P2.3 **Performance of drop-counting rain gauges in an operational environment**

P.W. Chan * and C.M. Li
Hong Kong Observatory, Hong Kong, China

1. INTRODUCTION

Located at a subtropical coastal area, it is quite common for Hong Kong to be affected by torrential rain associated with surface troughs of low pressure, southwest monsoon and tropical cyclones. The instantaneous rainfall rate could reach several hundreds of millimetres per hour (mm/h). At the same time, in accordance with the recommendation of the World Meteorological Organization (WMO, 2008), the rainfall intensity should be reported at a resolution of 0.1 mm/h and an uncertainty of 0.1 mm/h for 0.2 to 2 mm/h and 5% for rainfall intensity greater than 2 mm/h. It is not straightforward to look for a rain gauge fulfilling both requirements.

For operational rainfall measurement at the synoptic station in Hong Kong (which is the weather station at the Hong Kong International Airport, HKIA), a drop-counting rain gauge has been selected. By using an optimal drop size value, it has been shown in Chan and Yeung (2004) that the rain gauge measures at 0.1 mm resolution up to a rainfall rate of 100 mm/hour fulfilling the accuracy requirement in WMO (2008). However, considering the rain drop formation mechanism inside this rain gauge, it is anticipated that there may be random error in the rainfall measurement associated with the drop size variability. However, direct verification of this random error by measuring the size (or volume) of each rain drop formed inside the rain gauge may not be practical, especially when rain drop formation is abrupt at high rainfall rates.

To ensure the continuous availability of rainfall data to support the operation of the Hong Kong synoptic station, three identical drop-counting rain gauges have been working at HKIA since the middle of 2007. All the three gauges have been regularly maintained and calibrated (calibration frequency is once per year, following the procedure described in Chan and Yeung (2004)). The variability of rainfall measurement among the three gauges may provide an indication of the random error associated with this type of rain gauge because of its intrinsic design. It is the subject of the present study, following the method described in Ciach (2003).

2. RAIN GAUGE AT HKIA

The internal design of the rain gauge under study is shown in Figure 1. This gauge has a reservoir between the water collecting funnel and the drop formation device. The reservoir is always maintained full to ensure a practically constant static water pressure for water drop formation. Rain collected at the funnel first flows into the bottom of the reservoir, displacing the water inside the reservoir which then flows out at the top through a tube. At the other end of the tube, water drops are formed at a nozzle. According to the manufacturer's specification, a drop corresponds to a rainfall of 0.01 mm. The total rainfall is determined by counting the number of drops passing through an optical counter. The manufacturer states that the gauge is capable of making measurements at rainfall rates reaching 200 mm/h.

The rainfall data output from the rain gauge is in the form of electrical pulses. An in-house electronic device has been devised to count the pulses and pass on the pulse number f (drops per hour) to a personal computer for further data processing and archival. An optimal drop size is obtained during routine calibration of the rain gauge. It is chosen so that the rainfall measurement could fulfill the accuracy requirement of WMO (2008) over the largest possible range of rainfall (starting from a rainfall rate of nearly zero). The determination of the optimal drop size v (mm^3/drop) is described in Chan and Yeung (2004). Rainfall rate r (mm/hour) is then determined by:

$$r = v \bullet f / A \qquad (1)$$

where A (mm^2) is the area of the gauge orifice. The orifice of the rain gauge at HKIA has a diameter of 152.4 mm (6 inches).

The three identical drop-counting rain gauges at HKIA are set up in the form of a triangle (Figure 2). They are separated by a distance of about 1.68 m from each other. The pulses from the three gauges are sampled at the same time at a frequency of about 30 Hz. At the data processing and archival computer, the rainfall data are time-stamped simultaneously and as such there is no time offset problem among the data series of the three gauges.

3. ANALYSIS OF THE LOCAL RANDOM ERROR

The analysis method is described in detail in Ciach (2003). Only a summary of the major equations adopted in the present study is described. For a given time interval T, the rainfall data from a single rain gauge is denoted by $R_{1,T}$. The average of the rainfall from the three gauges, viz. $R_{3,T}$, is considered to give an indication of the "true" rainfall with the local random error being averaged out. Of course, in comparison with the study by Ciach (2003) in which 15 identical tipping bucket rain gauges were employed, the use of just 3 gauges in the present study appears to have a much smaller sample of rainfall data only. However, to the knowledge of the authors, it is not common to have three identical rain gauges to work in an operational environment and their average rainfall is anticipated to have better representation of the "actual" rainfall amount compared to a single gauge.

