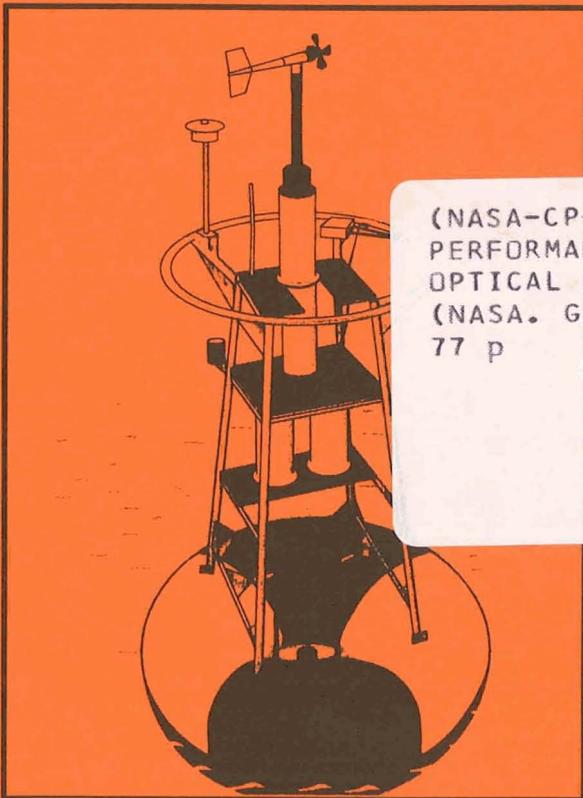


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Optical Rain Gauge Performance

Second Workshop on Optical Rain Gauge Measurements



(NASA-CP-3288) OPTICAL RAIN GAUGE
PERFORMANCE: SECOND WORKSHOP ON
OPTICAL RAIN GAUGE MEASUREMENTS
(NASA, Goddard Space Flight Center)
77 p

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*Proceedings of workshop held at
NASA Goddard Space Flight Center
Greenbelt, Maryland
April 21-22, 1994*



Errata

NASA Conference Publication 3288

Optical Rain Gauge Performance: Second Workshop on Optical
Rain Gauge Measurements

O. W. Thiele, M. J. McPhaden, and D. A. Short, Editors

December 1994

This errata is issued to add page numbers to the Table of
Contents. Please replace page v with the enclosed page.

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NASA Conference Publication 3288

Optical Rain Gauge Performance

Second Workshop on Optical Rain Gauge Measurements

Edited by

David A. Short
Otto W. Thiele
*Goddard Space Flight Center
Greenbelt, Maryland*

Michael J. McPhaden
*NOAA Pacific Marine Environmental Laboratory
Seattle, Washington*

*Proceedings of workshop held at
NASA Goddard Space Flight Center
Greenbelt, Maryland
April 21-22, 1994*



National Aeronautics and
Space Administration

Scientific and Technical
Information Branch

1994

AGENDA
Second Workshop on Optical Rain Gauge (ORG) Measurements
NASA-Goddard Space Flight Center, **Building 22, Room 365**
April 21-22, 1994

This Workshop is intended to be a working meeting to evaluate ORG performance in a number of environments, address problems, consider solutions or potential solutions and discuss future expectations, etc. Those that have short (10-15 minutes) presentations of material under the general topics listed will be worked in as we go along allowing for adequate discussion of key issues in between. The institutions noted under each topic are our best guess for input in those areas but everyone is free to jump in anywhere if they have something to contribute.

Thursday, April 21, 1994

- 0900-0905Welcome and Introductory Remarks..... Otto Thiele
- 0905-0925Brief Overview of First ORG WorkshopMichael McPhaden
- 0925-1115I: Instrument ComparisonsPMEL, AOML/U. Miami,
in Natural Rain NDBC, GSFC/WFF, STi
- 1115.....EARLY LUNCH
- 1245-1345II: Field Experience..... NOAA/NESDIS, PMEL,
(TOGA/COARE, others) GSFC/WFF, Texas Tech. U.
- 1345-1445III: Data Archives.....NOAA/NESDIS, PMEL, GSFC/WFF
- 1445-1500BREAK
- 1500-1600IV: Design/Fabrication/Reliability.....PMEL, STi, GSFC/WFF
- 1600-1700V: Calibration: Factory/Field.....STi, GSFC/WFF, PMEL

