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Method for Analysis on Optimization of Averaging Interval of Rainfall Rate Measured by Tipping-Bucket Rain Gauges

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Abstract : Rainfall data from three different types of rain gauge system have been collected for the summertime rain event at Mokpo in the Korean peninsula. The rain gauge system considered in this paper is composed of three tipping-bucket rain gauges with 0.1, 0.2, and 0.5 mm measuring resolutions, the Optical Rain Gauge (ORG), and the PARSIVEL (PARticle SIze and VELocity). The PARSIVEL rainfall rate has been considered as the reference for comparison since it gave good resolution and performance on this event. Comparison with the PARSIVEL rainfall rate gives the results that the error and temporal variation of rainfall rate are simultaneously reduced with increasing the averaging interval of rainfall rate or decreasing the size of tipping bucket. This suggests that the estimated rainfall rate must be optimized, differently for the type of tipping-bucket rain gages, by minimizing the averaging interval of rainfall rate under the condition satisfying the given performance of rainfall rate.

Key Words : Tipping-bucket rain gauge; Optical rain gauge; ORG; PARSIVEL; Averaging interval.

1. Introduction

The tipping-bucket rain gauge is a reliable rainfall measuring instrument that has guaranteed worldwide acceptance. Although it has the mechanical limitation to measure the rainfall rate precisely, this is world widely employed by its low cost and easy maintenance.

Nystuen (1998, 1999) has examined the performance of the six different types of automatic rain gauges including tipping-bucket, weighing, capacitance, optical, disdrometer and acoustical sensors, under different rainfall conditions. The tipping-bucket rain gauge tends to be underestimated for extremely high rainfall rates (over 100 mmh^{-1}) and exhibits a significant instrumental noise for the light rainfall rates (under 2 mmh^{-1}). In his works, the general measurement limitations of rain gauges have been well described, but the optimization of averaging interval of tipping-bucket rain gauge has been not suggested.

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Pikounis *et al.* (2002) have analyzed the factors affecting the estimation of rainfall: the averaging interval, the sampling interval and the bucket volume for the accuracy of a tipping-bucket rainfall rate by the simulation method. They suggested a combination of 15-minute averaging interval and 5-second sampling interval as the optimized rainfall rate for the simulated bucket-type rain gage. Thus, the averaging interval for the real tipping-bucket rain gage measurement is needed to be investigated.

This work is to investigate the optimized averaging interval, simultaneously maximizing the measurement performance and minimizing the peak delay, of the tipping-bucket rainfall rate. We determine the reference of rainfall measurement among the rain gage system components, and then analyze the characteristics of measured rainfall rate against its averaging interval by comparing with the reference.

2. Rain gage system

The rain gauge system including three tipping-bucket rain gauges with 0.1 (TB01), 0.2 (TB02), and 0.5 (TB05) mm bucket, Optical Rain Gauge (ORG), and the PARSIVEL (PARticle SIze and VELocity) was operated for the precipitation event on 22 June 2006 at Mokpo (Fig. 1). All of the rain gauges were located on the Mokpo observation site and the distance between them is 3 - 20 m. Since the 15-min rainfall rates measured within 100 m has $R^2 > 0.9$ (Emad and Witold, 2001), the measurement of rain rate is assumed to be influenced by this distance difference.

1) Tipping-bucket rain gauge

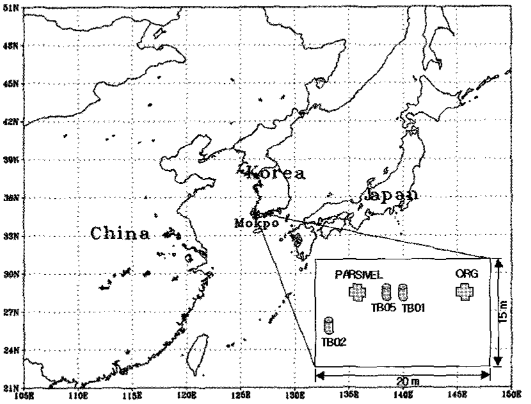

Fig. 1. Location of Mokpo (*) located on the Korean peninsula.

