Comparisons of Parsivel and MRR Disdrometer Under a Heavy Rainfall Period

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Abstract

The thunderstorm on 14 June 2015 in Taipei Basin produced almost 200 mm rainfall in 3 hours over Taipei City and led to severe flash flood. The dynamic and thermodynamic processes resulted in the severe heavy rain have already been discussed by both observational and numerical simulation studies earlier. However, the rain microphysical characteristic of this heavy rain system is still not explored, which is important for the accurate quantitative precipitation estimation and forecasting (QPE/QPF).

This study will emphasize more on the rainfall processes near the ground using data from two different types of disdrometer, Parsivel and Micro Rain Radar (MRR). During the most intensive rainfall period, high concentration of small raindrop was observed and is possible dominated by breakup process. Compare the measurements from near-the-surface, e.g., Parsivel and above-the-surface, e.g., MRR, the results show the raindrop size distribution (RDSD) of MRR tilted more to the smaller drops but less concentrations of drop size larger than 1.4 mm, which means MRR better correlated with the breakup process.

On the other hand, the reflectivity of MRR is less than of Parsivel during intensive rainfall period, the effects of attenuation and decreased large raindrops still need investigation. Finer gate resolution should be considered for MRR to observe the convective rainfall, so that there could be chance to correct its own measurements at higher level.

Key words: microphysical process, raindrop breakup, polarimetric radar, and disdrometer

1. Introduction

The raindrop size distribution (RDSD) is shaped by the rain-forming microphysical processes, and it is highly related with the development of rainfall systems. Disdrometer is an important instrument to understand the DSD, while Central Weather Bureau established network of Parsivel disdrometers around Taiwan from 2016. Appropriate relationship between radar parameter and rain rate could be derived via Parsivel and help to improve the quantitative precipitation estimation (QPE) of radar network. However, the additional measurements lie between radar and disdrometer could extend our understanding of the rainfall process near ground.

Micro rain radar (MRR) acquires the DSD in the zenith direction so it could compensate the gap between surface and lowest elevation of radar. Via the DSD intercomparison, Chang et al. (2020) proposed the MRR is relatively accurate due to large sampling volumes and accurate measurement of the Doppler power spectrum. The MRR also outperformed other instruments for Z for entire averaging time. Tsai and Yu (2012) firstly discussed observing typhoon by MRR in Taiwan, while they proposed that the MRR underestimates the reflectivity > 45 dBZ. Of summer rainfall of eastern China, Wen et al. (2015) claimed that the MRR underestimate rain rate while the reflectivity > 35 dBZ due to the attenuation.

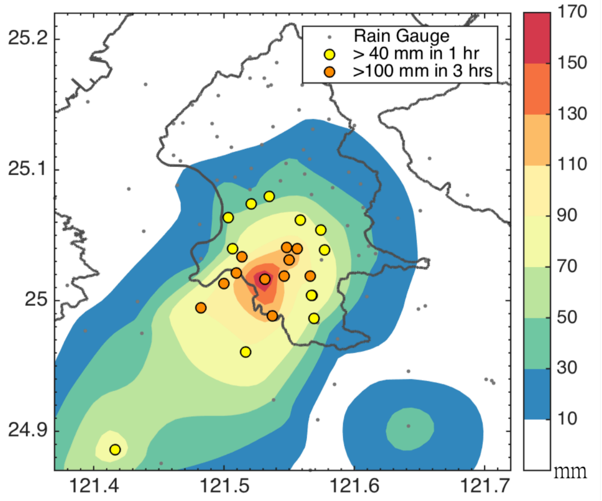

Fig. 1. The map of rainfall accumulation around Taipei City in the afternoon, 14 June 2015. The shaded color is the rainfall accumulation and the grey dots show the location of rain gauge. The yellow and orange circles represent the station that exceeds the category of heavy rainfall and extremely heavy rainfall. The gauge station with the largest rainfall amount is Gongguan, where both Parsivel and MRR were at the same location.