Friday, April 22, 1994

- 0900-1030VI: Future Plans/Potential Improvements.....All
- 1030-1045BREAK
- 1045-1200Wrap-up Discussions
- 1200.....LUNCH
- 1300-1500Meeting Reports/Action Items and Assignments if Applicable

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Second Workshop on Optical Rain Gauge Measurements

TRMM Office/910.1
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771
April, 21-22, 1994

INTRODUCTION

The primary focus of the Workshop was on the performance and reliability of STi mini-Optical Rain Gauges in a number of environments, including deployments on ships and buoys in the western equatorial Pacific Ocean during the TOGA/COARE field experiment, deployments on buoys in U. S. coastal waters, and comparisons with other types of rain gauges on the Virginia coast and in Florida. The Workshop was attended by 20 investigators representing 10 different institutions (see attached list) who gathered to present new results obtained since the First Workshop (April 1993), to discuss problems, to consider solutions and to chart future directions. Post-TOGA/COARE calibration studies were also presented.

In addition, discussions were held on the broader goals of improving instrumentation and techniques used to obtain surface rainfall measurements over the oceans for the purpose of validating satellite-based rainfall estimates (Tropical Rainfall Measuring Mission (TRMM), Global Precipitation Climatology Project (GPCP), Global Energy and Water Cycle Experiment (GEWEX), etc.). Progress continues on technologies such as acoustic rain gauges, deployed beneath the ocean surface and on pressure sensitive piezo-electric plastic composites.

The Workshop opened with a review of the first Optical Rain Gauge Measurements Workshop which was held at PMEL in Seattle on March 31,- April 1, 1993 (a summary was published in TOGA Notes, 1993, Number 13, p. 18-19). The recommendations of the PMEL workshop were used to focus discussion over the next 2 days, during which participants reported progress on specific topics related to mini-ORG performance. The recommendations of the first workshop, plus a brief summary of progress for each, are described below.

RECOMMENDATION #1: Post deployment calibration checks at NASA/Wallops will be done for all mini-ORG's returned from the field.

A total of 42 Scientific Technology, Inc. (STI), mini-ORG's (model 100 series) were deployed during COARE on ships, buoys, and/or islands. Of this total, 26 were returned to Wallops Island, Virginia, in working order (see attached mini-ORG inventory), the remainder being either lost or damaged in the

field. Post-calibration in natural rain of the 26 returned units has been underway at Wallops during the past year.

Preliminary results indicate that between rain rates of 1 to 100 mm hr⁻¹, the calibration is stable and linear. At rain rates below 1 mm hr⁻¹, the mini-ORG tends to overestimate rainfall, perhaps because of electronic noise or the effects of atmospheric turbulence. Electronic noise may also be enhanced by the presence of dew or moisture on the receiver lens. These irregularities would defocus light on the optical receiver, causing the automatic gain control to boost power to the emitter, thereby, amplifying electronic noise as well.

Occasional calibration outliers have been identified (e.g., the mini-ORG #2238 on the R/V *Shiyan* #3); however, the calibration offset in these outliers appears to be constant with rainrate, suggesting that post calibration can improve the accuracy of these data sets substantially.

Consistent with results reported at the first workshop, based on test data taken at Wallops, STI found it possible to calibrate a subset of 4 mini-ORG's against a precision weighing gauge to a relative accuracy of about 10%; in addition, the 4 ORG's agreed with one another after post-calibration to within about 5%.

**RECOMMENDATION #2:* More calibration data in natural rain rates greater than 100 mm hr⁻¹ are needed. NASA/Wallops will undertake the collection of sufficiently long time series to check the performance of the mini-ORG in this rain rate range.

Accuracies for rain rates higher than 100 mm hr⁻¹ are still not firmly established. The number of natural rain events in this range recorded at the NASA/Wallops ensemble is small so far. However, 25 high rain rates events > 100 mm hr⁻¹ were recorded at AOML in Miami during a series of intercomparisons between a precision weighing gauge, tipping bucket rain gauge, RM Young capacitance gauge, the STI mini-ORG (model 105), and STI ORG (model 700). The tipping buckets tended to read low by about 15% in rain rates over 100 mm hr⁻¹, whereas the ORG (model 105) and ORG (model 700) tended to read high by 14% and 23%, respectively. However, only one instrument each in the ORG series was tested. It remains to be seen whether these results will apply to a larger ensemble of instruments.