Tipping-bucket rain gauge measures the amount of rainfall by allowing rainwater to flow into a bucket that tips and drains after a given amount of rainwater has been collected. Each tip triggers a magnetic switch that sends a signal to a recording device. TB01, TB02, and TB05 have the tipping bucket corresponding to the 0.1-, 0.2-, and 0.5-mm rainfall accumulation and the 6, 12, and 30 mmh^{-1} of rainfall rate precision for the 1-min interval, respectively. Because of this poor precision for the light rainfall, it is recommended for the tipping-bucket rain gauges to use the averaging interval over 10 - 15 minutes (Nystuen 1998; Pikounis *et al.*, 2002). For the heavy rainfall, the abruptly large water flow into the bucket during the tipping time may bring about the loss of measured rainfall, and this type of rain gage underestimates the rainfall rate.

Compared with the optical instrument, the tipping-bucket rain gauge has the limitation for the measurement of both the light and heavy rainfall. On the other hand, in the high wind speed of values over 5 ms^{-1}, it is reported a limit that optical instruments overestimate the rainfall rates due to over-sampling problem and fringe effect (Löffler-Mang and Joss 2000; Smith *et al.* 1993).

2) Optical rain gauge (ORG-805)

Optical rain gage (ORG) measures the intensity variation produced by the shadows of raindrops falling between a light source and an optical receiver (Wang and Clifford 1975; Wang *et al.* 1977, 1978).

The intensity variation caused by natural raindrops is proportional to rainfall rate (Wang *et al.* 1978). The ORG-805 model built by Scientific Technologies, Inc, has the LED source modulated at 50 kHz in the near infrared (0.85 μm) and a beam length of 0.86 m, giving effective catchments areas of 308 cm^2.

3) PARSIVEL

PARSIVEL disdrometer (Löffler-Mang and Joss 2000; Löffler-Mang and Blahak 2001) is also an optical sensor designed to measure the actual drop size distribution during rain. A laser diode produces a horizontal sheet of light 30 mm wide, 180 mm long, and 1 mm high. The horizontal sampling area is 54 cm^2, which is similar to the 50 cm^2 sampling area of the Joss-Waldvogel disdrometer (Waldvogel 1974). The laser light is received at a photo diode that samples at 50 kHz. When particles pass through the light sheet, a portion of the transmitted laser light is blocked and the voltage produced by the photo diode is reduced compared to when no particles are present in the beam. The amplitude and duration of the voltage drop are related to the size and fall speed of the particle, respectively. The particle size and fall speed for every particle detected over the measuring period are tabulated in an array whose dimensions are the number of size bins by the number of fall speed bins. A spheroid model derived from Andsager *et al.* (1999) is used to estimate the size of the particles as a function of voltage reduction. For a detailed description of the instrument, see L?ffler-Mang and Joss (2000).

3. Results

While both the estimated rainfall rates of ORG and PARSIVEL have the high resolution of 0.001 mmh^{-1}, the tipping-bucket rain gauge has the low resolution: 6, 12, and 30 mmh^{-1} for the 0.1-, 0.2-, and 0.5-mm bucket, respectively. Therefore, we will consider one of the optical instruments as the reference of rainfall measurement rather than the tipping-bucket rain gauge, under the condition that the wind speed is less than 5 ms^{-1}.

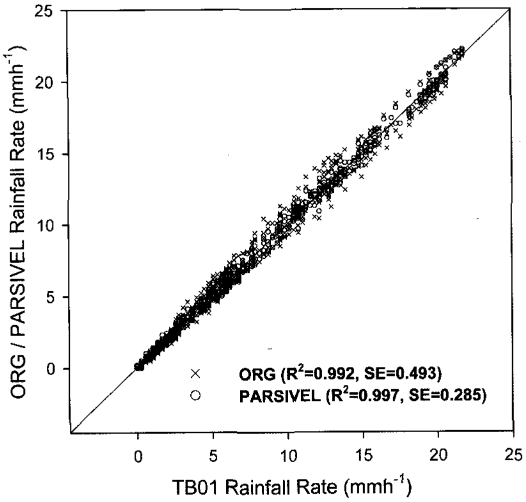

Fig. 2. Scatter diagram of the 30-min averaged ORG (X) and PARSIVEL (O) rainfall rate versus the TB01 one. The SE denotes a standard error and solid line is the linearly fitted line.

To find a reference of the rain gauge system components, the 30-min averaged rainfall rates of ORG and PARSIVEL are compared against that of TB01 for the event of 22 June 2006 (Fig. 2). The rainfall rate measured by the PARSIVEL gives the better agreement with that of TB01 than that of ORG. Thus, the PARSIVEL rainfall rate, showing the better measuring precision and agreement with that of TB01, is considered as the reference of measured rainfall for this precipitation event hereafter.