The lowest radar beam crosses Taipei Basin above 1-km height. To effective estimate the rainfall evolution near ground is critical to urban disaster prevention. In this study, observational characteristic of an urban flash flood case in Taipei basin associated with afternoon thunderstorm (14 June 2015) is examined using Parsivel and MRR disdrometer, fortunately both of them located besides the gauge where the heaviest rain rate occur (Fig. 1). The urban flash flood associated with afternoon thunderstorm is characterized with extreme rainfall intensity with short duration (almost 200 mm in 3 hours). The intercomparison of rain rate and DSD between Parsivel and MRR is the first step to understand the performance and limitation of these instruments. Then the probable rainfall microphysical processes are discussed.

2. Data and Methodology

The brief introductions of Parsivel and MRR are in this section. The calculation of rainfall parameter is also described. The rainfall recorded by Gongguan gauge station and radar reflectivity of RCWF S-band radar, which are released by Central Weather Bureau, are used for comparison with derived parameter of disdrometer.

A. Parsivel

Parsivel is a kind of optical disdrometer that measures the size and falling velocity of hydrometeor. The sensor's transmitter unit generates a flat, horizontal beam of light, which the receiver unit converts into an electric signal. This signal changes whenever a hydrometeor falls through the beam anywhere within the measurement area. The degree of dimming is a measure of the hydrometer's size, and together with duration of the signal, the fall velocity can be derived. The Parsivel measures 32 bins of diameter from 0 to 25 mm every minute, but the first two size bins (< 0.25 mm) are not recorded because of the low signal-to-noise ratios. The observed target is raindrop in this study, so the size bins larger than 10 mm are removed. The measurements whose rain rate less than 1 mm h^{-1} or number of sampled drops less than 10 is also eliminate (according to Tokay et al. 2013). Due to the measuring principle, the smaller particle could be blocked by large particle while they pass through the sensing zone simultaneously. Previous studies have found that the Parsivel disdrometer would underestimate small raindrops and resulted in relatively higher D_m.

B. Micro Rain Radar (MRR)

The MRR instrument is a 24-GHz (K-band) continuous-wave radar that derives profiles of drop size distributions and rain parameters from measured spectral power backscatter intensity. The MRR signal is transmitted vertically into the atmosphere where a small portion is scattered back to the antenna from raindrops or other forms of precipitation. Due to the falling velocity of the raindrops, there is a frequency deviation between the transmitted and the received signal (Doppler frequency). This frequency is a measure of the falling velocity of the raindrops. Since drops with different diameters have different falling velocities (Gunn and Kintzer, 1949; Atlas 1973), the backscattered signal consists of a distribution of different Doppler frequencies. The spectral analysis of the received signal yields a power spectrum, which is spread over a range between 0.246 and 5.03 mm. The raw spectrum data is averaged every 1 minute. More about the observing principle of MRR could refer to Löffer-Mang et al. (1999). The MRR resolves 30 range gates vertically and its adjustable range is 10 - 1000 m, while the gate is 200 m (as same as Tsai and Yu, 2012) in this study to make the maximum height above melting level.

C. Rainfall Parameters

The rain rate RR (mm h^{-1}) is computed from the DSDs as below:

$$RR = \frac{6\pi}{10^4} \sum D_i{}^3 V_i N(D_i) \Delta D_i \quad (1)$$

where D_i (mm) is the equivalent spherical raindrop diameter, V_i (m s^{-1}) is the fall speed obtained with the theoretical formula from Brandes et al. (2002), $N(D_i)$ (m^{-3} mm^{-1}) represents the corresponding number concentration of raindrops in a unit volume of air and unit size interval, and ΔD_i is the corresponding diameter interval (mm) for the i-th bin, respectively.

