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Inter-Comparison of Automatic Rain Gauges

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The Ocean Acoustics Division (OAD) of the Atlantic Oceanographic and Meteorological Laboratory (AOML), in cooperation with NOAA/NESDIS and NASA, has deployed six rain gauges for calibration and inter-comparison purposes. These instruments include: 1) a weighing rain gauge, 2) a RM Young Model 50202 Capacitance Rain Gauge, 3) a ScTI ORG-705 (long-path) Optical Rain Gauge, 4) a ScTI ORG-105 (mini-ORG) Optical Rain Gauge, 5) a Belfort Model 382 Tipping Bucket Rain Gauge, and 6) a Distromet RD-69 Disdrometer. The system has been running continuously since July 1993. During this time period, roughly 150 events with maximum rainfall rate over 10 mm/hr and 25 events with maximum rainfall rates over 100 mm/hr have been recorded. All rain gauge types have performed well, with inter-correlations 0.9 or higher. However, limitations for each type of rain gauge have been observed.

OAD is interested in determining the accuracy of the rainfall rate measurement over relatively short time intervals. The optical rain gauges (ORGs) are designed to measure rainfall rate directly via optical scintillation, however there is an Automatic Gain Control (AGC) with an exponential time filter constant of 10 seconds built into the mini-ORGs. This filter limits the temporal resolution of the mini-ORGs to roughly 20 seconds. The weighing and capacitance gauges' measurement of rainfall rate is controlled by the flow rate (or dripping) of rainwater from the catchment basin into the measurement reservoir for each intstrument. The nature of this "dripping" controls the accuracy of the rainfall rate measurement. It was found that a smoothing filter with a time constant of about one minute was necessary to remove noise associated with the dripping. The one minute rainfall rate accuracy for the weighing and capacitance rain gauges is about 1 mm/hr, although the capacitance rain gauge recorded isolated rainfall rate errors associated with large "drips" of more than 10 mm/hr. The tipping bucket rain gauge has a minimum one minute rainfall rate precision of ± 12 mm/hr (one tip in one minute) and was not used to study rainfall rate. The disdrometer has a built-in time resolution of one minute. To facilitate inter-comparison of data, all rainfall rate data were processed to one minute time resolution.

One feature unique to the ORGs was the background voltage level. The ORG rainfall rate measurement is based on the scintillation of an optical NIR beam ($\lambda = 0.85$ µm wavelength). In fact, the total voltage variance measured is the sum due to rainfall, background turbulence, and electronic noise. In the absence of rainfall, the voltage variance due to background turbulence and electronic noise can be falsely interpreted as rainfall. By properly chosing a minimum threshold, one should be able to avoid false data, however the upper limit of the equivalent rainfall rate due to noise is variable. In January, this level exceeded 1 mm/hr on 3 occasions for over 6 consecutive hours (Fig. 1). Dr. Wang (ScTI) suggested that this was due to dew collecting on the receiver lens. Dew on the receiver lens would cause attenuation of the optical beam and cause the AGC circuit to amplify the receiver's signal, amplifying the noise and resulting in a high equivalent rainfall rate. Note that ScTI does not believe that a variable AGC level should affect the rainfall rate measurement. This is an issue which should be examined more carefully.

Figure 2 shows a comparison of accumulation totals for 33 rain events during September and October. The accumulation totals are highly correlated with the capacitance and tipping bucket rain gauges biased slightly low relative to the weighing rain gauge and the ORGs biased high by 10-20%. The tendency of the ORGs to bias high is also evident in Figure 3. Fig. 3 shows a comparison of 1 minute rainfall rate estimates between the ORG-105 (mini-ORG) and the weighing rain gauge during 5 convective events. Note the high correlation coefficient ($r = 0.98$). The slope of the regression is 1.14 (14% bias high). For the ORG-705 (long-path), the correlation coefficient was $r = 0.97$ and the regression slope was 1.23. For both instruments the scatter about the mean regression was roughly ± 20%. Figure 4 shows that the regression slopes for several individual events (indicated by Julian date) are widely scattered about the September mean value. This scatter is unrelated to the background voltages (AGC values?) of the ORGs on the days of the rain events. This result suggests that after the ORGs are corrected for a mean bias, for any given event, the rainfall estimate is still ± 20%. Within a single event, this statement still holds. Figure 5 shows rainfall rate estimates during Event 275. The capacitance, weighing, disdrometer agree closely, while the short and long-path optical gauges show more variance.

It has been suggested that variations in the drop size distribution are responsible for the ± 20% disagreement between the ORGs and the other gauges. To investigate this possibility, the disdrometer data from Event 275 was examined. During the first minutes of this event (see Fig. 5), the rainfall rate increased rapidly with many very large (over 3 mm diameter) raindrops present (Minutes 2-8). During Minutes 8-20, very heavy (convective) rainfall was present, which was followed by low rainfall rates (stratiform rain) from Minutes 21-100. Figure 6 shows the percentage rainfall rate error [(ORG-105 minus Weighing)/Weighing] of the mini-ORG compared to the weighing rain gauge. During the initial minutes (Min 2-8) of the event, the error is ± 50%. During the heaviest rainfall rates (Min 8-20), the error is ± 20%. During the light drizzle (Min 21-100), the relative error can be very high (± 300%), however the absolute error is relatively small. The tendency of the ORGs to overestimate light rainfall rates is possibly due to the background noise levels (the AGC issue). ScTI suggested that the optimal dynamic range of the ORGs could be adjusted to provide better "low end" sensitivity.

