Response Letter for Anonymous Referee #1

Overall Comments

This manuscript provides an interesting new method to estimate microstructural and bulk rainfall properties from a CCTV camera. The idea is intriguing and the topic is fully appropriate for the journal. The manuscript needs overall a major and mandatory revision, as detailed in the following comments.

Answer:

We appreciate for your valuable comments and revision suggestions. As suggested by the referee, all the comments were considered in the revision of the manuscript.

Q1. Methodology section: the authors move forward to directly discuss and describe the algorithm. Important information on the measurement device is missing at this point, crucial for the scope of this journal. The reader at this point has the following questions: what are the technical characteristics of the camera? What are the actual input data? (description of the images, their resolution, acquisition rate, discussion of possible artifacts/issues…). Figure 1 is rather generic, it would be good to see visually step by step the data processing in a similar sequential order. I recommend then to anticipate the description of the devices at the beginning of the methodology section.

Answer:

Reflecting the referee's opinion, '2.1 Recording video containing rain streaks using infrared surveillance camera' was newly created in the methodology section and a supplementary explanation was added as follows.

(Revised Manuscript, Lines 70-92)

2.1 Recording video containing rain streaks using infrared surveillance camera

The surveillance camera records video. The video looks continuous, but it is also composed of discrete still images, so-called frames. The frequency of recording frames (i.e., acquisition rate) is called frames per second (fps). In other words, fps is how many images are taken per second for recording video. Another important factor in video recording is exposure time. Exposure time, also called shutter speed, refers to the time the camera sensor is exposed to light to capture a single frame. The real raindrops are close to a circle, but in a single image, the raindrops look like a streak. This is because raindrops move at a high speed during the exposure time. Therefore, the raindrops that moved during the exposure time are visualized in the rain streaks in a single frame.

Fig. 2 shows an example of capturing a raindrop for a single frame. Here, only the raindrops in the front and rare that a little far from the point of focus are clearly visible, and objects that are more than a certain distance appear invisible. That is, the point where the focus is best is called the focus plane, and there is a range in which it can be recognized that objects are focused before and after the focus plane. The closest plane that can be considered to be in focus is called the near-focus plane, and the farthest plane is called the far-focus plane. This range is generally called depth of field (DoF). Ultimately, the rainfall intensity can be estimated based on the volume and raindrops in the DoF.

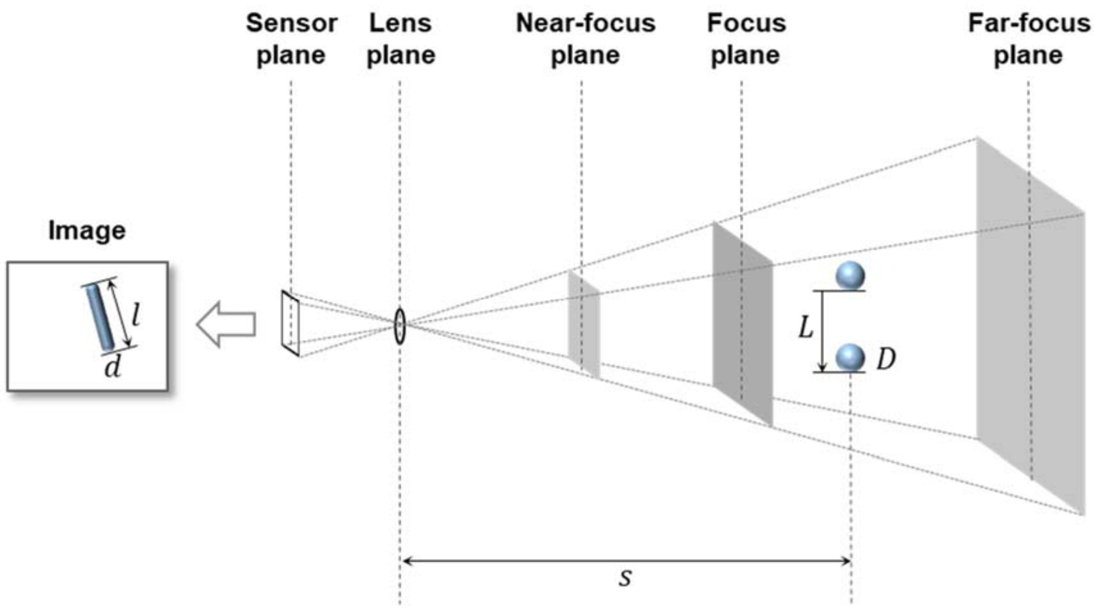


Figure 2: Schematic diagram of the photographed rain streak in the image and the movement of a raindrop during the exposure time

On the other hand, the description of the applied device and input data is described in Section 3 in the original manuscript (lines 211-215). In addition, an example of processing data sequentially following Figure 1 is already described in Section 4 in the original manuscript (lines 279-315).

Q2. I would like to better understand the concept of "dark conditions". I invite the authors to elaborate more and discuss accordingly the perspectives of this type of measurements. How does the performance continuously evolve in the transitions from dark to light and vice versa?

Answer:

In this study, the term 'dark condition' refers to the case of low illuminance. In other words, the dark condition is a condition in which raindrops cannot be captured by a general surveillance camera with visible light. For this reason, we considered recording raindrops in dark conditions using infrared (IR) mode. In the methodology section, we have added a description of this type of measurement (i.e., surveillance camera with IR mode).

(Revised Manuscript, Lines 85-88)

> In this study, an infrared surveillance camera was considered under dark conditions. Here, the dark condition refers to a condition in which raindrops cannot be captured by a general surveillance camera with visible light. Infrared cameras emit near-infrared rays through an infrared emitter and receive the reflected light from the objects. Accordingly, there is an advantage in that raindrops that are invisible to the human eye can be detected.

Recording video in the daytime is affected by many factors (background, sunlight, moving objects, etc.). Several conditions are required to capture the raindrops. For example, there should be a wall or tree that can serve as a background, and the amount of illuminance should not be too strong. In particular, the difference in the amount of illuminance is expected to cause an extreme difference in the accuracy of estimating rainfall intensity. On the other hand, infrared cameras used at night can be immune to the effects of these factors. Therefore, it is thought that there would be less uncertainty in the night mode, but the result could be markedly different depending on the observation sites. However, unfortunately, this study focused on the infrared mode when recording at night. The performance between day and night mode will be compared in our future study.

Q3. The evaluation needs more data (more precipitation events). This will also help to better understand the differences at the tail of the distribution illustrated in the manuscript. At the present stage it is very hard to understand the potential and the error structure of this new measurement principle.