Fig. 3 shows the time series of the PARSIVEL and ORG rainfall rate and the wind speed during the considered event. In Fig. 3a, the rainfall rate of PARSIVEL has good agreement with that of ORG except for the peaks above the 20 mmh^{-1} of rainfall rate. This deviation of the ORG rainfall rate from the PARSIVEL one shows an effect of the uncertainty by

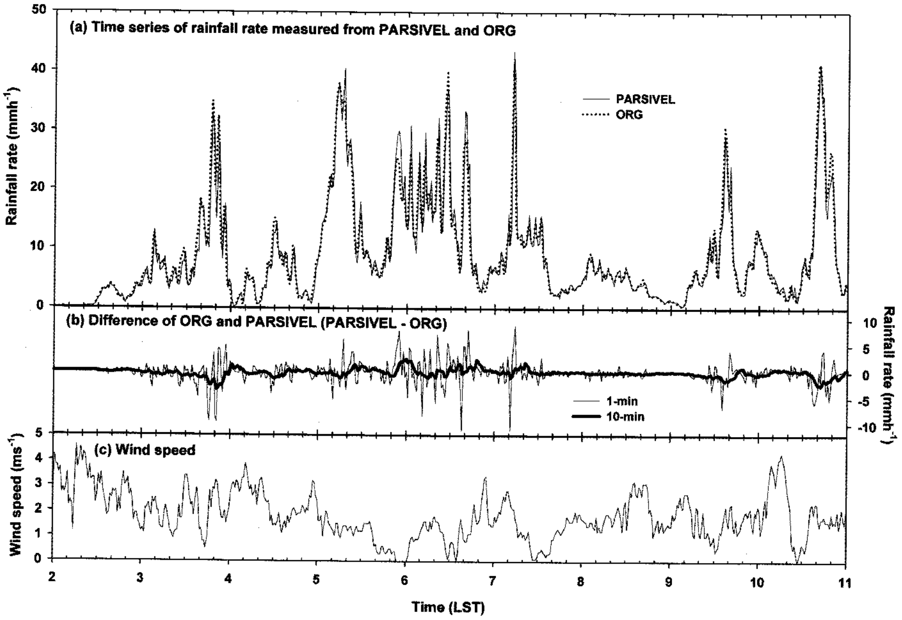

Fig. 3. Rainfall rate measured by PARSIVEL and ORG; (a) Time series, (b) difference of the rainfall rate, and (c) wind speed at Mokpo for a precipitation event on 22 June 2006. In (a), the solid and dotted lines denote the rainfall rate of PARSIVEL and ORG, respectively. In (b), the light-solid and bold-solid line denote the 1-min and 10-min averaged rainfall rates, respectively.

the larger sampling space of ORG. In Fig. 3b, it is shown that this difference above 20 mmh^{-1} may be reduced at higher averaging interval. Since the horizontal wind speed is always less than 5 ms^{-1} during the period of considered case (Fig. 3c), the overestimation problem of optical instrument (Löffler-Mang and Joss 2000; Smith *et al.* 1993) may be neglected for this precipitation event.

Fig. 4 shows the ORG estimate of rainfall rate against that of PARSIVEL with increasing averaging interval. The standard error for the 1-, 10-, 30-, and 60-min averaging interval are 1.522, 0.525, 0.347, and 0.280 mmh^{-1}, respectively. It is well shown that the deviation of data from the fitted line is linearly reduced with increasing averaging interval. This suggests that the 30-min accumulated rainfall rate of ORG as well as that of the PARSIVEL may be considered within the 0.4 mmh^{-1} of standard error as another reference of rainfall rate.

Fig. 5 shows the sensitivity of the measuring resolution and averaging interval of tipping-bucket gage on the rainfall measurement. In Fig. 5, it is well shown that the correlation coefficient (R^2) and standard error of tipping-bucket rainfall rate against those of PARSIVEL are getting better with increasing the averaging interval or decreasing the volume of tipping bucket. The step-like scatter behavior, due to the resolution limitation of tipping-bucket gage, is well appeared with increasing the bucket size, as well shown in Fig. 5a, b, and c. Also, the spread from the linearly fitted line goes narrow with increasing averaging interval, as well shown in Fig. 5c, f, and l.