Using the disdrometer data, it is possible to calculate different moments of the drop size distribution. These moments are given by:

$$M_x = \sum_{i=1}^{20} D_i^x \cdot dsd(D_i)$$

where $dsd(D_i)$ are the disdrometer data in 20 drop size categories. Some of the moments are proportional to physically significant quantities. For example, M_0 is the number of drops per unit volume, M_2 is proportional to the cross-sectional area of the rain (mm^2/m^3), $M_3 = M$ is the liquid water volume, $M_{3.6}$ is proportional to R, the rainfall rate, and M_6 is reflectivity (radar). By theory, the ORGs should correlate most highly to the moment associated with rainfall ($x = 3.6$) (Wang, pers. comm.). Fig. 7 (ORG-105) and Fig. 8 (ORG-705) show the correlation between the moments of the drop size distribution and the ORG rainfall rate estimate for six individual rainfall events. The mini-ORG (Fig. 7) tends to correlate most highly to a lower moment of the drop size distribution than rainfall, while the long-path ORG correlates most highly to a higher moment. On an event by event basis, the ORG-105 correlates most highly to a lower moment of the drop size distribution than the ORG-705. ScTI noted that the optical source used in the ORG-105 (mini-ORG) is less coherent than for the ORG-705. A less coherent source would imply a more diffuse shadow and thus a smaller signal per raindrop. Apparently the incoherent optical source affects the signal from the larger raindrops more than that of the smaller raindrops. It should be noted that the overall correlation levels in Figs. 7 and 8 are very high for all events ($r \sim 0.95$).

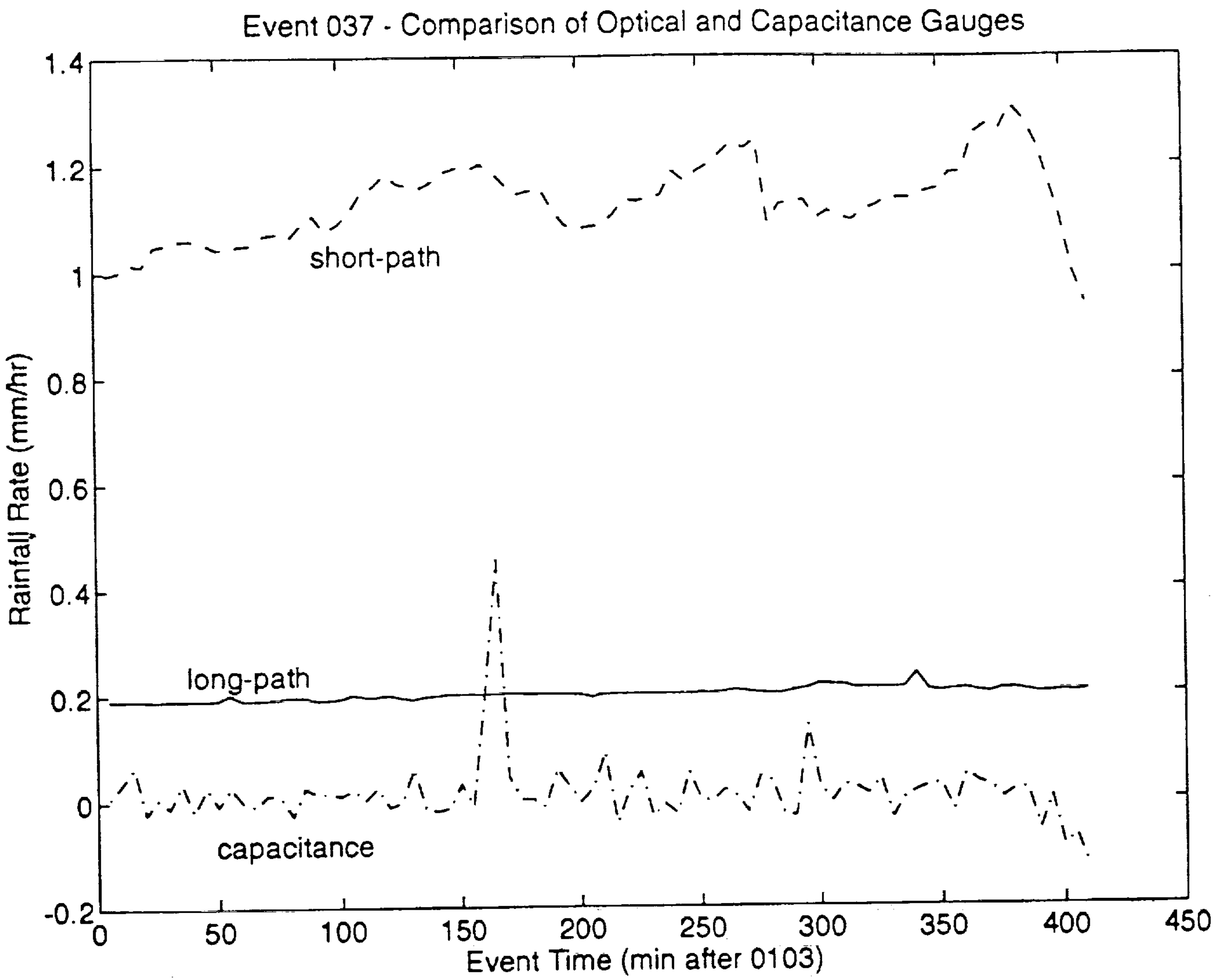


Figure 1. A time series showing the temporal variation in the equivalent rainfall rate due to background turbulence and electronic noise. The ORG-105 (short-path) is reading above 1 mm/hr. ScTI suggests that dew collecting on the receiver lens causes the AGC circuit to amplify the background noise levels. The ORG-705 (long-path) does not show high levels. The ORG-705 has a heater on the lens to prevent dew build up. The acoustic rainfall sensor indicated that no rain was present during this 400+ minute record.