**RECOMMENDATION #3:* NASA/Wallops will incorporate disdrometer measurements into calibration procedures to determine drop size distribution of both natural and artificial rain used in mini-ORG calibrations.

NASA/Wallops this past year has been working with AOML to develop a low cost disdrometer for inclusion into ORG calibration procedures. A first of these disdrometers was tested at AOML, with results presented at the

workshop. The disdrometer consists of a cone-like delron surface to which a piezoelectric sensor is attached. Raindrops striking this surface produce a voltage output proportional to their size. Additional disdrometers will be built for use in calibrating ORG's and other rain sensing devices at Wallops, PMEL, and AOML, and several will be deployed at TRMM "ground truth" sites to calibrate radars and rain gauges.

**RECOMMENDATION #4:* A high temporal resolution (5 second) buoy data set will be collected to evaluate the effects of buoy motion and spray on the performance of mini-ORG's.

This recommendation had not been carried out during the past year, in part because the ORG test will be included in a more general engineering test to examine the response of other sensors (e.g., short wave radiation) to buoy motion. However, sea spray is likely not to be a problem for moored buoy ORG measurements. A typical drop size for spray is less than 0.5 mm, the signal for which would be attenuated by the ORG instrument response. Furthermore, the vertical distribution for spray is such that the largest spray drops are not transported to the level of the ORG height on TAO buoys (3 m above the mean water line) even at wind speeds greater than 10 m s^{-1} (Wu, 1986).

In lieu of the recommended engineering test, PMEL deployed 2 mini-ORG's side-by-side on 2 different moorings in the western tropical Pacific (0° , 156°E and 0° , 165°E) this past year to examine the consistency of sensor performance in the field. In each case, the moorings were in place for about 6 months. Cross-correlations for the doublet time series were 0.97 and 0.99, respectively, for hourly values. However, for one doublet, amplitudes differed on average by 55%, and for the other doublet they differed by 29%. This highlighted the need for more careful factory calibration of the instruments, and the need for a field tester to check instrument calibration before deployment.

**RECOMMENDATION #5:* The sensitivity of mini-ORG rain rate estimates to the assumed shape of the drop size distribution (e.g., exponential, gamma, lognormal), and to truncation effects of the instrument on drop size distribution, will be further examined.

The sensitivity of ORG rainfall estimates to drop size distribution was examined both theoretically (by STI) and empirically (by AOML). STI performed calculations to show that the calibration for an exponential drop size distribution would theoretically provide rain rate estimates accurate to within $\pm 5\%$ for rain rates between 1 and 500 mm hr^{-1} . These calculations were extended to other drop size distributions, with results indicating little change in calibration for drop size distributions substantially differing from exponential. Thus, the shape of the drop size distribution would not

introduce significant uncertainty into the estimate of rain rate, provided the mean drop size was the same.

Disdrometer measurements were incorporated into the rain gauge tests at AOML described above. These tests corroborated the theoretical calculations on the sensitivity to drop size distribution. On a minute-by-minute basis, the drop size distribution throughout the evolution of a rain event could vary significantly. However, for rain rates above 10 mm hr^{-1} , where most of the rainfall accumulation occurred, differences between weighing gauge and ORG rainrate estimates ($\pm 20\%$ minute-by-minute, but less if averaged over longer periods) appeared not to vary in a consistent way with variations in drop size distribution. At very low rain rates, the relative errors could be much larger; however, little rain accumulation occurred at the lower rain rates.

**RECOMMENDATION #6:* An electronic field tester is needed for checkout and tuning of mini-ORG's prior to deployment. This field tester and a port to plug it in will be provided with the new ORG-100 series.

Scientific Technology, Inc., is redesigning its ORG series. There will no longer be distinct 100 and 700 series. Rather, a single series with the electronics configuration of the mini-ORG will be introduced in the next 6 months. The new design will include a field tester which will permit check-out of the entire system (electronics and optics) over a range of simulated rain rates. The manufacturer will offer an option to retrofit older style mini-ORG's with the field tester interface when it becomes available.

