) R(Z,Z_{DR}), (c) R(K_{DP},Z_{DR}), (d) R(Z,K_{DP},A_H), and (e) R(Z,Z_{DR},K_{DP},A_H) with raindrop axis ratio relations in the three rainfall categories.

$$R=17211Z^{-0.27}K_{DP}^{0.619}A_H^{0.650}$$

$$R=4502Z^{0.14}Z_{DR}^{-0.39}K_{DP}^{0.486}A_H^{0.653}$$

➢ Second optimum rainfall algorithm with rainfall rate in Korea

Summaries

- ✓ R(Z,Z_{DR},K_{DP},A_H) and R(Z,K_{DP},A_H) were relatively good performance in all rainfall regime. The combination of R(Z,Z_{DR}), R(K_{DP},Z_{DR}), and R(K_{DP}) with rainfall intensity would be an optimum rainfall algorithm if the reference of rainfall defines correctly.
- ✓ Regardless rainfall intensity, R(Z,Z_{DR},K_{DP},A_H) and R(Z,K_{DP},A_H) obtained by assuming DS3 can be used as a representative rainfall relation without consideration of rainfall intensity regime. Especially if the qualified Z_{DR} is not available, R(Z,K_{DP},A_H) with DS3 drop shape assumption can be used as an optimum rainfall relation in Korea.

References

- Andsager K., Beard K. V., Laird N. S., “A laboratory study of oscillations and axis ratios for large raindrops”, *Journal of the Atmospheric Sciences*, 55, 208-226, 1999.
- Beard K. V., Chuang C., “A new model for the equilibrium shape of raindrops”, *Journal of the Atmospheric Sciences*, 44, 1509-1524, 1987.
- Beard K. V., Kubesh R. J., “Laboratory measurements of small raindrop distortion, Part 2: oscillation frequencies and modes”, *Journal of the Atmospheric Sciences*, 48, 2245-2264, 1991.
- Brandes E. A., Zhang G., Vivekanandan J., “Experiments in rainfall estimation with a polarimetric radar in a subtropical environment”, *Journal of Applied Meteorology*, 41, 674-685, 2002.
- Goddard J., Morgan K., Illingworth A., Sauvageot H., “Dual-wavelength polarization measurements in precipitation using the CAMRA and Rabelias radars”, Preprints, *27th Conference on Radar Meteorology*, Vail, CO, American Meteorology Society, 196-198, 2005.
- Huang G.-J., Bringi V. N., Thurai M., “Orientation angle distributions of drops after 80 m fall using a 2D-video disdrometer”, *Journal of Atmospheric Oceanic Technology*, 25, 1717-1723, 2008.
- Mishchenko M. I., Travis L. D., Mackowski D. W., “T-matrix computations of light scattering by nonspherical particles: A review”, *Journal of Quantitative Spectroscopy and Radiative Transfer*, 55, 535-575, 1996.
- Pruppacher H. R., Beard K. V., “A wind tunnel investigation of the internal circulation and shape of water drops falling at terminal velocity in air”, *Quarterly Journal of the Royal Meteorological Society*, 96, 247-256, 1970.
- Thurai M., Huang G.-J., Bringi V. N., Randeu W. I., Schonhuber M., “Drop shapes, model comparisons, and calculations of polarimetric radar parameters in rain”, *Journal of Atmospheric Oceanic Technology*, 24, 1019-1032, 2007.
- Waterman P. C., “Symmetry, unitarity, and geometry in electromagnetic scattering”, *Physical Review D*, 3, 825-839, 1971.
- You C., Kang M., Lee D., Uyeda H., “Rainfall estimation by S-band polarimetric radar in Korea, Part I Preprocessing and preliminary results”, *Meteorol. Appl.* 21, 975-983, 2014,
- You C.-H., Lee D.-I., Kang M.-Y., “Rainfall estimation using specific differential phase for the first operational polarimetric radar in Korea”, *Advances in Meteorology*, vol. 2014, Article ID 41317, 10 pages, doi:10.1155/2014/413717, 2014.

Acknowledgements
This work was funded by the Korea Meteorological Industry Promotion Agency under Grant KMIPA 2015-5050.

37th Conference on Radar Meteorology, 14-19 September 2015, Norman, OK, USA