With increasing averaging interval of rainfall rate, the reliability of rainfall rate increases but its temporal variation becomes weak. Fig. 6 shows that the temporal sensitivity of rainfall rate decreases with increasing averaging interval. Moreover, it is shown that there is the peak delay problem that the rainfall rate was delayed according to the averaging interval

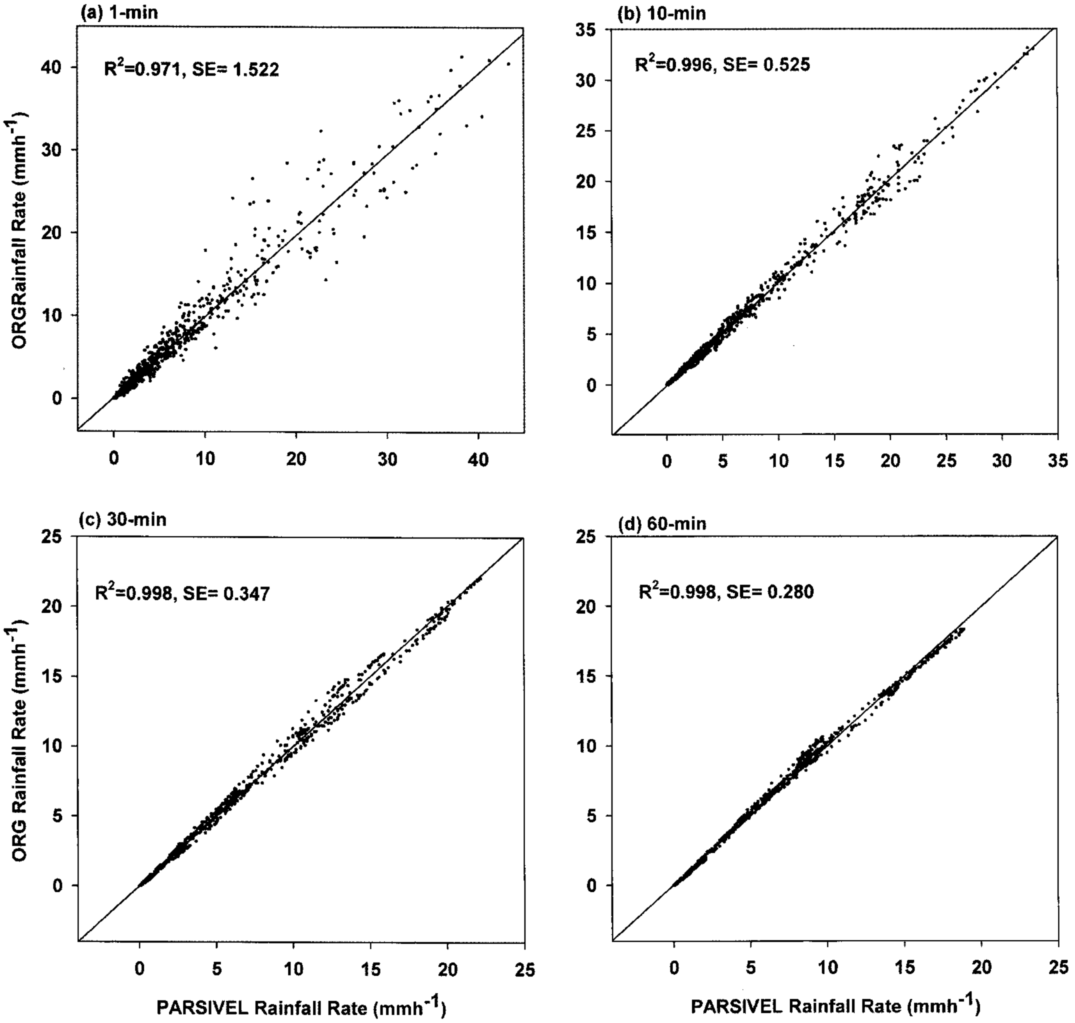

Fig. 4. Comparison between the ORG rainfall rate versus the PARSIVEL one for the (a) 1-min, (b) 10-min, (c) 30-min, and (d) 60-min averaging interval. The solid line shows the linearly fitted line.

and smoothed several rainfall peaks to one peak or less than that of them. The peak of the 1-min rainfall rate was recorded at 0512 LST, but the 10-, 30-, and 60-min rainfall rates have the peak at 0520, 0530, and 0602 LST, respectively. Comparing with the 1-min rainfall rates, the 30- and 60-min averaging rainfall rates show the smoothed and delayed peaks evidently.