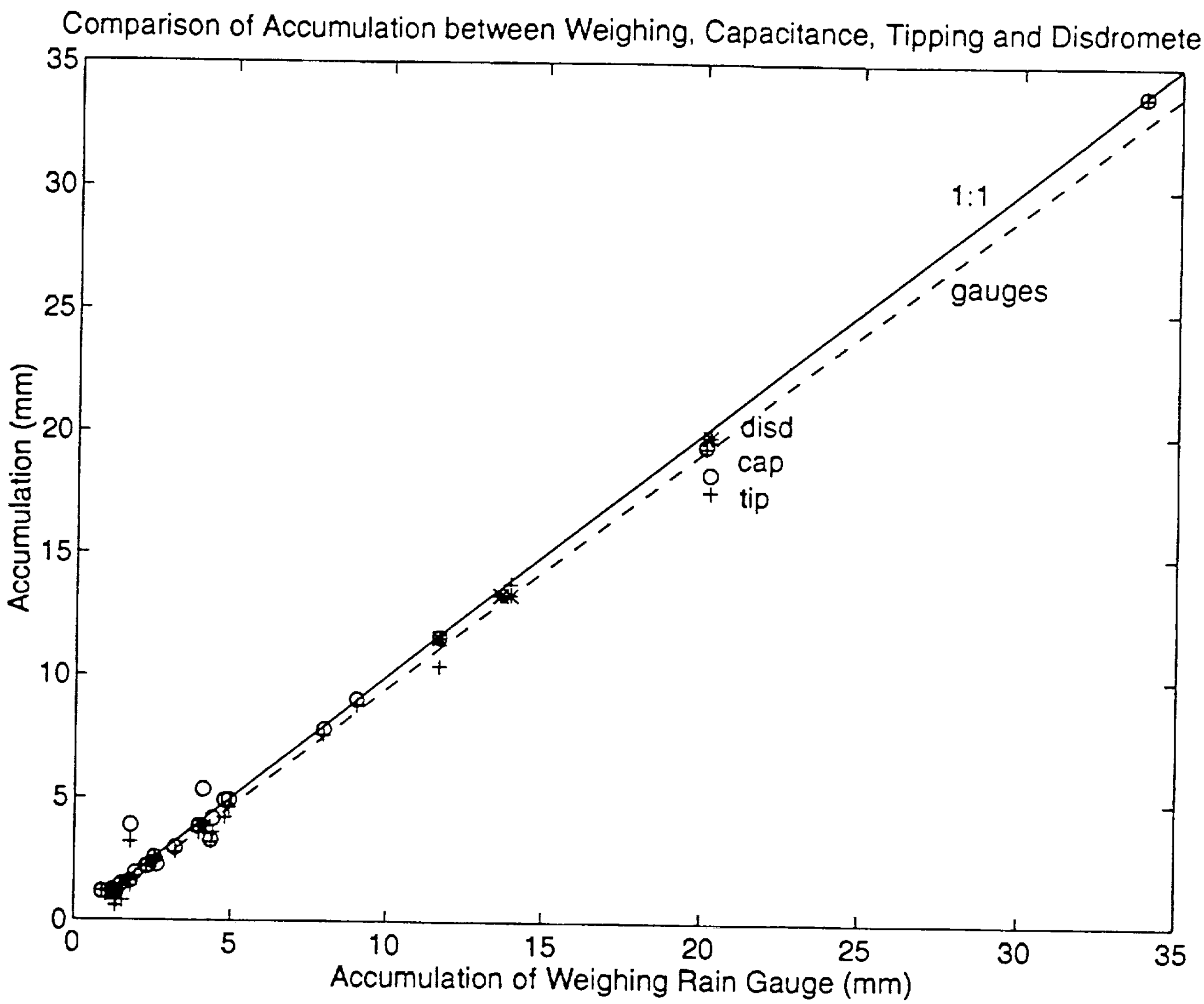


Figure 2a. A comparison of accumulation totals for 33 rainfall events in September and October 1993. The regression slope between the weighing rain gauge and the disdrometer (disd, *), capacitance (cap, 0) and tipping bucket (tip, +) rain gauges is 0.97.