Answer:

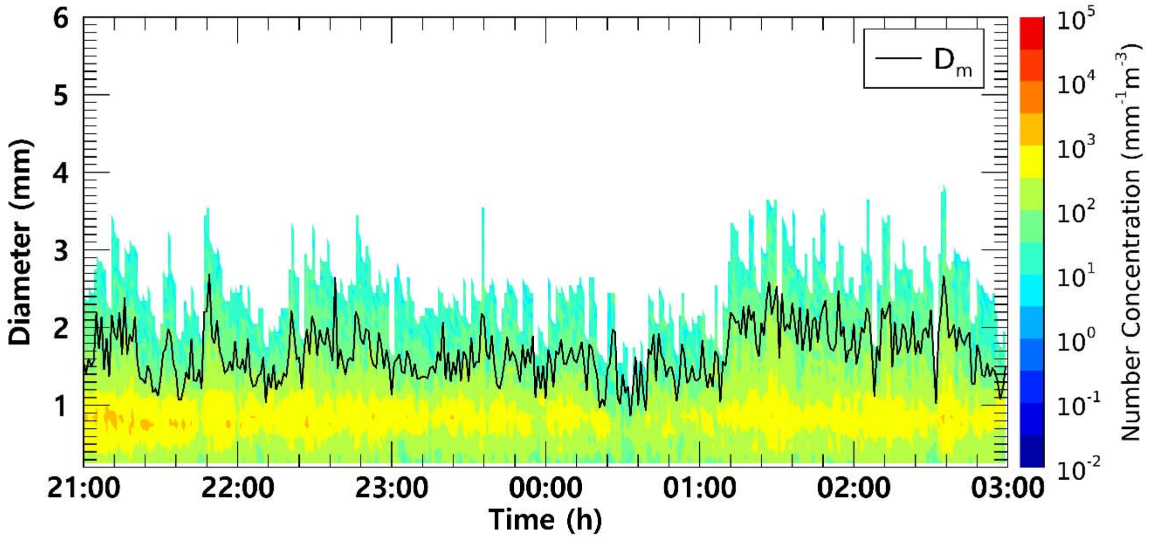
As mentioned by the referee, a new case of precipitation analysis was added. By adding an analysis case different from the previously presented precipitation case, the possibility of utilizing existing public CCTV images is presented through the rainfall intensity and DSD (Drop Size Distribution) calculation method based on the observation data of the infrared surveillance camera newly proposed in this study.

(Revised Manuscript, Lines 402-445)

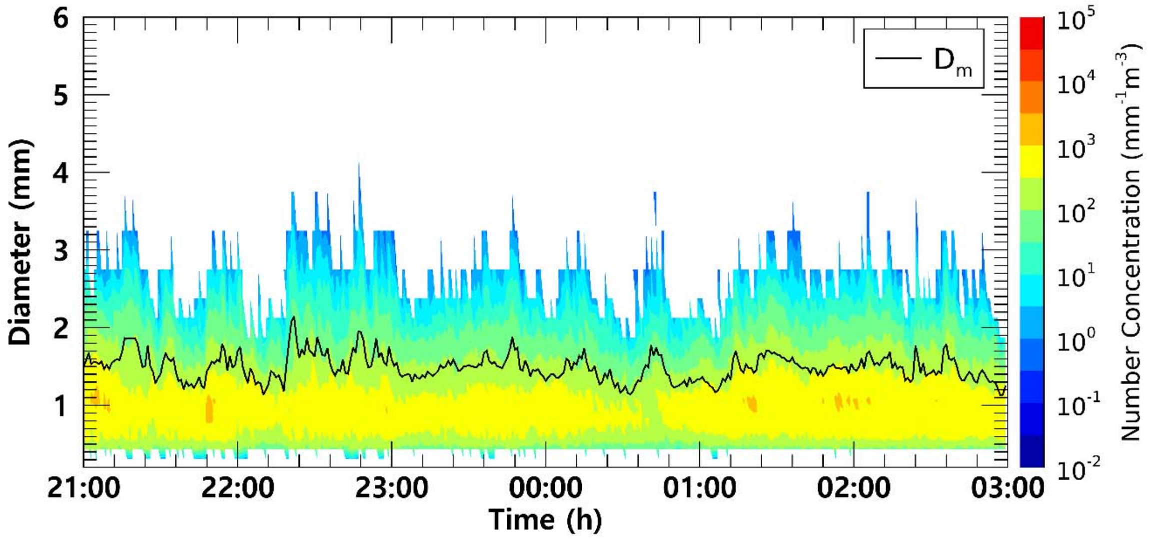
Fig. 13 illustrates the time series of the number concentration and D_m obtained from CCTV and PARSIVEL for case 2. In both CCTV and PARSIVEL observation data, the number concentration for a diameter between 0.5 mm and 1.5 mm had a value between 500 $mm^{-1}m^{-3}$ to 1,000 $mm^{-1}m^{-3}$, and there was no significant change in the number concentration with time.

The maximum diameter also consistently had a value close to about 3 mm, and the D_m was also similar to about 1.5 mm because the maximum particle diameter and the number concentration of 1 mm intermediate drop had similar values.

From 0100 LST to 0230 LST, the maximum particle diameter through CCTV was overestimated, resulting in a large value close to 4 mm. As a result, the Dm value increased significantly to more than 2 mm. PARSIVEL data showed a sharp decrease in the number concentration of 1 mm particles at 0030 LST, and an increase in D_m under the influence of the sharply decreased number concentration. However, in the case of CCTV, only raindrops smaller than of 2 mm were observed at the time, and there was a difference in that Dm did not increase and was maintained.



(a) CCTV



(b) PARSIVEL

Figure 13: Time series of number concentration and Dm (black coloured line) from (a) the surveillance camera images, (b) the PARSIVEL observation data from 2100 LST on September 5 to 0300 LST on September 6, 2022.

As clearly shown in Fig. 13, there was no significant difference in number concentration according to the time change. The average number concentration distribution also showed similar results because the number concentration values were concentrated at 1,000 $mm^{-1}m^{-3}$ concentration in both observation instruments. (Fig. 14). As in case 1, PARSIVEL observation data showed a tendency to underestimate in sections less than 0.5 mm, and underestimated in sections larger than 2 mm compared to CCTV data. The diameter section where CCTV data is underestimated compared to PARSIVEL data is from 1 mm to 2 mm. Since the number concentration of the CCTV data was underestimated in this section, the rain rate based on the number concentration data was also underestimated compared to the rainfall intensity based on the PARSIVEL data.

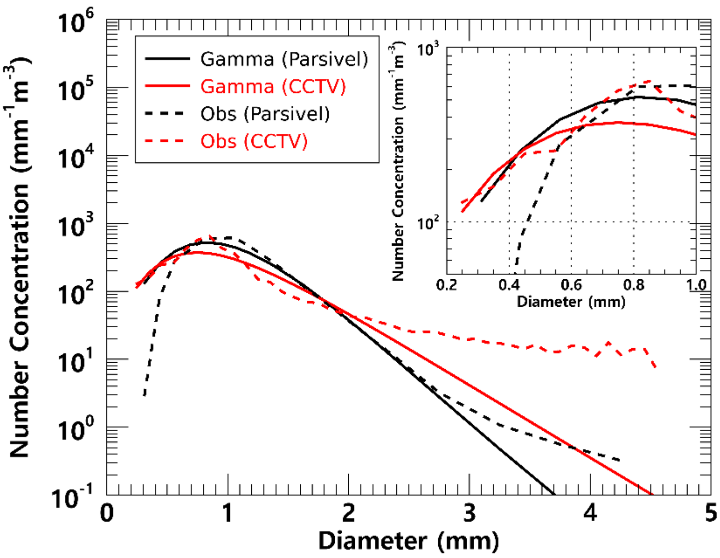


Figure 14: Average number concentration versus diameter from the surveillance camera images and the PARSIVEL.

Between 2100 LST on September 5 and 0100 LST on September 6, when the number concentration of about 1 mm raindrops is similar and the maximum diameter size is similar, the rain rate time series distribution has a value of about 5 mm h^{-1} and has a very similar flow. However, between 0130 LST and 0300 LST, which is a time period with overestimation of particle diameter in CCTV observation data, the increase and decrease in rain rate was similar. However, the magnitude of the increase and decrease rain rate differed every 15 minutes. During that time, the maximum rain rate was less than 20 mm h^{-1} in the PARSIVEL observation data, while strong rainfall of 60 mm h^{-1} or more was observed in the CCTV observation data.