The nth-order moment of the DSDs can be expressed as:

$$M_n = \int_0^{D_{max}} D^n N(D) dD$$

where D (mm) represents the equivalent diameter and $N(D)$ (mm^{-1} m^{-3}) is the number concentration of raindrops, as in (1). The mass-weighted mean diameter D_m (mm) equals the ratio of the fourth to the third moment of the size distribution:

$$D_m = \frac{M_4}{M_3} \quad (3)$$

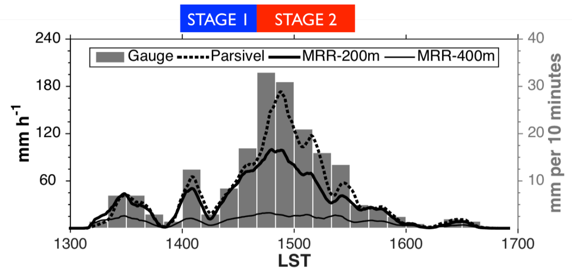

Fig. 2. The hyetograph of Gongguan gauge station on 14 June 2015. The instruments used to measure rainfall are shown as the legend. The rain rate is smoothed in every 10-minutes interval. The samples whose rain rate ≧ 20 mm h^{-1} are identified and divided into two stages.

3. Results and Discussions

The Parsivel-derived and MRR-derived rain rate shows good consistency with gauge measurement of 14 June 2015 (Fig. 2). The rainfall accumulation of Parsivel is 153.9 mm, which is more than 80% of gauge (192.0 mm). The main period of under estimation occurred from 1440 to 1500 LST, when the rain rate is the most intensive. However, the MRR highly underestimate the rainfall (117.1 mm) of the lowest available height (200 m), which is about 60% of gauge. The MRR-derived rainfall is dramatically low at he higher level (400 m), so that the measurement at 200 m of MRR will be discussed.

During the analyzed period, the lag correlation between MRR and Parsivel is 0 minute. The significant difference of derived rainfall between Parsivel and MRR could be found during the time of rain rate ≧ 20 mm h^{-1}. The higher the rain rate is, the more the difference increases (as Fig. 3). Two stages are selected around 1400-1440 and 1440-1530 LST, when is before and during the heaviest rainfall occurred. The characteristics of DSD will be discussed later.

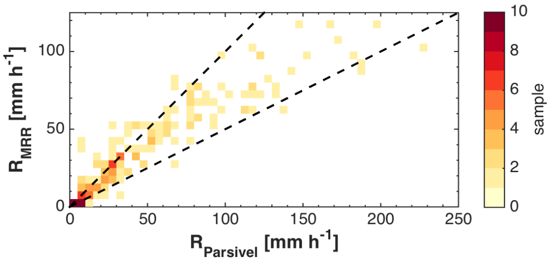

Fig. 3. Comparison for the rain rate of Parsivel (X-axis) and MRR (Y-axis). The dashed lines represent the aspect ratio 1:1 and 2:1, respectively.

The comparison of reflectivity between S-band (RCWF) and K-band (MRR) radar over Gongguan is shown as Fig. 4. In the analyzed period, most of the reflectivity > 40 dBZ measured by RCWF could reach the melting layer (5.3 km), and the 50 dBZ in the lowest observed level is highly correlated with the heavy rainfall on ground. In contrast, 40 dBZ seldom measured by MRR above 1-km height even though the fall streak of rainfall could be resolved clearly. Due to the severe attenuation heavy rainfall, the significant “blank” could be seen between 1 and 4 km during the stage 1 and 2. While Tsai and Yu (2012) considered the first gate (200 m) of MRR is easily interrupted and the second gate (400 m) is sufficient for the DSD measurement. In this study, the first gate at 200 m still provides valuable DSD but not for the second gate.