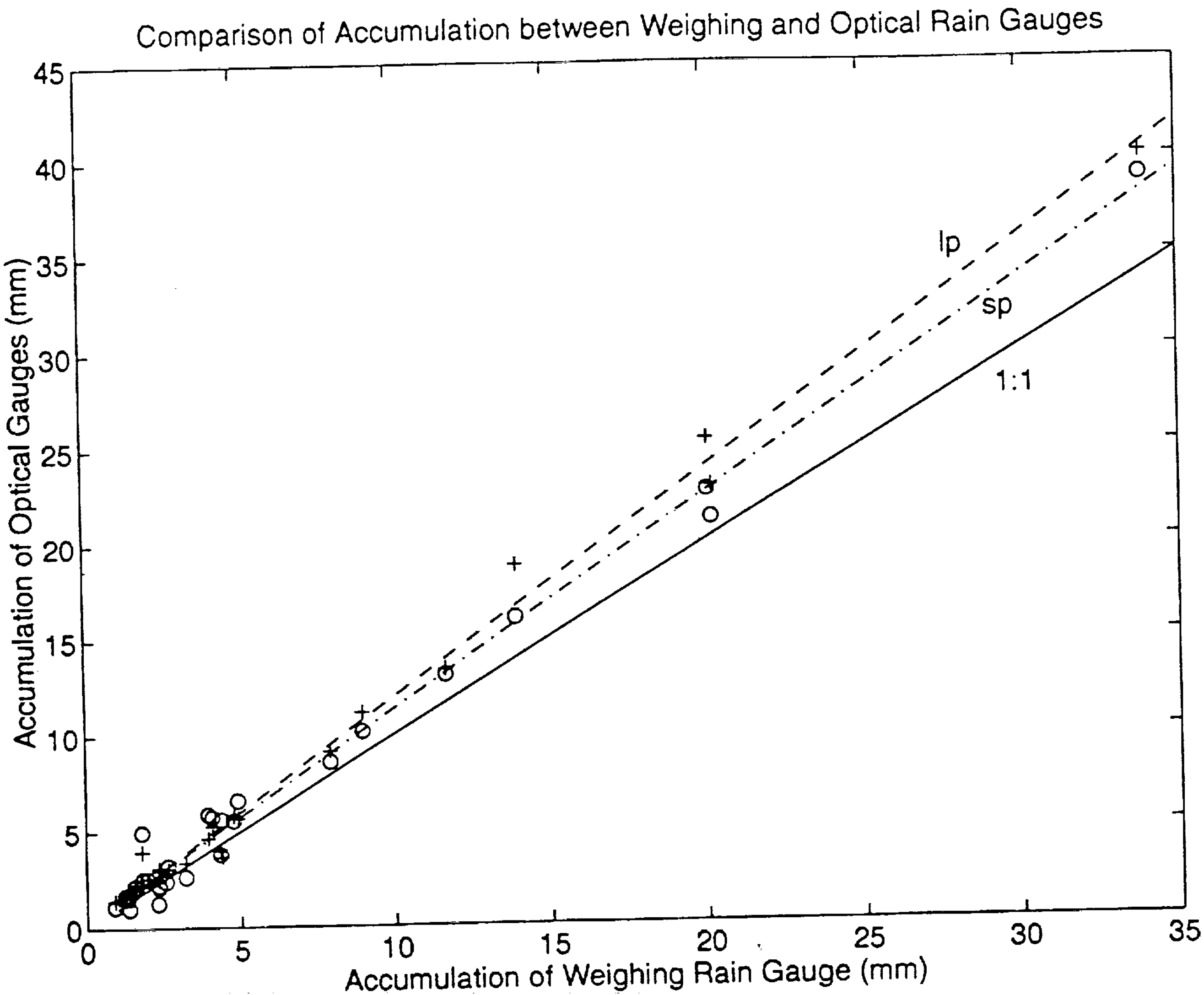


Figure 2b. A comparison of accumulation totals for 33 rainfall events in September and October 1993. The regression slope between the weighing rain gauge and the ORG-105 (sp,0) is 1.12 and for the ORG-705 (lp, +) is 1.19.

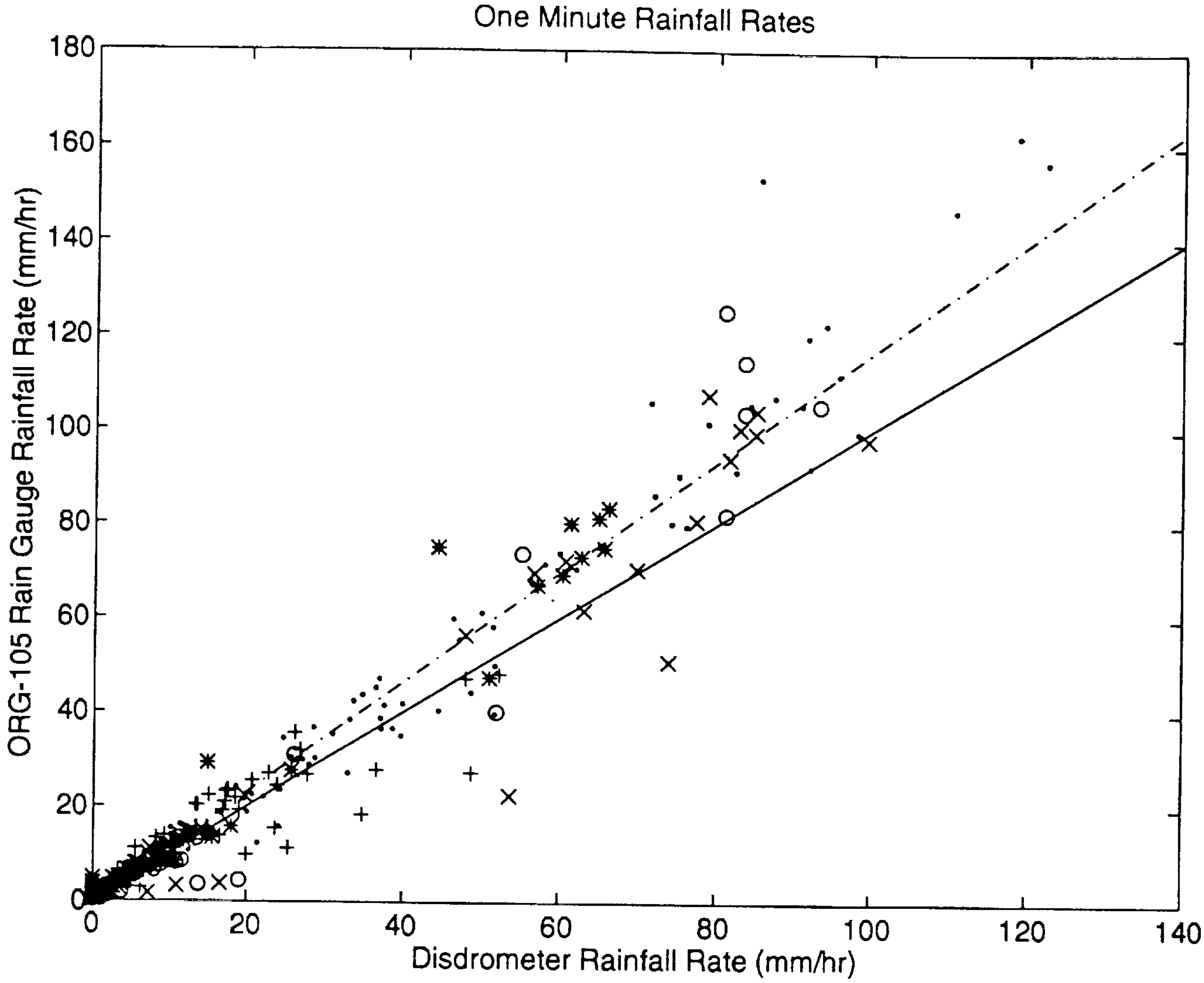


Figure 3. One minute rainfall rate estimates from the disdrometer and the ORG-105 optical rain gauges. The first order regression (dash-dot line) is shown. Data from five events (Event 271, *; Event 272, o; Event 275, x; Event 287, +; Event 289, •) are shown. Note the high correlation (r = 0.98) and the scatter about the mean regression (± 20%).