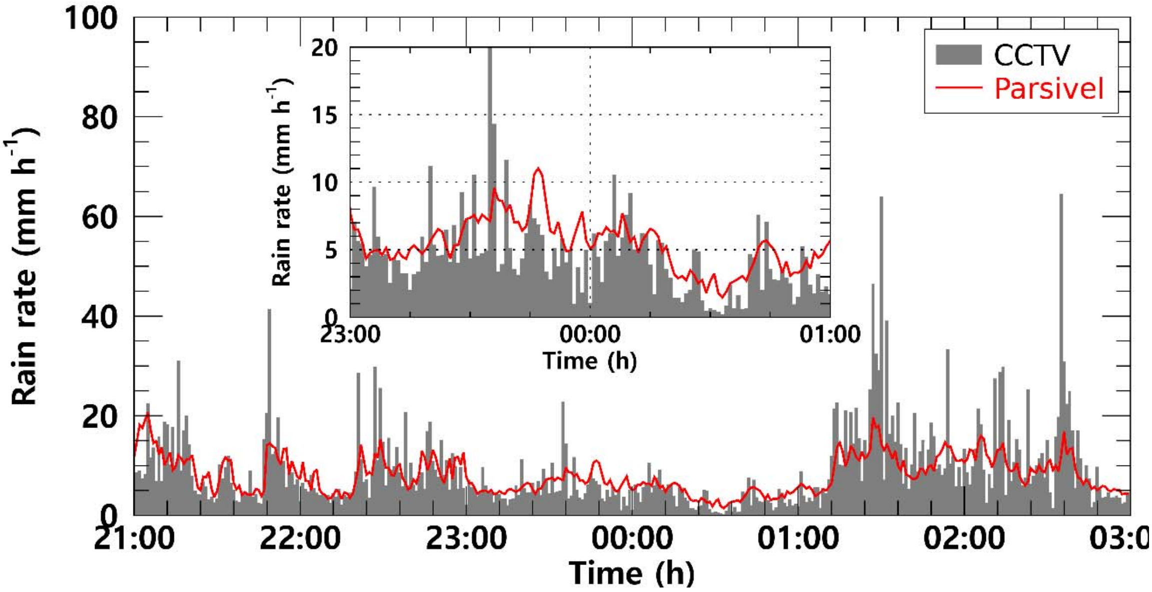


Figure 15: The rain rate time series calculated from the surveillance camera images (gray bar) and PARSIVEL observation data (red line) from 2100 LST on September 5 to 0300 LST on September 6, 2022.

Fig. 16 illustrates the scatter plot of the average rain rate every 15 min from the PARSIVEL observation and the CCTV images for case 2. Compared to case 1, case 2 was a strong rainfall case with a rain rate of about 8.94 mm h^{-1}. Compared to the PARSIVEL observation data, the CCTV observation data showed a larger D_m by 0.221 mm, while the $Log_{10}N_0$ showed a small feature of 1.1 $mm^{-1-\mu}m^{-3}$. As the weight of medium and large drops over 1 mm increased, μ and Λ showed lower values of 4.262 and 5.397 mm^{-1}, respectively (Table 4). According to the 15-minute cumulative rain rate comparison result, the rain rate based on CCTV image data tends to be underestimated when it is less than 6 mm h^{-1}. Conversely, there was a tendency to overestimate the rainfall period of 6 mm h^{-1} or more. This phenomenon was confimed in Case 1 which may be caused by recognizing overlapping rain streaks as a single big raindrop. MAPE had a low value of 0.35% or less regardless of the rain rate, and even though the rainfall intensity was relatively large compared to case 1, MAE and RMSE did not significantly increase. This is because there was no abnormally large value of

CCTV rainfall during the rainfall period of case 2 compared to case 1.

Table 4: Statistical values of the rain rate and DSD parameters for the rainfall case 2.

		R (mm h^{-1})	D_m (mm)	$\log_{10}N_0$ (mm$^{-1-\mu}$m^{-3})	μ (unitless)	Λ (mm^{-1})
PARSIVEL	Mean	8.12	1.445	5.900	6.379	7.341
	Variance	13.82	0.020	1.160	6.498	5.596
	Skewness	0.65	0.447	1.061	0.9467	1.198
	Kurtosis	-0.13	0.472	2.480	1.818	2.792
CCTV	Mean	8.94	1.666	4.813	4.262	5.397
	Variance	69.33	0.121	1.185	4.577	6.714
	Skewness	2.75	0.355	2.596	1.903	2.640
	Kurtosis	11.71	-0.202	8.962	5.714	9.756

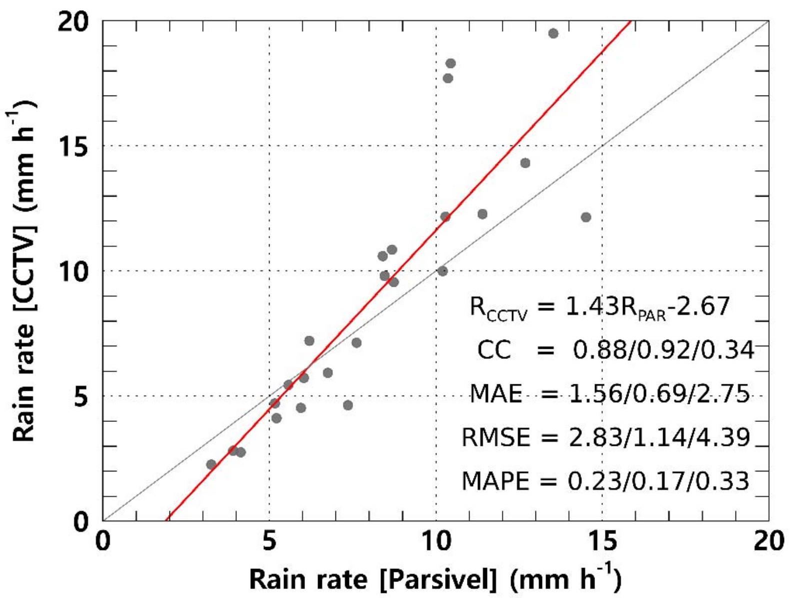


Fig. 15. Scatter plot of average rain rate every 15 minutes from the PARSIVEL observation and the surveillance camera images. Red line is linear regression. Scatter plot displays CC, MAE, RMSE, MAPE for R > 0 mm h^{-1}, R < 5 mm h^{-1}, and R ≥ 5 mm h^{-1} (sequentially from left to right).

Q4. I do not see any statement about data and code availability. I strongly recommend to provide the data as well as the code in an appropriate repository. I consider it almost mandatory for this type of papers describing new methods.

Answer:

The analysis of this study was performed through the collaboration of the authors. Thus, codes are written in multiple languages in IDL, Matlab, and Python. The partial code and data will be provided upon request of the readers, and this code availability was mentioned in the revised manuscript. In addition, all codes are currently being unified tit is currently in the process of unifying codes into Python. In the future, input data and code for the sample rainfall event will be shared through Github.

(Revised Manuscript, Lines 497-498)

Data availability The data and code can be provided by the corresponding author (hjkim22@cau.ac.kr) upon request.