Fig. 5 shows the DSDs per minute acquired from Parsivel and MRR. The variation trend of all size intervals shows similar pattern between Parsivel and MRR but several differences are listed below. First, the measured size is limited at about 5 mm for MRR, meanwhile Parsivel could measure centimeter-sized particle. Next, the number density for Parsivel is calculated from the actual number of particles, but it’s retrieved from power spectrum for MRR. So the MRR contain number density smaller than order of 10^{-1}, but not for Parsivel. Third, the MRR shows obviously much more small particle (< 1 mm) than Parsivel especially during stage 1 and 2. At last, the mean diameter D_m shows very different distribution of these two instruments. The D_m of MRR never exceeds 2 mm, meanwhile the Parsivel often shows D_m > 2 mm. (as Fig. 6). Before the time of heavier rainfall (≧ 20 mm h^{-1}), the D_m of Parsivel even exceeds 3 mm.

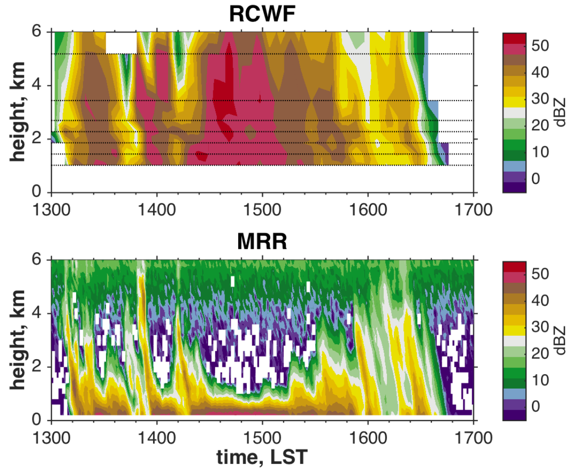

Fig. 4. The height-time-indicator (HTI) of reflectivity over Gongguan gauge station. The upper panel is measured by RCWF S-band radar and the lower panel is measured by MRR.

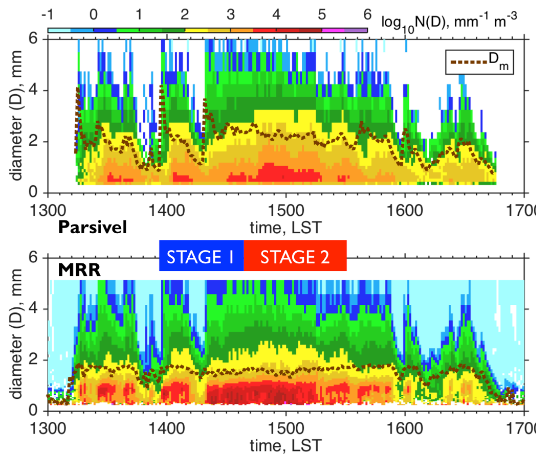

Fig. 5. Time series of DSDs from Parsivel (upper panel) and MRR (lower panel) at Gongguan gauge station. The color shading represents the DSD in logarithmic units of m^{-3} mm^{-1} and the Y-axis on indicates the equivalent volume diameter (mm) of raindrops, while the brown dashed line represents the mean diameter (D_m).

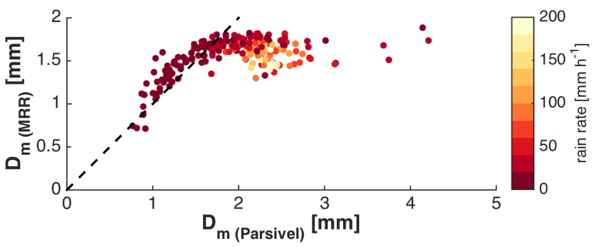

Fig. 6. Comparison for the mean diameter (D_m) of Parsivel (X-axis) and MRR (Y-axis). The color of dot represents the rain rate of Parsivel, and the dashed line shows the aspect ratio 1:1.