To preserve the performance of rainfall rate and reduce the peak delay problem, it is important to find the optimized averaging interval of the tipping-bucket rain gauges. In Fig. 7, the correlation coefficient and RMSE (Root-Mean-Square-Error) between the tipping-bucket rain gauges and PARSIVEL against the averaging interval is shown, which may give guidance for the tipping-bucket rainfall rate. For example, if we admit the correlation coefficient over 0.98 and RMSE below 1 mmh^{-1}, it may be recommended that the optimized averaging interval for the rainfall of TB01, TB02, and TB05 be 8 minutes, 12 minutes, and 20 minutes, respectively in Fig. 7a and 7b.

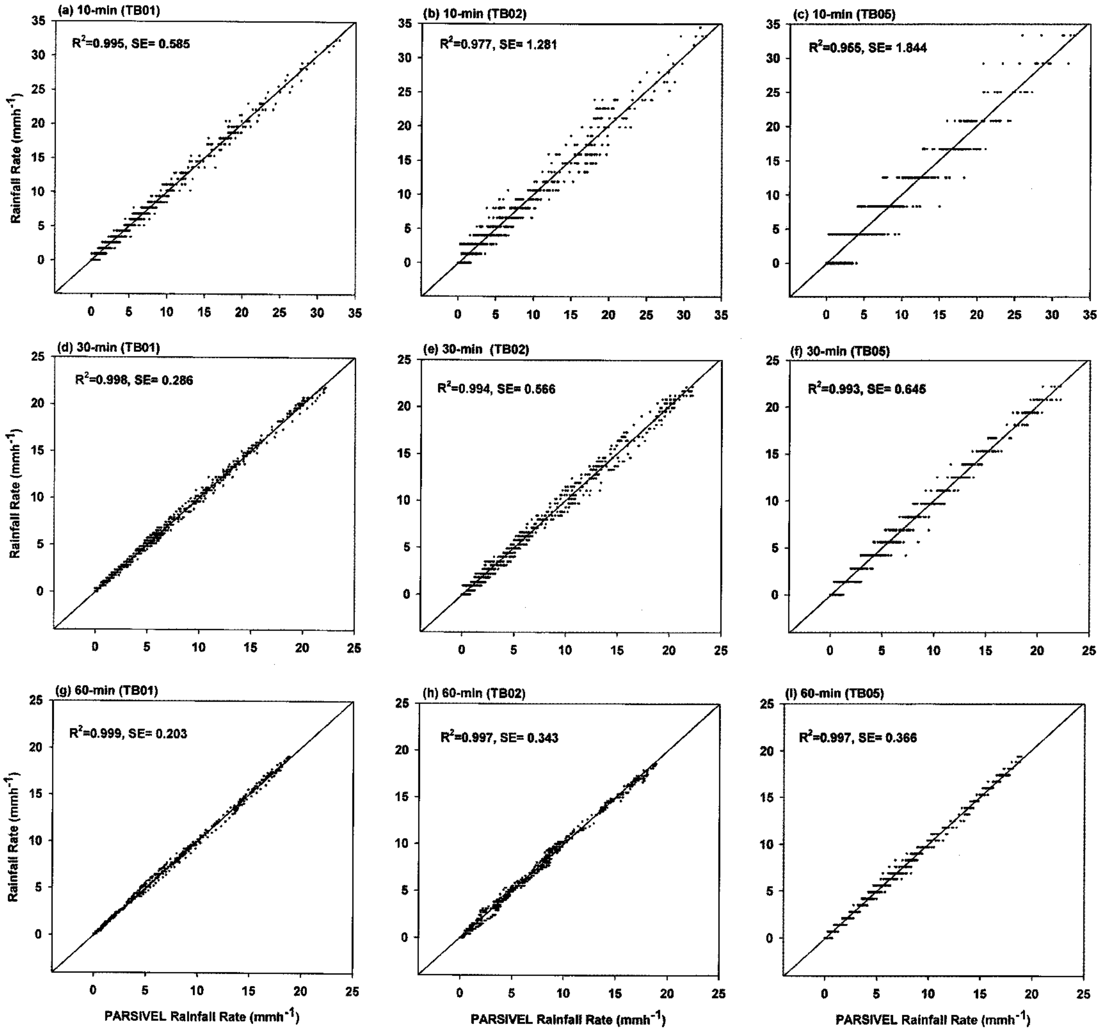

Fig. 5. Comparison of the tipping-bucket (TB01; the left panel, TB02; the middle panel, and TB05; the right panel) measured rainfall rates with the averaging interval of rainfall during the precipitation event. The upper (a, b, and c), middle (d, e, and f), and lower (g, h, and i) are the 10-, 30-, and 60-min averaged rainfall rate, respectively. The solid line is the linearly fitted line.