Q5. L12: please quantify "similar"

Answer:

The numerical difference in the number concentration obtained through CCTV and PARSIVEL observations for the 0.5-1.5 mm diameter section was presented, indicating that the number concentration values were similar.

(Revised Manuscript, Lines 12-15)

Second, the number concentration of raindrops obtained through closed-circuit television (CCTV) images had values between 100 $mm^{-1}m^{-3}$ and 1,000 $mm^{-1}m^{-3}$, the RMSE for the number concentration by CCTV and PARticle Size and VELocity (PARSIVEL) was 72.3 $mm^{-1}m^{-3}$ and 131.6 $mm^{-1}m^{-3}$ ~~was similar to the actual PArticle SIze and VELocity (PARSIVEL) observed number concentration~~ in the 0.5 to 1.5 mm section.

Q6. L13: it is not clear why you focus here only on the 0.5 to 1.5 mm interval

Answer:

The rain rate calculated through the raindrop size distribution is proportional to the third power of the diameter of the raindrops, and the difference in the influence weight appears according to the diameter difference. Reference Figure 6-1 shows the contribution rate to rain rate by diameter for each rain rate section. The precipitation cases selected in this study mainly focus on weak rainfall of less than 5 mm h^{-1}. The rain rate value in the rain rate section weaker than 5 mm h^{-1} is affected by the number concentration value for the 0~2 mm diameter section by more than 80% and as large as more than 90%. The high accuracy of number concentration obtained from CCTV image data in the corresponding diameter section affects the accuracy of rain rate estimation.

In addition, as shown in the PARSIVEL correction factor (Fig. 6-2) proposed by Raupach and Berne (2015), it can be seen that the difference in number concentration based on PARSIVEL and 2DVD (Two-dimensional Video Disdrometer) observation data in less than 0.5 mm diameter section increases sharply compared to the number concentration difference in the 1 mm. This result means that the accuracy of the number concentration value based on the PARSIVEL observation data for drops smaller than 0.5 mm is low. Therefore, this study focused on the 0.5-1.5 mm diameter section considering the constraints of the PARSIVEL observation instrument and the effect on the rain rate calculation accuracy.

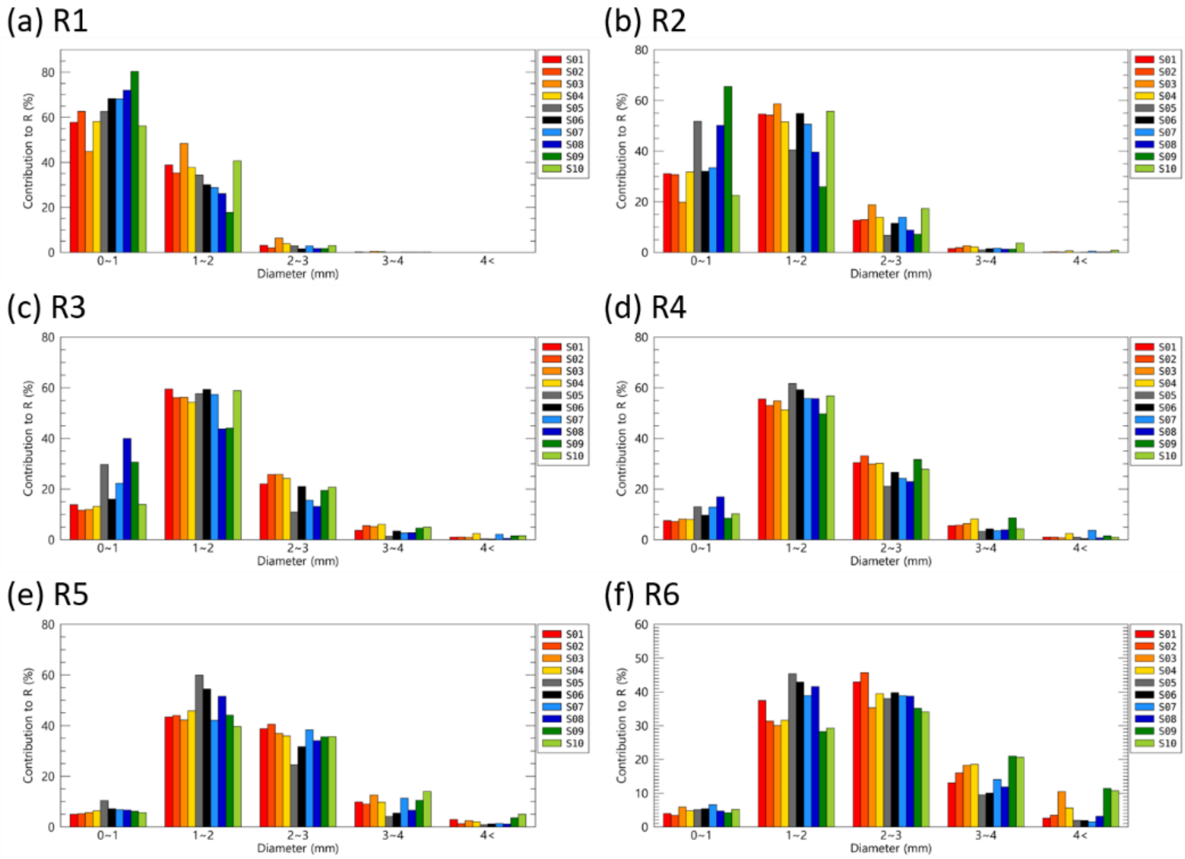


Fig. 6-1. The contribution rate of the N(D) of each diameter category to the rain rate (Kim et al., 2022).

(R1: ~ 1 mm h^{-1}, R2: 1~5 mm h^{-1}, R3: 5~10 mm h^{-1}, R4: 10~20 mm h^{-1})

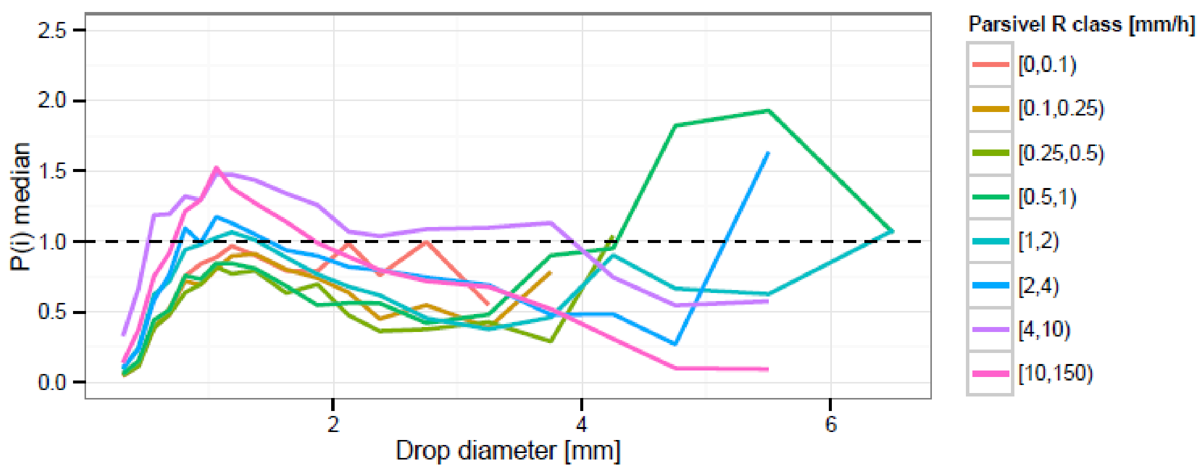


Fig. 6-2. Median P(i) values classed by Parsivel-derived intensity (Raupach and Berne, 2015).