The local rain gauge error is defined by the

* *Corresponding author address:* P.W. Chan, Hong Kong Observatory, 134A Nathan Road, Hong Kong email: pwchan@hko.gov.hk

following expression:

$$e_{1,T} = \frac{R_{1,T} - R_{3,T}}{R_{3,T}} . \tag{2}$$

A plot of the above quantity against the "true" rainfall would in general appear to be rather scattered. For high rainfall rates, some residual scatter still persists. For a more quantitative description of the local random error, a nonparametric regression estimation of the standard deviations of $e_{1,T}$ as a function of the "true" local rainfall intensity is performed. Following Ciach (2003), the Nadaraya-Watson kernel regression estimator is used, and the standard deviation expression is given by:

$$\sigma_K^2(T, R_T) = \frac{\sum k(\frac{R_{3,T} - R_T}{h}) \bullet e_{1,T}^2}{\sum k(\frac{R_{3,T} - R_T}{h})} \tag{3}$$

where R_T is a given local rainfall rate value, $h = a\ R_T$, a = 0.2 and the summation is made over all the available rainfall data *k(.)* is called the smoothing kernel, and the Epanechnikov kernel is employed here:

$$k(x) = \begin{cases} 0.75(1 - x^2), x \in [-1,1], \\ 0, x \notin [-1,1]. \end{cases} \tag{4}$$

4. ANALYSIS RESULTS

The rainfall data collected by the three drop-counting rain gauges at HKIA between 4 June 2007 and 30 September 2008 are considered, i.e. over a period of about 1 year and 3 months. A typical diagram of the average standard error (i.e. σ_K calculated from Equation (3) but with k(.) = 1 all the time) against the "true" (or average) rainfall rate is given in Figure 3 (for a rain accumulation time interval T = 50 minutes). It could be seen that the data points are rather scattered, which makes further statistical analysis of the results quite difficult. As such, nonparametric estimation method is adopted. Figures 4(a), (c) and (e) show the nonparametric estimate of the local standard error for three accumulation time intervals, namely, 1 minute, 10 minutes and 50 minutes. In the present study, the accumulation time interval up to 60 minutes is considered because in practice it is quite common to look at rainfall amount within a period of 1 minute up to 1 hour. In general, it is observed that, for a particular accumulation time interval, the nonparametric estimate value drops with increasing rainfall rate, as fitted by the logarithmic curves (black curves) in Figures 4(a), (c) and (e).

To describe the trend of σ_K against R_T in a more concise mathematical manner, the standard error σ_K is represented by the analytical model σ_m by the following expression as in Ciach (2003):

$$\sigma_m(T, R_T) = e_0(T) + R_0(T)/R_T \tag{5}$$

where e_0 and R_0 are the model coefficients that depend on the timescale T. Parameter R_0 determines the scale at which the standard error drops with increasing R_T and e_0 is the residual standard error at high rainfall rates. Figures 4(b), (d) and (f) show the same data points in the corresponding Figures 4(a), (c) and (f) but with the fitting by the mathematical model Equation (5). The variation of R_0 and e_0 with timescale T for the dataset considered in the present study is given in Figures 5(a) and (b) respectively.

5. COMPARISON WITH THE RESULTS OF A TIPPING-BUCKET RAIN GAUGE

The major results of this study are given in Figure 5, and they are compared with the corresponding graphs for the tipping-bucket rain gauge considered in Ciach (2003).

The two rain gauges have slightly different characteristics for coefficient e_0. In Ciach (2003), this residue standard error at high rainfall rate drops steadily with longer timescale T by a factor of about 10 over the range of accumulation time under consideration. That is to say, when a longer rain accumulation time is considered, the standard error of the tipping-bucket rain gauge under consideration would become smaller. This may be due to the fact that, with a longer accumulation time, the time-sampling effect caused by the discrete character of the tipping bucket measurement would become less significant. On the other hand, as shown in Figure 5(b), the standard error of drop-counting rain gauge has a smaller rate of decrease with timescale T (less than a factor of 10 for the range of accumulation time under consideration). The reason for this behaviour is not known. One possibility is that the local random error of this kind of rain gauge is associated with the *intrinsic* variability of the size of rain drops formed within the gauge, and this variability does not decrease so fast with the rain accumulation time under consideration. The coefficient e_0 is in the order of 0.02 to 0.06. It is smaller than that of the tipping-bucket rain gauge in Ciach (2003) up to a timescale of about 3 minutes. For a longer accumulation time, the residue local error of the drop-counting rain gauge is larger.