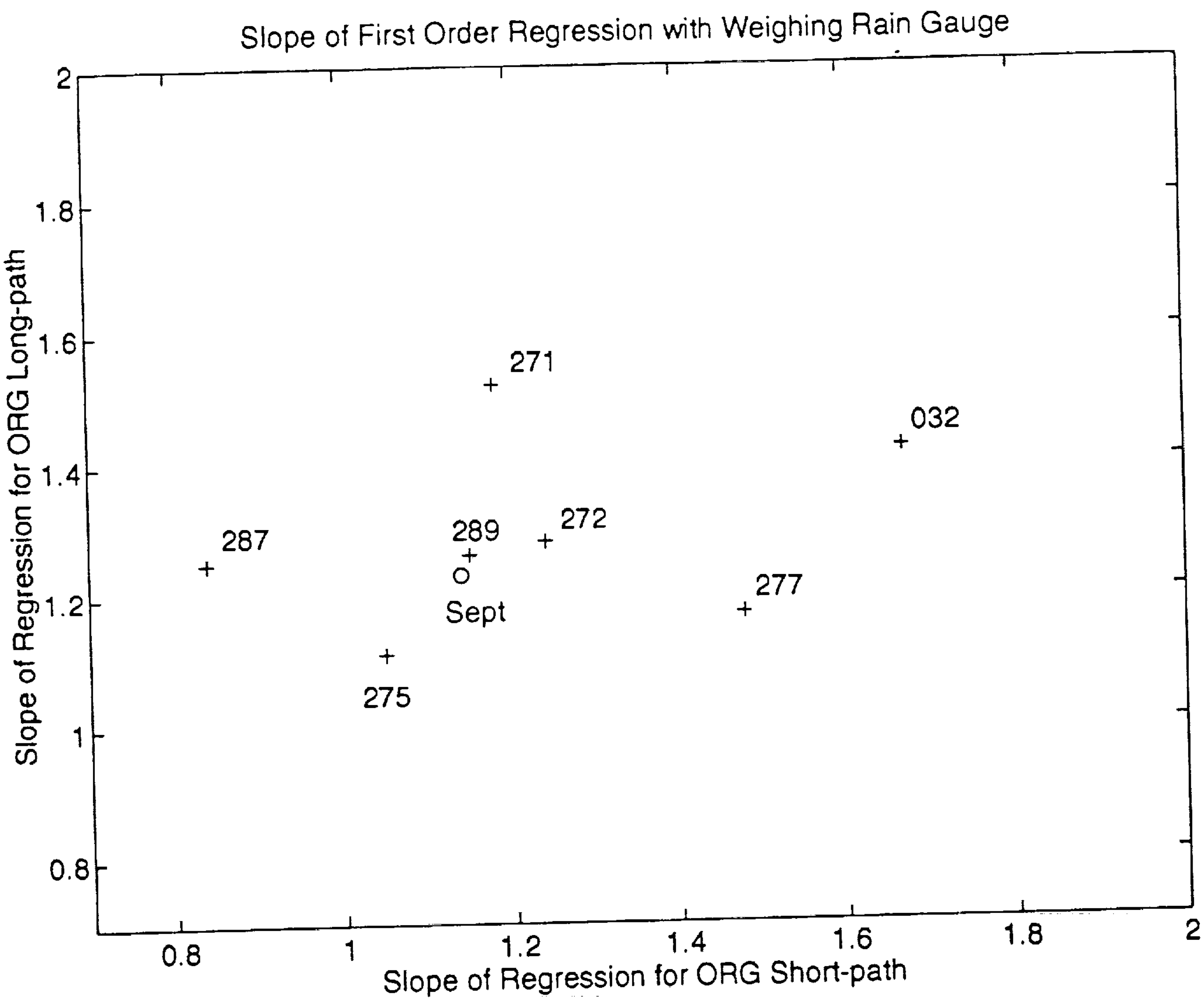
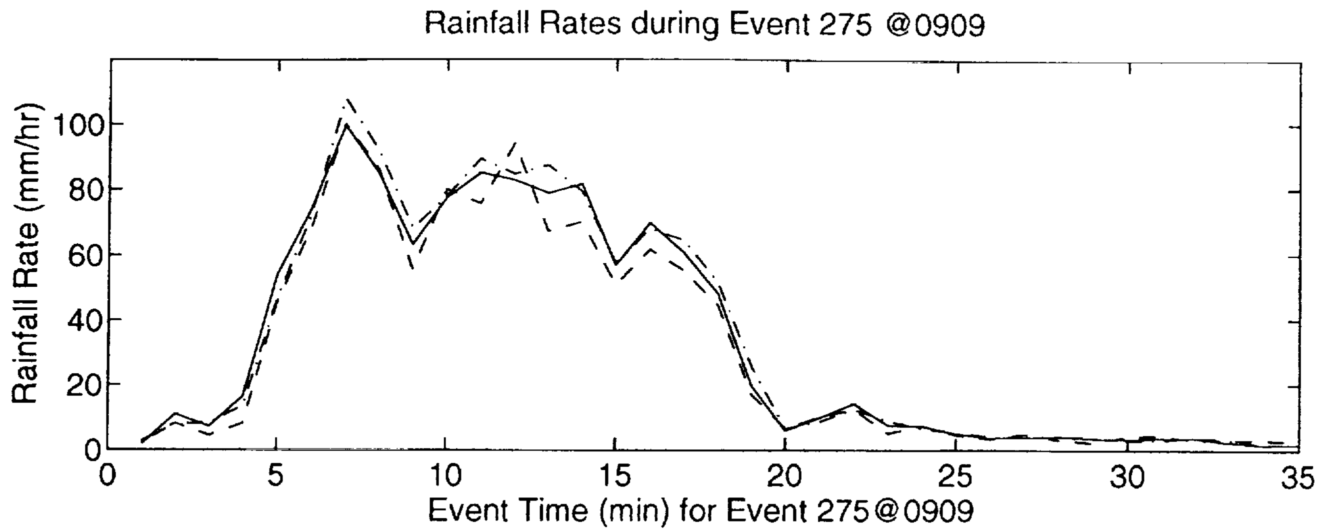