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Moored Rainfall Measurements During COARE

Michael J. McPhaden
NOAA/Pacific Marine Environmental Laboratory
7600 Sand Point Way NE
Seattle, WA 98115

This presentation discusses mini-ORG rainfall estimates collected from an array of six moorings in the western equatorial Pacific during the TOGA-COARE experiment (Figure 1). The moorings were clustered in the vicinity of the COARE Intensive Flux Array (IFA) centered near 2°S, 156°E. The basic data set consisted of hourly means computed from 5-second samples.

The TOGA-COARE Intensive Observing Period (IOP) took place from November 1992 to February 1993, during the El Niño/Southern Oscillation (ENSO) warm event of 1991-93. Rainfall accumulation for the period September 1992 to March 1993 overlapping the COARE IOP was 2589 mm from the moored mini-ORG array, more than 2.5 times larger than Morrissey and Greene's (1991) climatological estimate of 902 mm for the same months based on atoll data. Anomalously high rainfall in 1992-93 is consistent with enhanced deep convection in the region during ENSO events; and with the incidence of high rainfall accumulations in western Pacific atoll records in previous ENSO years (Ropelewski and Halpert, 1987).

The horizontal correlation structure for rainrate based on the moored ORG data was estimated for different temporal averaging intervals of 1 hour, 1 day, 5 days and 10 days (Figure 2). Space lags ranged from 1.5 degrees (166 km) to 11 degrees (1221 km). Spatial correlation increased with temporal averaging interval, from near zero for hourly data at all horizontal separations, to 0.6-0.8 for 10-day averages. Correlations were generally highest at shorter spatial separation, though significantly non-zero correlation was found for 5-day and 10-day averages even over 11 degrees separation.

The moored ORG data at 0°, 156°E, 0°, 157.5°E and 2°S, 156°E were averaged to 5-day pentads for comparison with 1) the GOES Precipitation Index (GPI) for the 2.5° by 2.5° square centered at 1.25°S, 156.25°E (Arkin and Ardanuy, 1989); 2) a 4-channel microwave SSM/I rain product for the 2.5° by 2.5° square centered at 1.25°S, 156.25°E (Berg and Chase, 1992; provided courtesy of Wesley Berg, University of Colorado); and 3) a preliminary analysis of Omegasonde data at 0000Z from the COARE IFA (provided courtesy of Dick Johnson and Xin Lin, Colorado State University). The 4 estimates (Figure 3) are all highly correlated. However, there are significant amplitude differences between them (Table 1). Some of the difference may be due to an overestimate of mini-ORG determined rainrate by O(10%) as suggested by preliminary ORG calibrations in high rainrate. The GPI, on the other hand, probably reads low because it does not detect "warm rain" falling from clouds whose cloud tops are above the GPI algorithm threshold of 235 K. The SSM/I may read low because the 15-70 km spatial resolution of the microwave sensor channels is coarse relative to the 10 km dimension of individual rain cells (Chang et al, 1993). The Omegasonde estimates may read low relative to the moored

estimates because the former apply to a much larger area (roughly 1°N-4°S, 151°E to 158°E). Regression offsets (B in Table 1) imply that the satellite and sounding estimates indicate rain when the buoy averages read zero; these offsets probably result from the different areal coverage of the buoys and the other rainrate estimators. This interpretation is supported by regression between the spatially coincident GPI-SSM/I time series, for which there is only 1 mm offset. Despite these differences (which can be rationalized in terms of the different sampling techniques and areal coverages), the results are very encouraging in that the time evolution of rainfall in the vicinity of the COARE IFA based on 4 completely independent estimates agrees so well. All 4 estimates, for example, show evidence of rainfall variability associated with the passage of 60-day Madden and Julian oscillations.