6. CONCLUSIONS

The local random error of a drop-counting rain gauge is studied in this paper following the approach adopted by Ciach (2003) for a tipping-bucket rain gauge. It is found that the drop-counting rain gauge has slightly different behaviour in the residue local error, viz. it does not fall as fast with the rain accumulation time scale. The real reason for this behaviour is not certain. One possibility is that it is related to the intrinsic variability of the size of rain drop formed within the gauge, which depends on the particular rain drop formation mechanism for the gauge under consideration. To test this hypothesis, it would be ideal to really measure the size of each drop formed inside the rain gauge. Nonetheless, the results of the present study indicate that a drop-counting rain gauge may perform better than a tipping-bucket rain gauge for a rain accumulation time up to a few minutes, in terms of the magnitude of the residue local error. Please note that the present study is based on a small number of rain gauges only (three gauges) and a more comprehensive study may require a larger number of gauges – something comparable with that in Ciach (2003). Moreover, the results in this paper are preliminary only and further quality control of the rainfall data might be performed.

References

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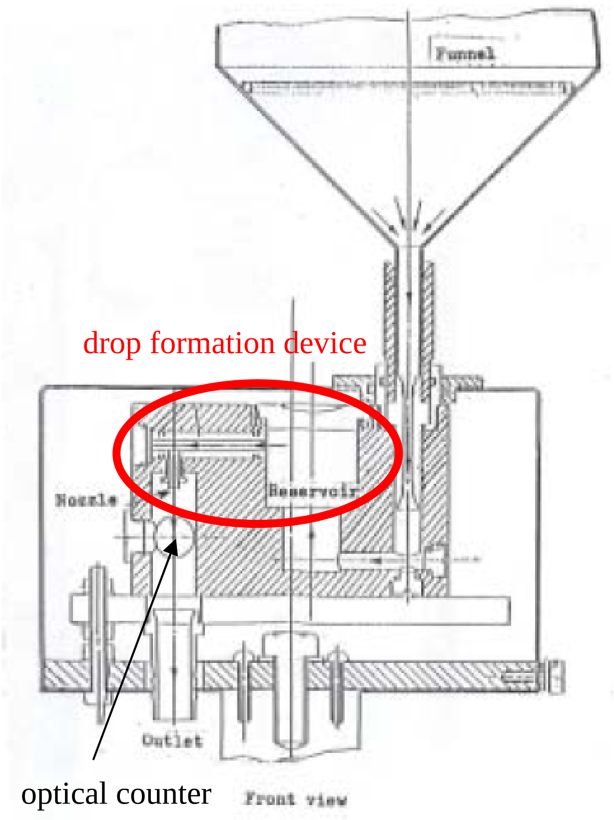


Figure 1 Internal structure of the rain gauge under the present study.

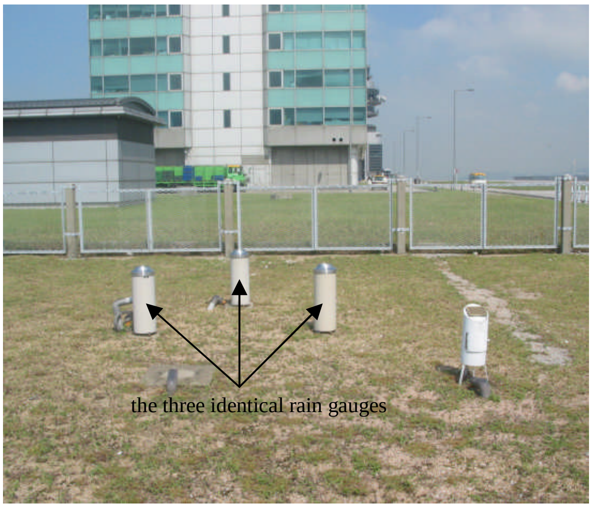


Figure 2 The setup of three identical rain gauges inside the meteorological garden at HKIA.