Figure 4. The slope of the first order regression between the weighing rain gauge and the ORG-105 (abscissa) and the ORG-705 (ordinate) for individual rain events. The events are identified by Julian date. The event on JD 032 (1994) is a light rainfall event (maximum rainfall rate 5 mm/hr). The other events are heavy rainfall events with maximum rainfall rates near 100 mm/hr.



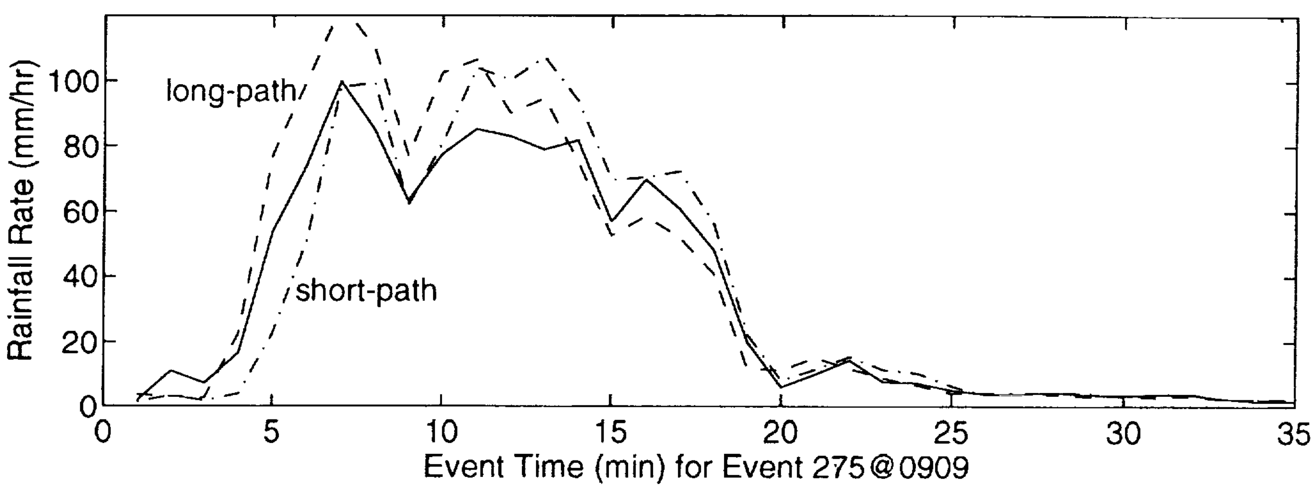


Figure 5. One minute rainfall rate estimates during Event 275. The upper panel shows that the rainfall rate measurements from the disdrometer (solid line), the capacitance rain gauge (dashed line) and the weighing rain gauge (dash-dot line) are in excellent agreement. The lower panel shows the rainfall rate measurements from the disdrometer (solid line), the ORG-105 short-path (dash-dot line) and the ORG-705 long-path (dashed line). While the ORGs tend to overestimate rainfall rate relative to the other gauges, however they are occasionally in agreement with or underestimate the rainfall rate relative to the other gauges.