*** References**

Kim, H. J., Jung, W., Suh, S. H., Lee, D. I., & You, C. H. (2022). The Characteristics of Raindrop Size Distribution at Windward and Leeward Side over Mountain Area. Remote Sensing, 14(10), 2419.

Raupach, T. H., & Berne, A. (2015). Correction of raindrop size distributions measured by Parsivel disdrometers, using a two-dimensional video disdrometer as a reference. Atmospheric Measurement Techniques, 8(1), 343-365.

Q7. L20-25: please note that weighing gauges are nowadays used very often instead of tipping bucket.

Answer:

As suggested by the referee, some description related to the weighing gauges and comparison with tipping-bucket-type were added.

(Revised Manuscript, Lines 27-31)

> For this reason, weighing gauge are nowadays used very often instead of tipping-bucket-type. the weighing gauge is a meteorological instrument used to observe and analyze various precipitation, including rainfall and snowfall. Also, the tipping bucket has a large error due to the observation time delay when the rainfall is less than 10 mm h^{-1} compared to the weighing gauge. However, when the observation time size is set to 10 to 15 minutes, the relative percentage error has a very low value of -6.7~2.5%, resulting in high accuracy (Colli et al., 2014).

(Revised Manuscript, References)

> Colli, M., Lanza, L. G., La Barbera, P., Chan, P. W.: Measurement accuracy of weighing and tipping-bucket rainfall intensity gauges under dynamic laboratory testing. Atmos. Res., 144, 186-194, 2014.

Q8. L63: provide a reference for the PARSIVEL instrument

Answer:

As suggested by the referee, the reference for the PARSIVEL instrument was added.

(Revised Manuscript, Lines 68-69)

The DSD was used to calculate rainfall intensity with physical optics analysis and verified using a PArticle SIze and VELocity (PARSIVEL) disdrometer (Löffler-Mang and Joss, 2000).

(Revised Manuscript, References)

Löffler–Mang, M., Joss, J.: An optical disdrometer for measuring size and velocity of hydrometeors. J. Atmos. Ocean. Technol. 17 (2), 130–139, 2000.

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Q9. Equation 5: please note that there may be significant uncertainties to this relation. I suggest a discussion about it after revisiting the relevant literature on the subject.

Answer:

Equation 5 is the terminal velocity relationship for each diameter of raindrops. Marzuki et al. (2013) analyzed the fall velocity distribution by raindrop diameter for various rainfall types using long-term two-dimensional video disdrometer (2DVD) observation data. The precipitation cases they selected were precipitation with winds in a wide range of 0.5 to 9 m s^{-1}, and all precipitation cases were reported by Atlas et al. (1973) suggested that it has a terminal velocity distribution. The precipitation cases they selected were precipitation cases accompanied by winds in a wide range of 0.5 to 9 m s^{-1}, all precipitation cases are fitted by terminal velocity distribution suggested by Atlas et al. (1973). In addition, as shown in Figure 9-1(b), even in the case of precipitation accompanied by strong wind speed, the difference between the fall velocity and the terminal velocity of the raindrops smaller than 4 mm was very low, less than 0.4 m s^{-1}.

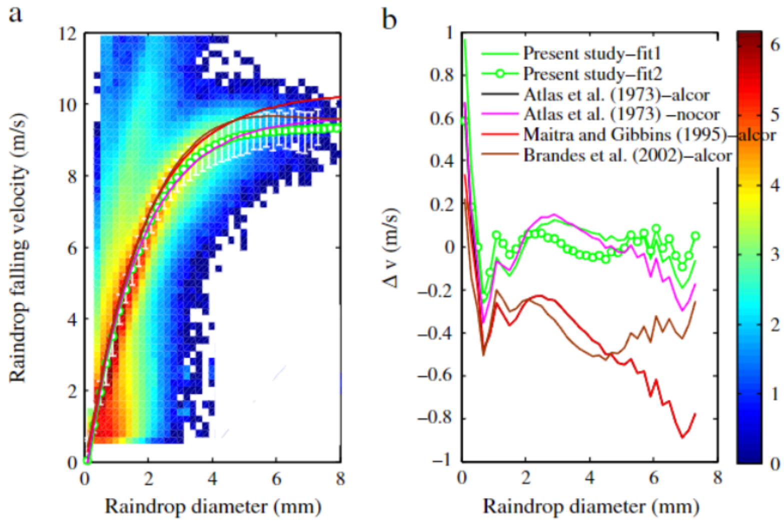


Fig. 9-1. (a) Fall velocity distribution by raindrop diameter, (b) average distribution of the difference between fall velocity and terminal velocity (Marzuki et al, 2013).

Chen et al. (2022) compared and presented the terminal velocity distribution by raindrop diameter based on observation and theoretical relationships. As shown in Figure 9-2, the difference in the fall velocity of raindrops with a diameter of 0 to 4 mm did not appear significantly. During precipitation, the diameter of most of the raindrops is usually less than 3 mm, so it can be seen that the terminal velocity relationship is followed except for exceptional cases such as typhoons.

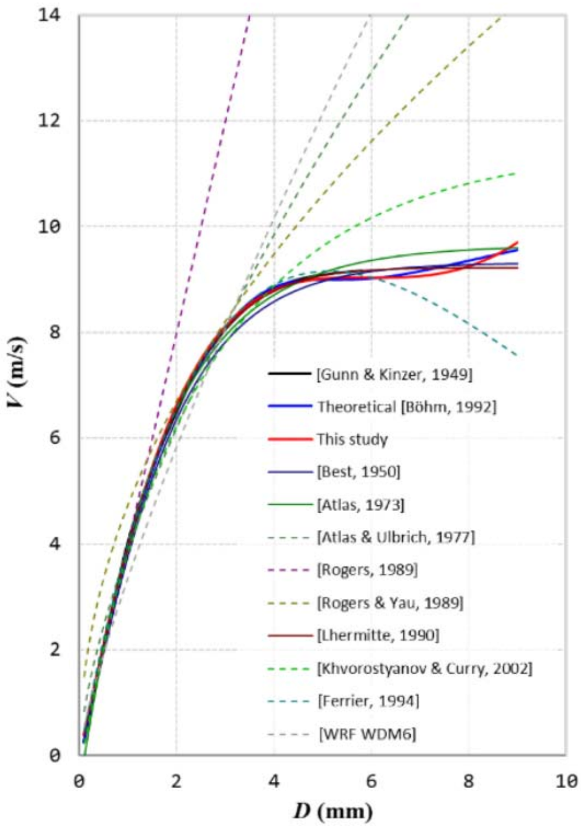


Fig. 9-2. Distribution of terminal velocity by diameter of raindrops based on various types of models (Chen et al, 2022).

*** References**

Marzuki, Randeu, W. L., Kozu, T., Shimomai, T., Hashiguchi, H., & Schönhuber, M. (2013). Raindrop axis ratios, fall velocities and size distribution over Sumatra from 2D-Video Disdrometer measurement. Atmospheric Research, 119, 23-37.