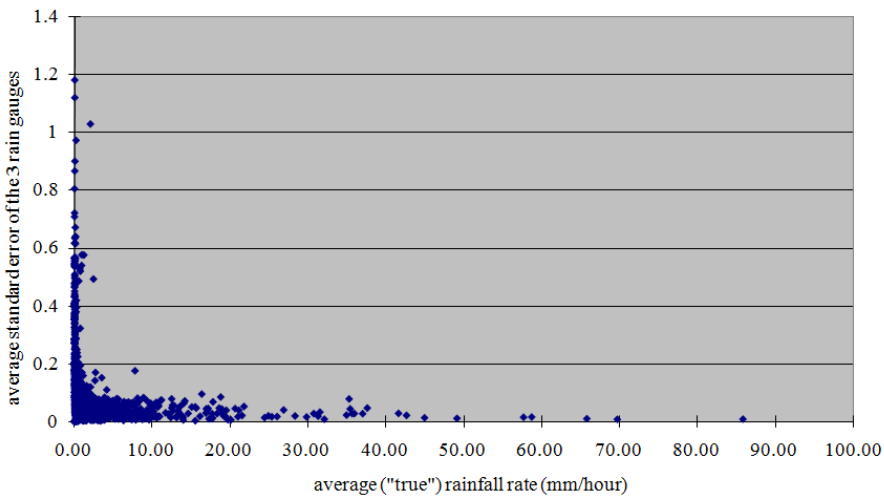
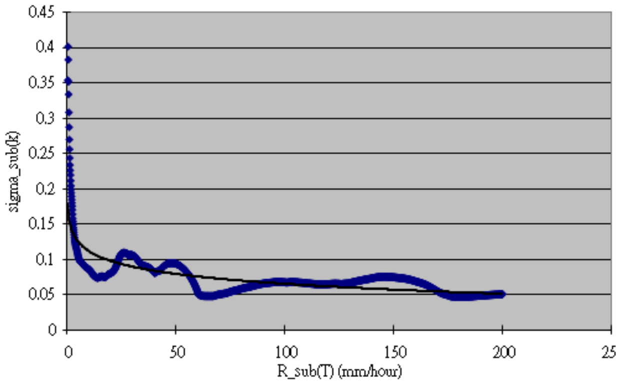
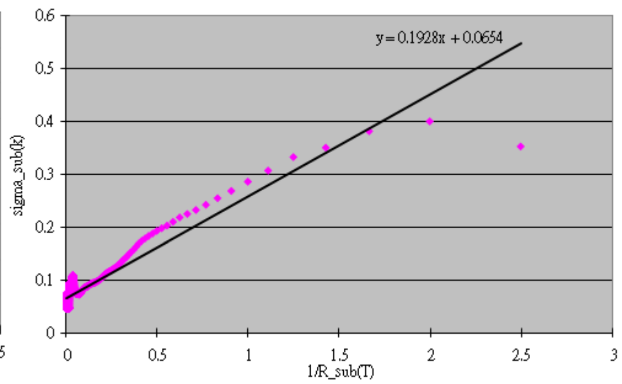


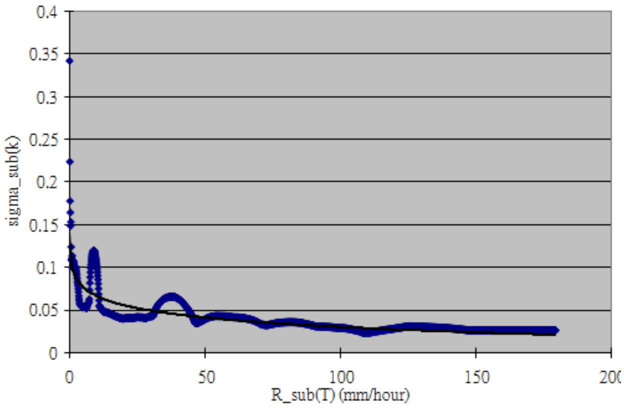
Figure 3 Average standard error of the 3 rain gauges as a function of the average ("true") rainfall rate for an accumulation time of 50 minutes.