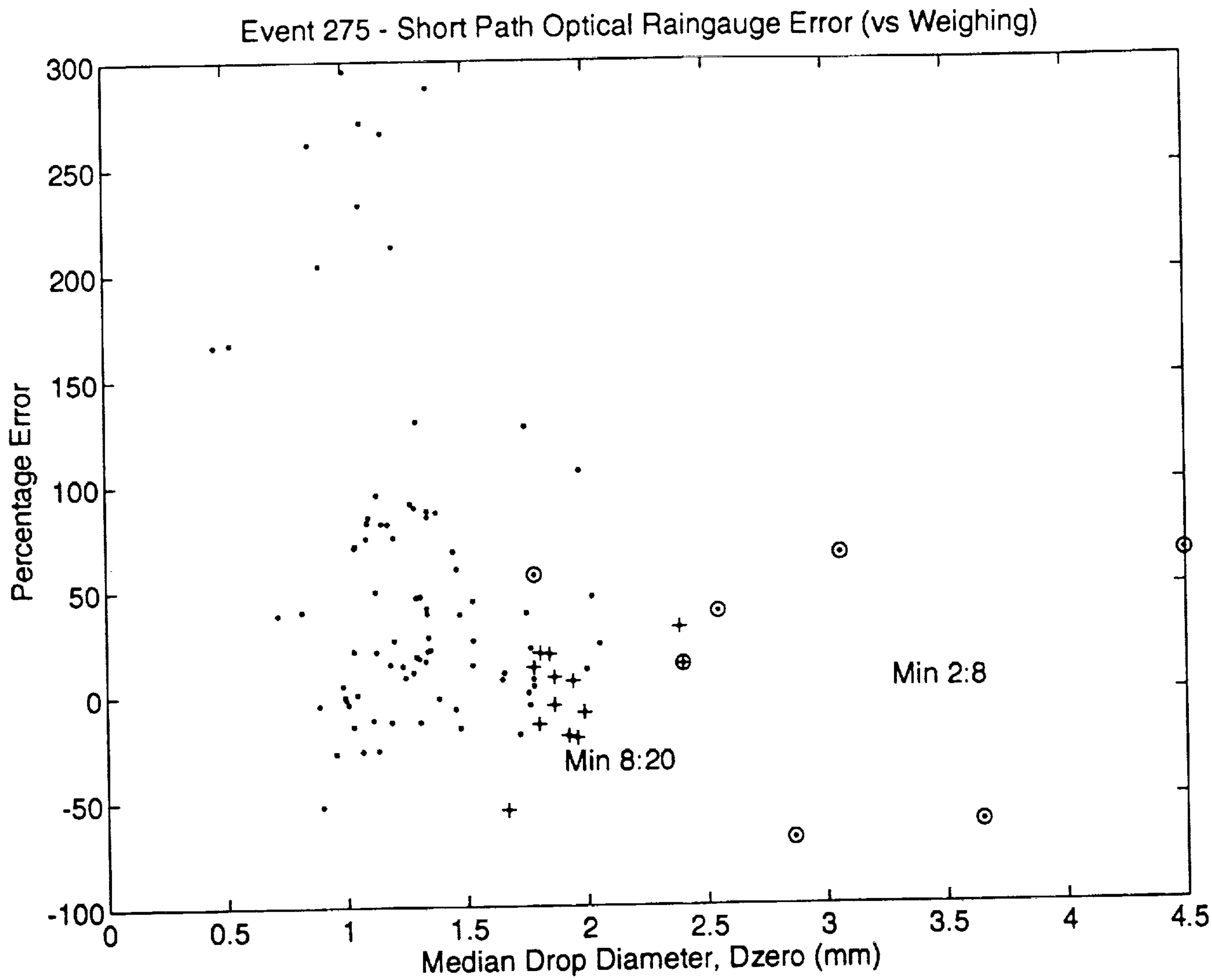


Figure 6. The percentage rainfall rate error between the ORG-105 (short-path) and the weighing rain gauge. The abscissa shows the median drop size (by liquid water volume, D_0, calculated from the disdrometer data. During minutes 2-8 (⊙ symbol), the rainfall rate is increasing and the rain contains relatively more very large raindrops (over 3 mm diameter). During minutes 8-20 (+ symbol), the rainfall rate is very high (60 - 100 mm/hr). During the remainder of the event (minutes 21-100) (o symbol), the rainfall rate is low (stratiform rain). No clear trend is evident in the percentage error values.