The similar rain rates could be resulted by very different DSDs. To discuss the consistency of DSDs measured by Parsivel and MRR, the samples from these two instruments with similar (±10%) rain rate and D_m of are selected. Only 6 minutes are identified in the 4-hours analyzed period, whose time, rain rate and D_m are listed in Table 1. All these samples are not included in stage 1 and 2, which shows the rain rate and D_m could be very variant between the disdrometers during heavy rainfall. The DSDs of aforementioned samples are plotted in Fig. 7, while the mean DSD of Parsivel and MRR are also shown. The ground measurement (Parsivel) shows decreasing small drops (< 1 mm) and big drops (> 3 mm) also increasing medium drops (1-3 mm) than measurement above ground (MRR), which is due to the combined coalescence and breakup process. The mean D_m of Parsivel is slightly larger than MRR. MRR shows an order larger than Parsivel for the drops < 0.5 mm, especially at 1333 LST.

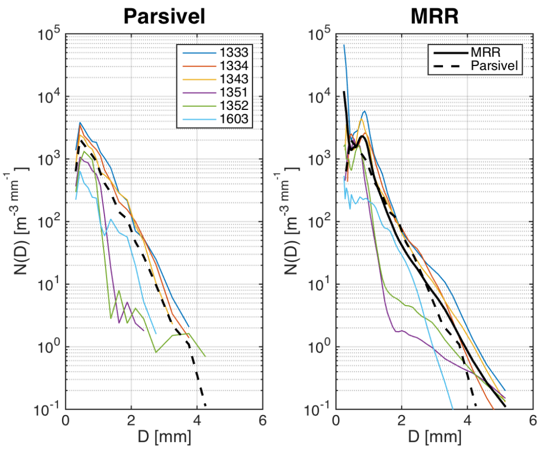

Fig. 7. The DSD for the similar rain rate and mean diameter (±10%) between Parsivel and MRR. The colored lines show the identified samples, while the black dashed and solid lines represent the mean DSD of samples from Parsivel and MRR, respectively.

Table 1. The rain rate and mean diameter of selected samples in Fig. 7.

	Parsivel		MRR	
Time [LST]	Rain rate [mm h^{-1}]	D_m [mm]	Rain rate [mm h^{-1}]	D_m [mm]
1333	30.7	1.69	33.0	1.56
1334	24.5	1.72	23.3	1.64
1343	22.2	1.68	21.2	1.65
1351	2.8	1.33	2.8	1.44
1352	3.5	1.77	3.8	1.62
1603	4.4	1.62	4.8	1.67

The samples whose D_m of Parsivel exceeds 3 mm are listed in Table 2. The difference of D_m between MRR and Parsivel could be more than 2 mm. Comparing the rain rate between MRR and Parsivel, these samples shows disparity but almost the same rain rates occur at 1420 and 1422 LST. DSD of MRR shows more (less) drops smaller (bigger) than 3 mm especially the significant difference of drop < 1 mm (Fig. 8), it could leads to the smaller D_m of MRR. Physically it represents the raindrop coalescence from 200-m height to ground, but the observing principle should be considered. Due to the limitation of observable Doppler frequency, the maximum retrieved drop size of MRR is about 5 mm. There may be drops > 5 mm existing in the sensing volume.

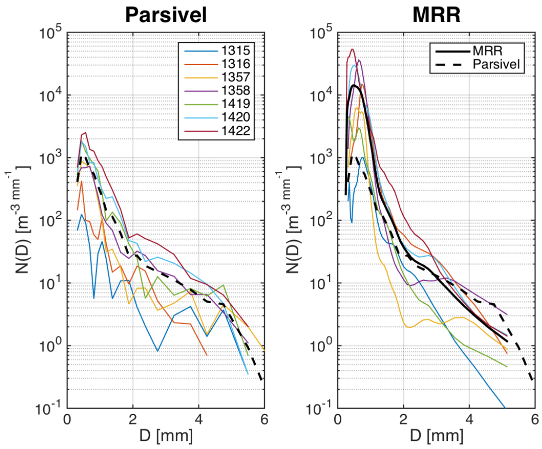

Fig. 8. The DSD for the Parsivel-measured mean diameter > 3 mm, and for the same time of MRR. The legends are as similar as Fig. 7.

Table 2. The rain rate and mean diameter of selected samples in Fig. 8.