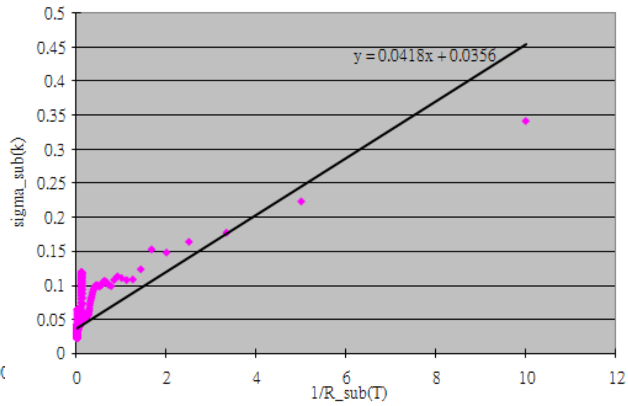
(a) 1 minute



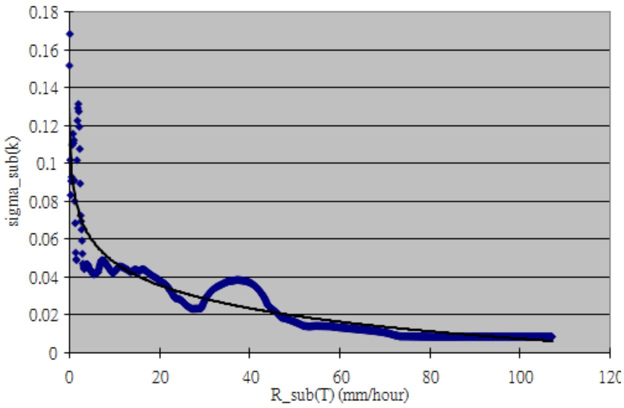
(b) 1 minute



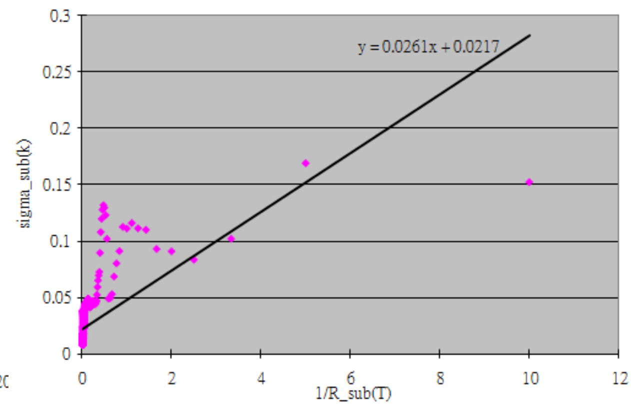
(c) 10 minutes



(d) 10 minutes

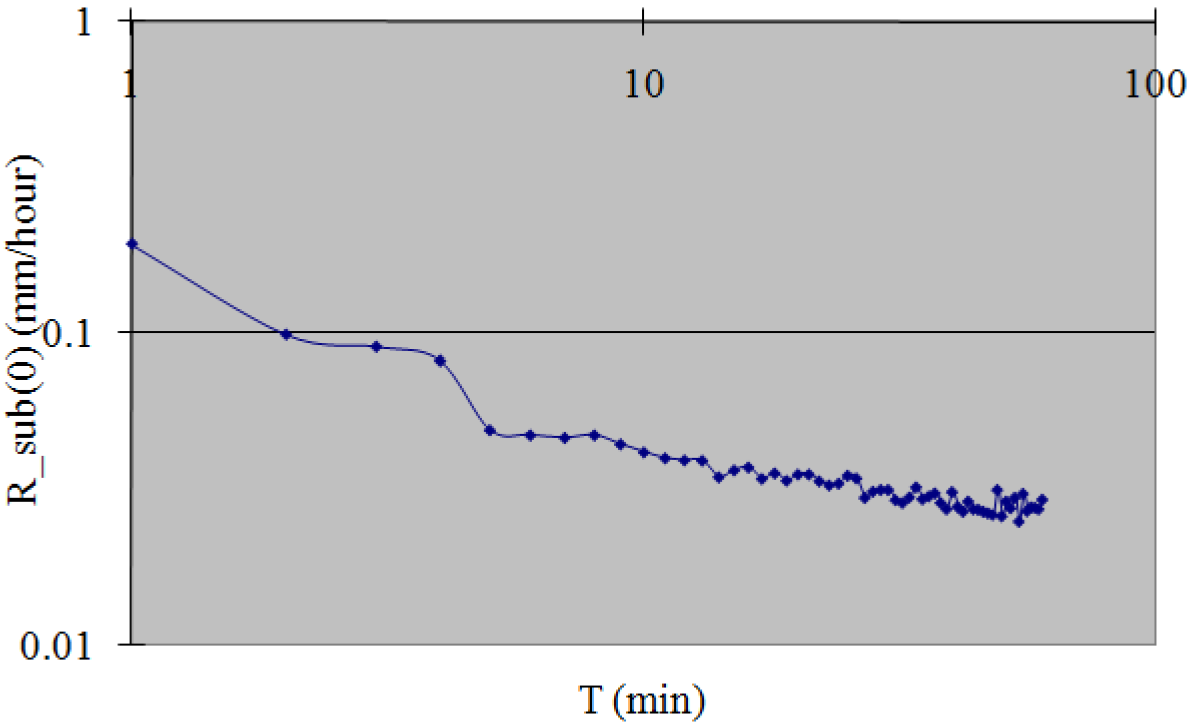


(e) 50 minutes

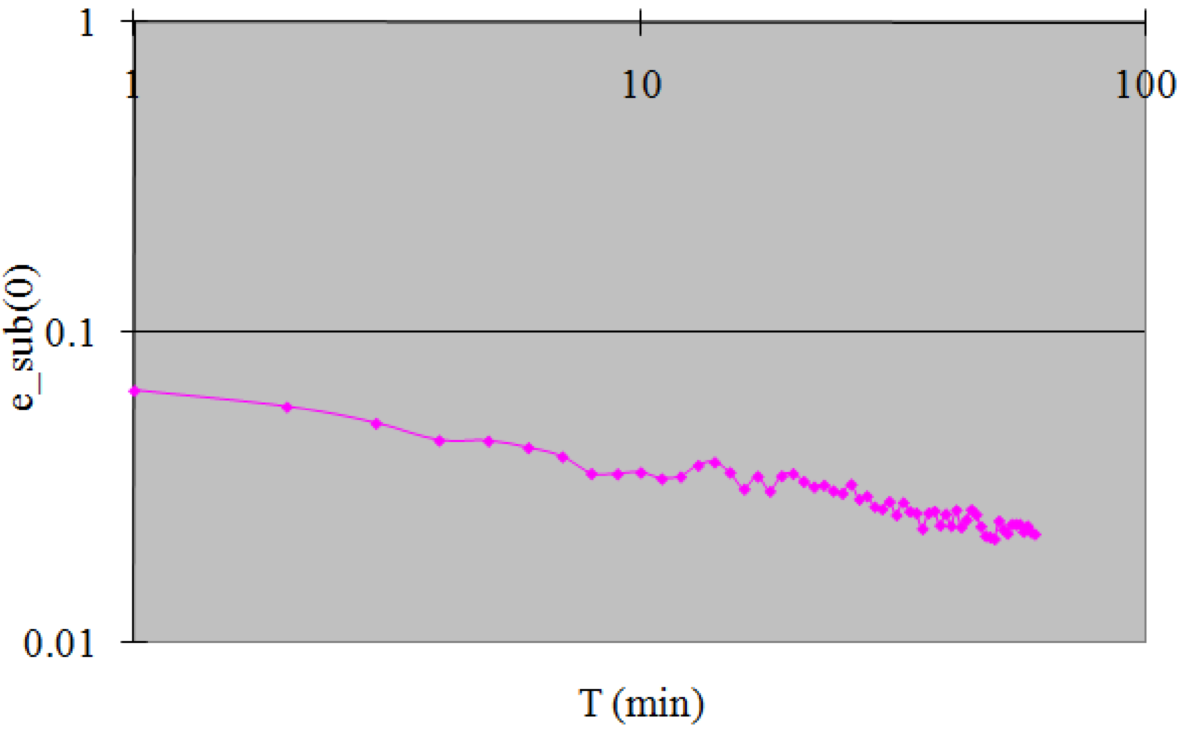


(f) 50 minutes

Figure 4 For the three accumulation times (1 minute, 10 minutes and 50 minutes), (a), (c) and (e) give the nonparametric estimate of the local standard error as a function of the rainfall rate with the best-fit logarithmic curves; (b), (d) and (e) show the same set of data but with the x variable being the inverse of rainfall rate, together with the best-fit straight line and its equation.



(a)



(b)

Figure 5 (a) R_0 and (b) e_0 in Equation (5) as a function of the accumulation time T.