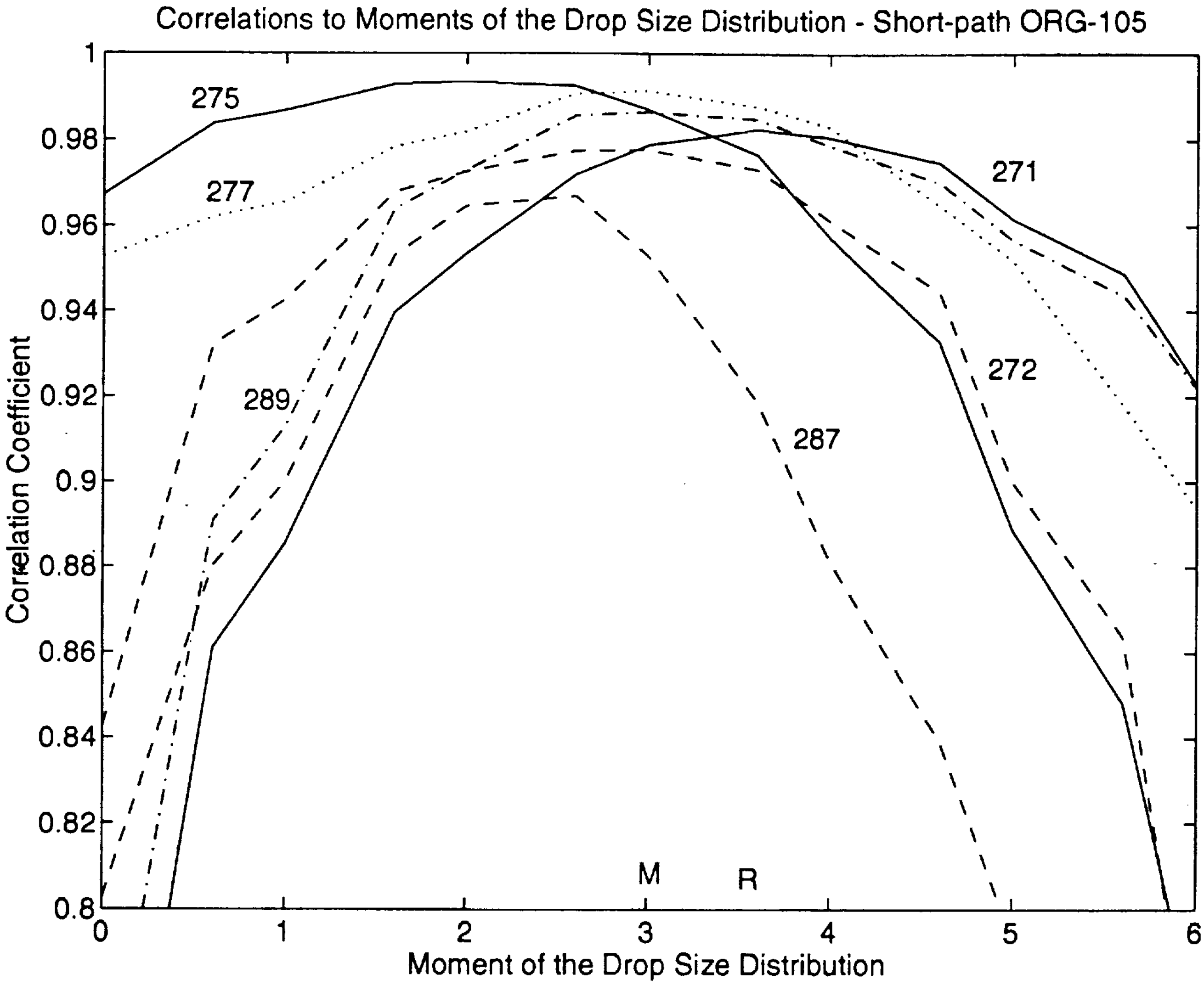


Figure 7. Correlation between the moments of the drop size distribution and the ORG-105 (short-path) rainfall rate estimate for 6 individual rain events. The rain events are identified by their Julian date. The highest correlation tends to be at a moment of the distribution that is less than rainfall rate (R, the 3.6th moment). Note that all of the correlation values are very high.

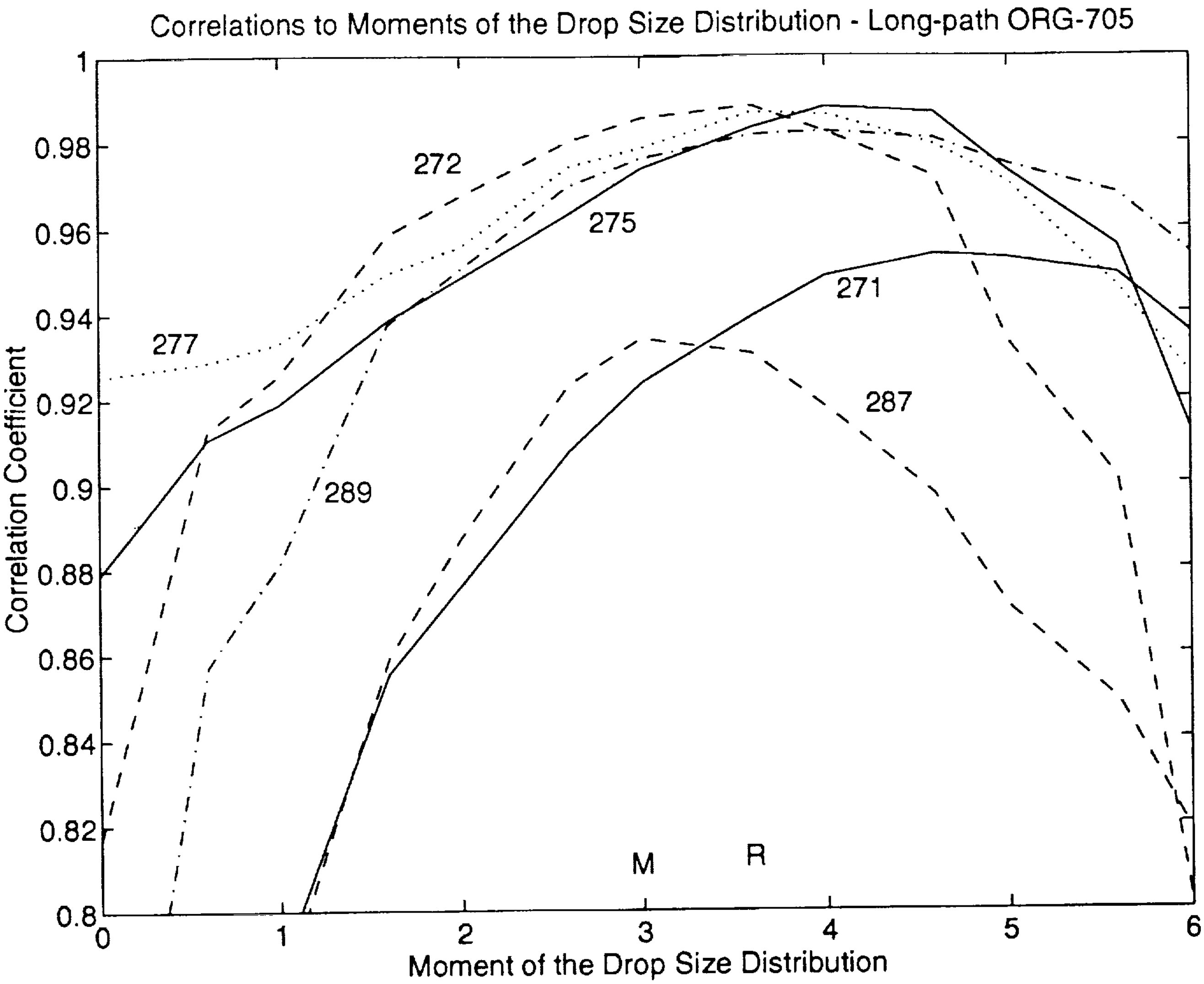


Figure 8. Correlation between the moments of the drop size distribution and the ORG-705 (long-path) rainfall rate estimate for 6 individual rain events. The rain events are identified by their Julian date. The highest correlation tends to be at a moment of the drop size distribution that is higher than rainfall (R is the 3.6th moment). For each event the ORG-705 is most highly correlated to a higher moment of the drop size distribution than the ORG-105 (Fig. 7). Note that all of the correlation values are very high.