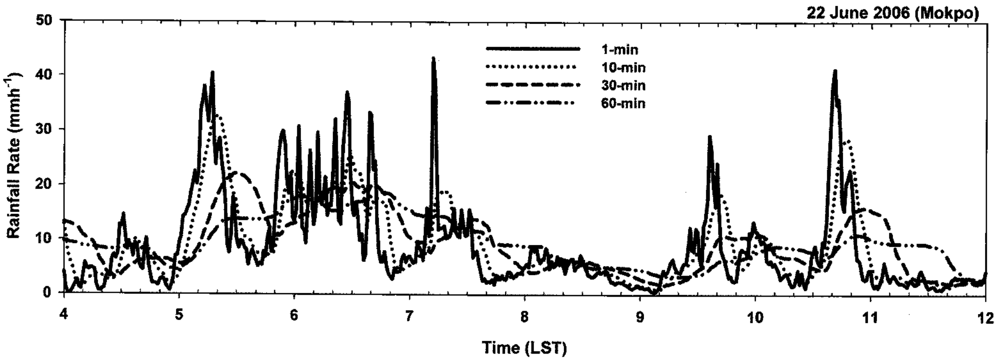

Fig. 6. Time series of rainfall rates estimated by PARSIVEL. The solid, short-dotted, dashed, and dash-dotted lines denote the 1-, 10-, 30-, and 60-min averaged rainfall rates, respectively.

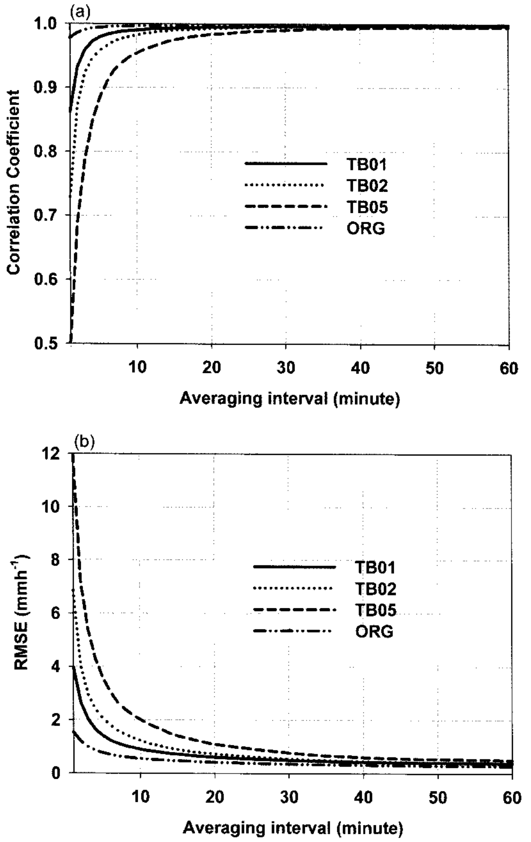

Fig. 7. (a) Correlation coefficient (R^2) and (b) RMSE of the tipping-bucket rain gauges and ORG rainfall rate with respect to the PARSIVEL one versus the averaging interval. The solid, dotted, dashed, and dash-dotted lines denote the corresponding values of the tipping-bucket rain gauges (0.1 mm, 0.2 mm, and 0.5 mm) and ORG, respectively.

4. Conclusion

Rainfall data collected for the summertime event on 22 June 2006 at Mokpo of South Korea have been investigated to understand the limitation of the tipping-bucket rain gauges. The PARSIVEL rainfall rates were considered to be the reference for comparison for the precipitation event because they present the best accuracy. The smallest averaging interval of rainfall rate is favorable to minimize such as the peak delay problem, but the observation performance increases with increasing averaging interval discriminatively for each rain gauge, as shown in this work. Therefore, we note that the practical averaging interval of rainfall rate must be differently optimized for each tipping-bucket rain gauge. It is recommended that the optimized averaging interval of TB01, TB02, and TB05 is 8, 12, and 20 minutes, respectively at less than 5.0 m/s wind speed.

Acknowledgements

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