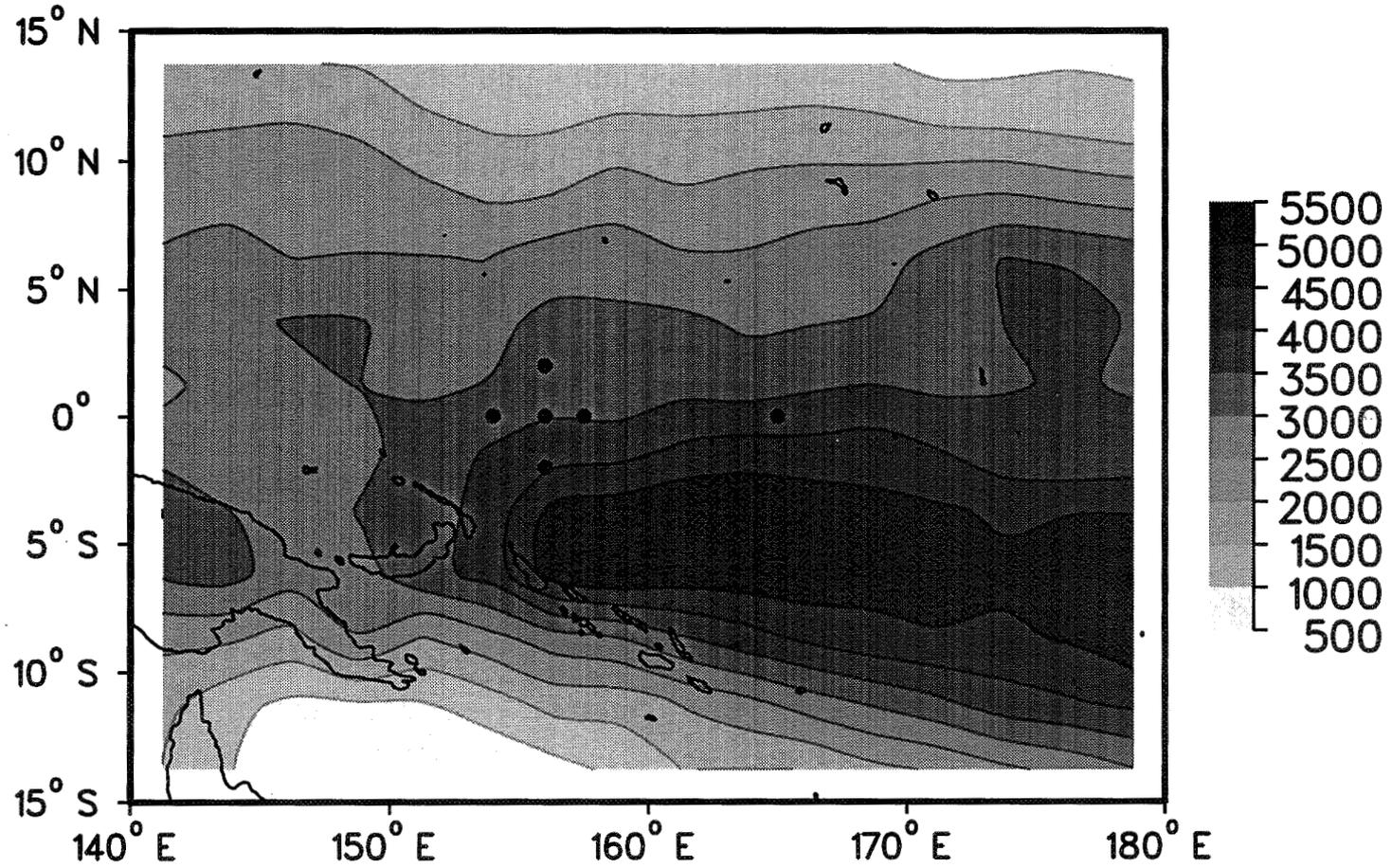
Table 1. Statistics of regression analysis for pentad rainfall accumulations (in mm) in the vicinity of the COARE IFA. Regression formula is given by $Y=A*X+B$, where X are the mini-ORG estimates, and Y is either GPI, SSM/I and atmospheric sounding based estimates of rainfall. N is the number of pentads used in the regression analysis

	Xcorr	A	B	N
GPI-ORG	0.77	0.51	20.6	51
SSM/I-ORG	0.77	0.41	4.8	24
Sounding-ORG	0.74	0.21	27.2	20