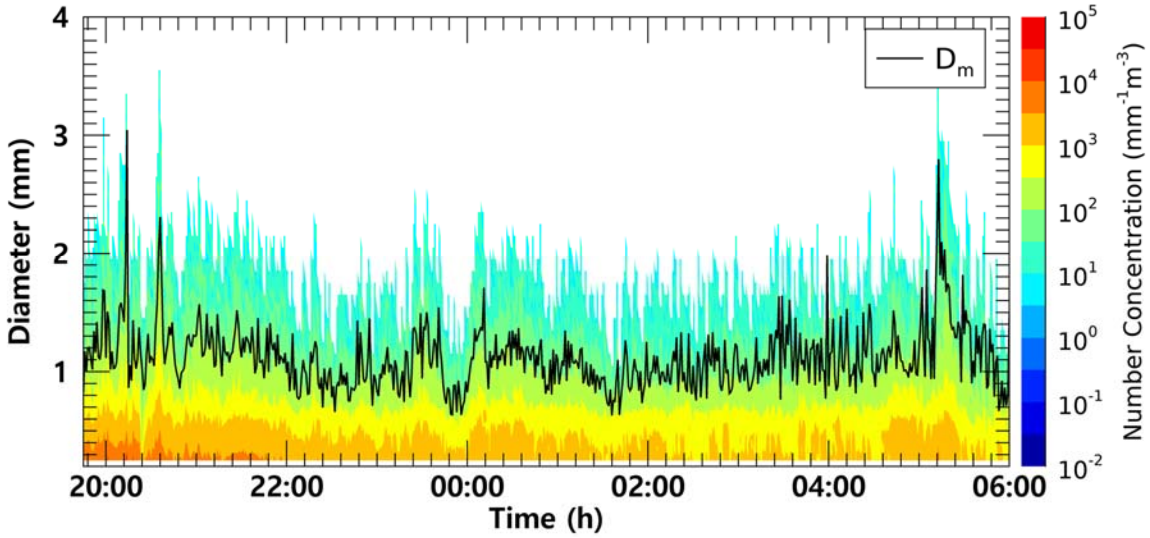
Chen, J. P., Hsieh, T. W., Lin, Y. C., & Yu, C. K. (2022). Accurate parameterization of precipitation particles' fall speeds for bulk cloud microphysics schemes. Atmospheric Research, 273, 106171.

Q10. Equation 8 (and discussion): is it possible also to obtain non-parametric (histograms) DSDs with this instrument? I would be curious to see how such histograms would look like.

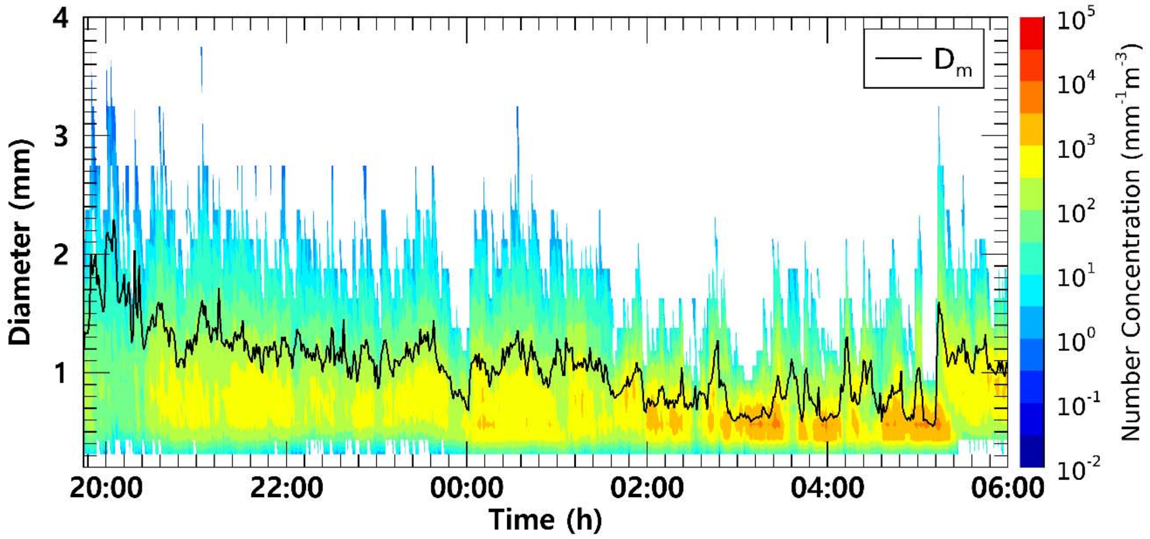
Answer:

This manuscript describes the analysis results based on the results of non-parametric DSDs based on actual observation data, the time series distribution of the number concentration (Revised Manuscript, Fig. 9 and Fig. 13), and the average number concentration distribution by diameter (Revised Manuscript, Fig. 10 and Fig. 14) are also the results of the observed DSDs.

(Revised Manuscript, Fig. 9 and Fig. 13)