	Parsivel		MRR	
Time [LST]	Rain rate [mm h^{-1}]	D_m [mm]	Rain rate [mm h^{-1}]	D_m [mm]
1315	10.0	4.15	6.2	1.89
1316	5.7	3.01	39.3	1.74
1357	20.6	4.21	9.6	1.73
1358	27.1	3.75	40.9	1.51
1419	31.7	3.69	7.9	1.68
1420	36.9	3.13	39.2	1.48
1422	51.8	3.12	50.1	1.46

The mean DSDs during heavy rainfall, which were identified as stage 1 and 2, are compared in Fig.9. The Parsivel and MRR both show that the mean DSD of stage 2 has higher concentrations for almost all drop size except for size > 4.5 mm. Of the stage 2, the breakup process could result the high concentration of small drops, but meanwhile the ongoing coalescence process could maintain the concentration of medium drops. For the comparison of these two instruments, MRR shows more (less) drops smaller (bigger) than 1.4 mm. It probably implies the collisional coalescence process while raindrop approach to ground. However, the curved down DSD of Parsivel for drop size < 0.5 mm might due to its blockage effect, on the other hand, MRR shows higher concentration of smaller drops and seriously underestimates the rain rate during heavy rain period. Reasonable speculation is that the DSDs measured by MRR should contain more big drops.

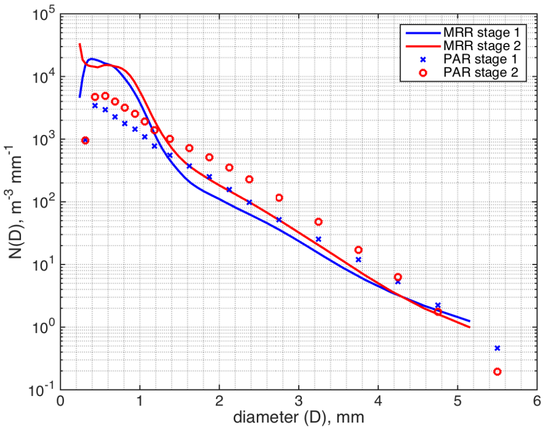

Fig. 9. Mean DSDs of specific period (stage 1 and 2) from Parsivel and MRR. The symbols, which represent different stages and instruments, are shown as the legend.

In this study, the highest and only available data of MRR is the gate of 200 m because of the increasing attenuation with height. The attenuation during heavy rainfall and the maximum measurable Doppler frequency would decrease number of big drops (> 5 mm), so that MRR cannot show its advantage of large sampling volume (Chang et al. 2020). Finer gate resolution should be considered for MRR to observe the convective rainfall, so that there could be chance to correct its own measurements at higher level.

4. Conclusion

During a severe afternoon thunderstorm impacting Taipei, both MRR and Parsivel are located near each other in Gongguan where were the heaviest rainfall occurred. The trend of rain rate of both instruments shows consistency with rain gauge but they both underestimates during heavy rainfall. For the heavy rainfall period, MRR is significantly attenuated above 400 m, and the amount of DSD is underestimated. So that the DSD at 200 m acquired by MRR is compared with Parsivel in this study.

For both of themselves, MRR and Parsivel shows the increasing number concentrations with increasing rain rate. But the MRR shows higher concentrations of small drops also lower concentrations of big drops than Parsiveland. The D_m of MRR scarcely exceeds 2 mm, and it directly limits the rain rate derived by MRR especially during heavy rainfall. While the rain rate is lower than 20 mm h^{-1}, composited analysis of MRR and Parsivel shows the combined raindrop coalescence and breakup process. But for the heavier rainfall, uncertainty increases for the comparison between these instruments.

For the DSD-derived rainfall parameters and corresponding polarimetric radar parameters, the bias needs further investigation via the collocated disdrometers, rain gauge and radar coverage. Much finer gate resolution of MRR would increases its applicability during heavy rainfall.

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