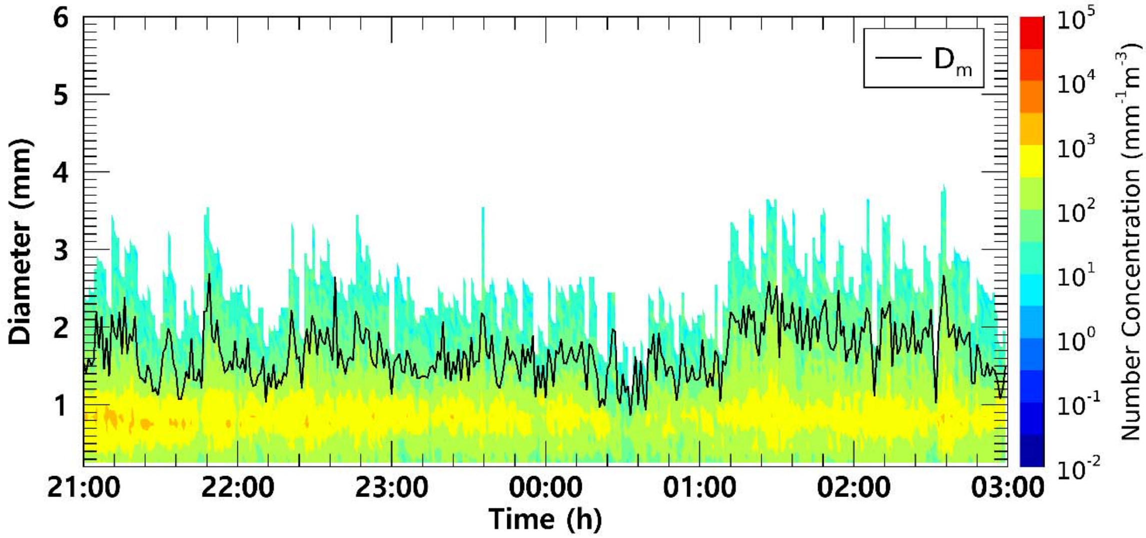


(a) CCTV

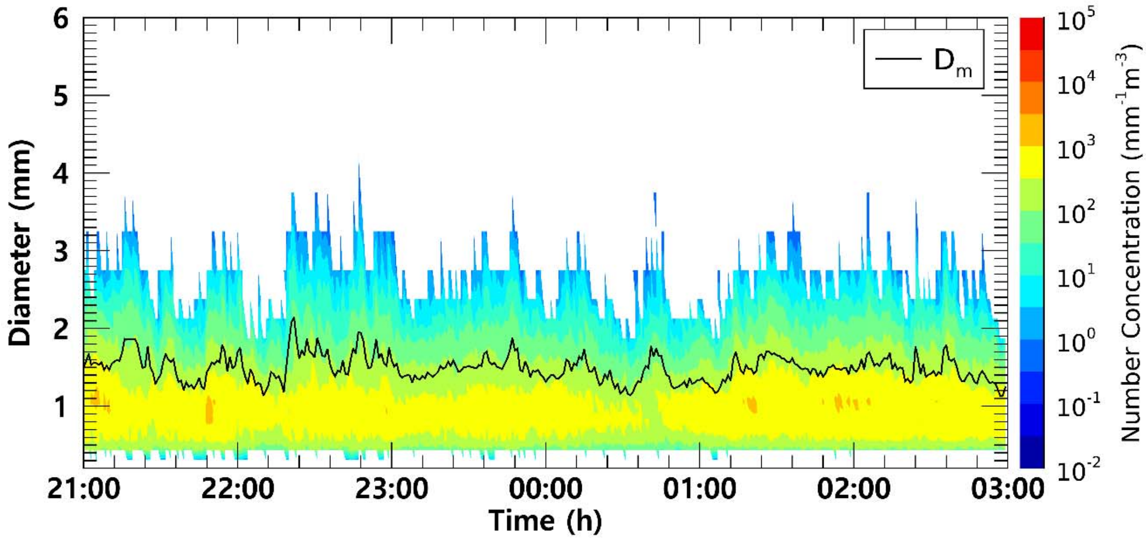


(b) PARSIVEL

Figure 98: Time series of number concentration and Dm (black coloured line) from (a) the surveillance camera images, (b) the PARSIVEL observation data from 1945 LST on March 25 to 0600 LST on March 26, 2022.



(a) CCTV



(b) PARSIVEL

Figure 13: Time series of number concentration and Dm (black coloured line) from (a) the surveillance camera images, (b) the PARSIVEL observation data from 2100 LST on September 5 to 0300 LST on September 6, 2022.

(Revised Manuscript, Fig. 10 and Fig. 14)

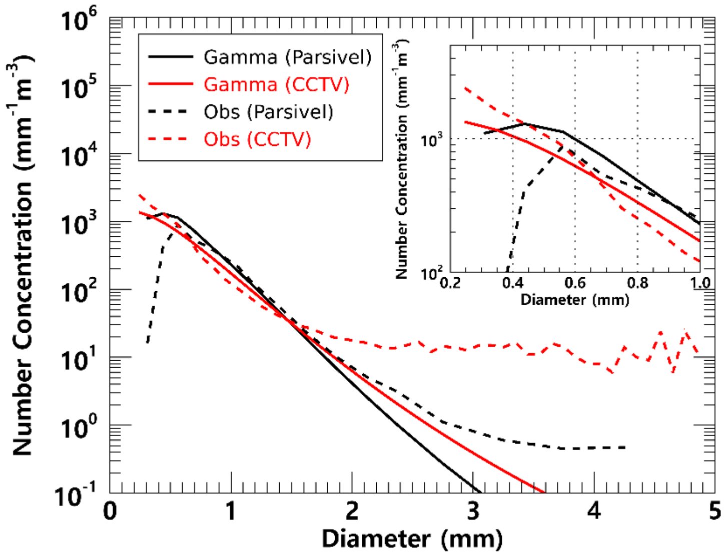


Figure 10: Average number concentration versus diameter from the surveillance camera images and the PARSIVEL.

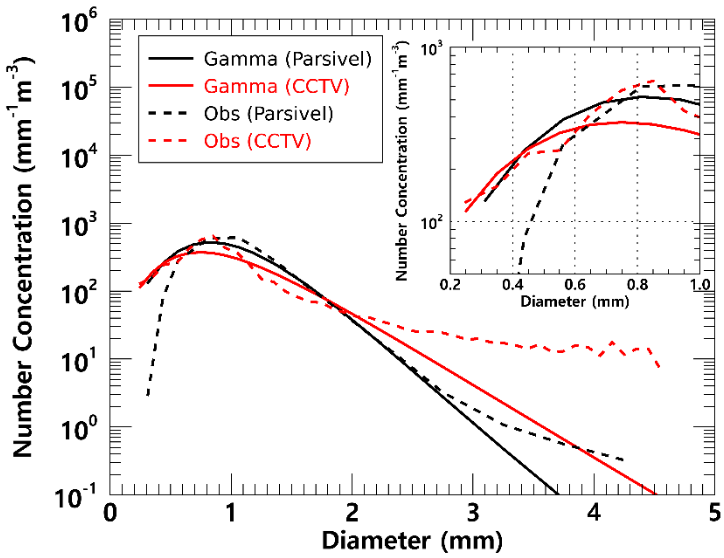


Figure 14: Average number concentration versus diameter from the surveillance camera images and the PARSIVEL.

Q11. L108: here the depth of field is mentioned. However, it was not previously introduced and discussed. See my larger comment on the methodology section.

Answer:

Reflecting the referee's comment, '2.1 Recording video containing rain streaks using infrared surveillance camera' was newly created in the methodology section, and a supplementary explanation for depth of field (DoF) was added.

(Revised Manuscript, Lines 79-92)

Fig. 2 shows an example of capturing a raindrop for a single frame. Here, only the raindrops in the front and rare that a little far from the point of focus are clearly visible, and objects that are more than a certain distance appear invisible. That is, the point where the focus is best is called the focus plane, and there is a range in which it can be recognized that objects are focused before and after the focus plane. The closest plane that can be considered to be in focus is called the near-focus plane, and the farthest plane is called the far-focus plane. This range is generally called depth of field (DoF). Ultimately, the rainfall intensity can be estimated based on the volume and raindrops in the DoF.

In this study, an infrared surveillance camera was considered under dark conditions. Here, the dark condition refers to a condition in which raindrops cannot be captured by a general surveillance camera with visible light. Infrared cameras emit near-infrared rays through an infrared emitter and receive the reflected light from the objects. Accordingly, there is an advantage in that raindrops that are invisible to the human eye can be detected.

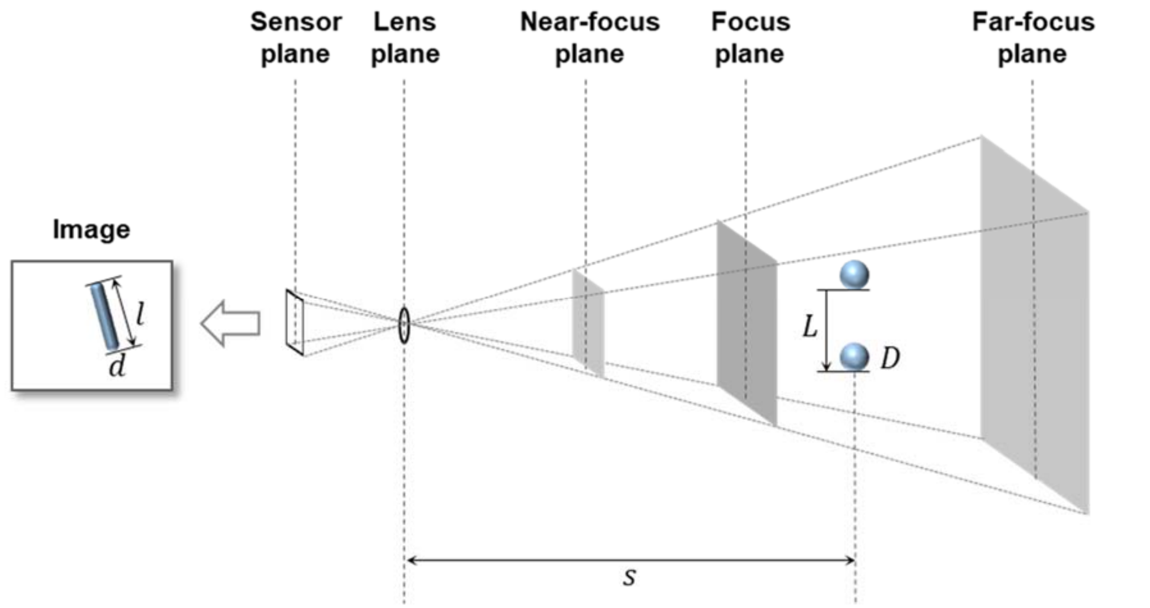


Figure 2: Schematic diagram of the photographed rain streak in the image and the movement of a raindrop during the exposure time

Q12. Table 2 and Table 3: I would recommend to move this information to the Appendix.

Answer:

As mentioned by Referee, Table 2 and Table 3 have been moved to the Appendix.

Q13. Figure 5: OK to show the data with different granularity, but I would like to see also the two time series with the same temporal resolution (by aggregating PARSIVEL data) as well as their cumulative curves, to understand if the Parsivel and the gauge are in decent agreement. Also, Figure 10 later on should be replicated to compare, at 15 minutes, the CCTV and the rain gauge which remains the real reference for rainfall amounts.

Answer:

We apologize for the confusion in the review process. The content related to the rain gauge should have been deleted, but it was entered by mistake during the editing process by the authors. At first, we tried to include analysis related to the rain gauge as well as PARSIVEL. But this study was changed to intend focus on comparison with PARSIVEL data because there were many missing data of the rain gauge. Therefore, the content related to the rain gauge was removed in the revised manuscript as follows. The contents mentioned by the referee will be actively reflected in our future research.

(Revised Manuscript, Abstract)

~~Furthermore, a tipping-bucket rain gauge was used for comparison.~~

(Revised Manuscript, Conclusion)

~~Furthermore, a tipping-bucket rain gauge was used for comparison.~~

Q14. Figure 8: the labels (a) and (b) are missing

Answer:

Thanks for the referee's kind review. You can see the labels (a) and (b) below the number concentration time series distribution in Figure 8 in original manuscript (Revised Manuscript, Figure 9). Please check.

Q15. Figure 9 (and discussion): why do you need to fit a gamma distribution for the Parsivel? Could you just use the <u>non parametric form</u> from the measurements?

Answer:

This study performed a comparative analysis based on the results of non-parametric DSDs obtained from actual observation data. In addition, a comparison with the fitted distribution based on the gamma distribution is also shown.

When the technique proposed in this study is applied to public CCTV, differences in the number concentration distribution may appear depending on various hardware conditions, image resolution, and differences in the observation area. Therefore, it is possible to estimate the rainfall intensity in which non-ideal drops are filtered by estimating the concentration distribution after obtaining the size and distribution information of the distribution of raindrops obtained in the image.

In addition, if the accuracy of estimating DSDs through CCTV images is secured, it is possible to acquire DSDs observation data with high observation resolution in various areas. The collected regional DSDs can be expected to increase their utility, such as verifying ground rainfall for microphysical schemes of numerical models.

Q16. Table 5 (and discussion): I believe you should increase the size of your side-by-side comparison dataset. One rainfall event is not enough in my opinion.

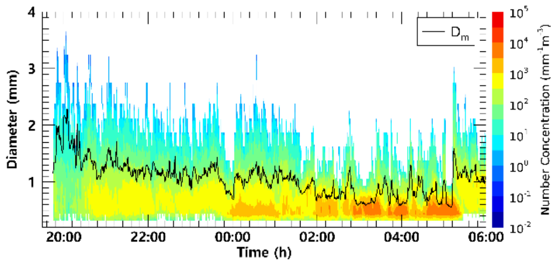
Answer:

As mentioned by the referee, analysis rain cases were added to allow comparison of results for other rainfall cases. By presenting the results of other rainfall cases and the accuracy of rainfall intensity estimation through this manuscript, it will be possible to use it as a reference for future CCTV video-based rainfall estimation research.

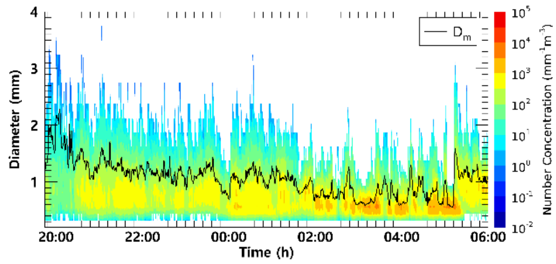
Q17. The Parsivel has its own limitations. How were the data corrected or processed in order to be sure of its measurements to be taken as reference? (example https://doi.org/10.5194/amt-8-343-2015 but other relevant literature on Parsivel data processing is available)

Answer:

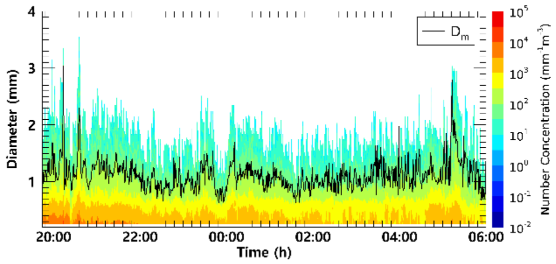
Thank you very much for the referee's very detailed review. We think the quality of this study could be improved through the referee's opinions. The number concentration correction factor of the PARSIVEL disdrometer observation data proposed by Raupach and Berne (2015) was applied to the actual observation data, and the related result figure was modified. Figure 17-1 compares the number concentration distribution before and after applying the correction factors. As a result of applying the correction factors of the number concentration, the number concentration value for the diameter section of 0.2 to 1 mm became smaller, so it can be seen that the difference with the number concentration distribution calculated through CCTV image data is reduced.



(a) PARSIVEL (non-corrected)



(b) PARSIVEL (corrected)



(c) CCTV

Fig. 17-1. Time series of number concentration based on (a) PARSIVEL (non-corrected), (b) PARSIVEL (corrected), (c) CCTV observation data.

*** References**

Raupach, T. H., & Berne, A. (2015). Correction of raindrop size distributions measured by Parsivel disdrometers, using a two-dimensional video disdrometer as a reference. Atmospheric Measurement Techniques, 8(1), 343-365.

Q18. Figure 10 (and discussion): please comment more in -depth about the origin of the extremely large overestimations around 20 LST and 06 LST. I am interested to see exactly how the transition from light to dark affects the data.

Answer:

The rainfall event was taken in the infrared mode under dark conditions. Therefore, we think it is safe to say that the transition effect from light to dark is almost negligible. However, large overestimation around 20 LST and 06 LST seems to have occurred for the following reasons. 1) When there is a lot of rainfall, there are many overlapping rain streaks in an image. 2) The current algorithm recognizes overlapping rain streaks as a single big raindrop. 3) Large-scale raindrops are overestimated in drop size distribution. 4) Rainfall intensity is overestimated. Similar tendency was confirmed in the newly added rainfall event. The discussion in the revised manuscript was added to reflect this issue.

(Revised Manuscript, Lines 371-372)

This may be because the current algorithm recognizes overlapping rain streaks as a single big raindrop.

Revised Manuscript, Lines 436-437)

This tendency was confirmed in case 1 which may be caused by recognizing overlapping rain streaks as a single big raindrop.