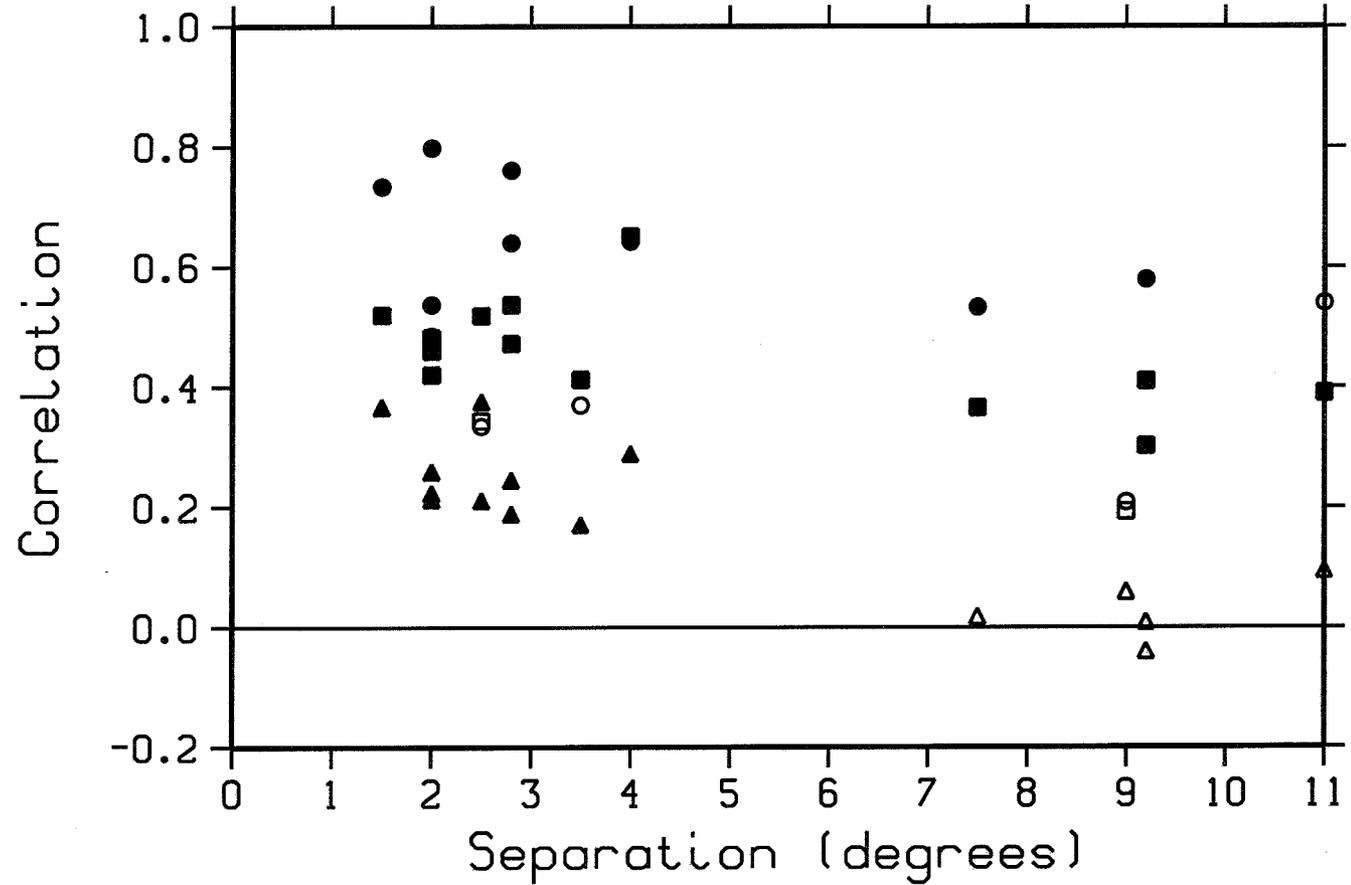
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- Ropelewski, C. F and M. S. Halpert, 1987: Global scale precipitation patterns associated with the El Nino/Southern Oscillation. *Mon. Wea. Rev.*, 115, 1606-1626.

1 Jan 92 – 31 Dec 92
Precipitation (mm)

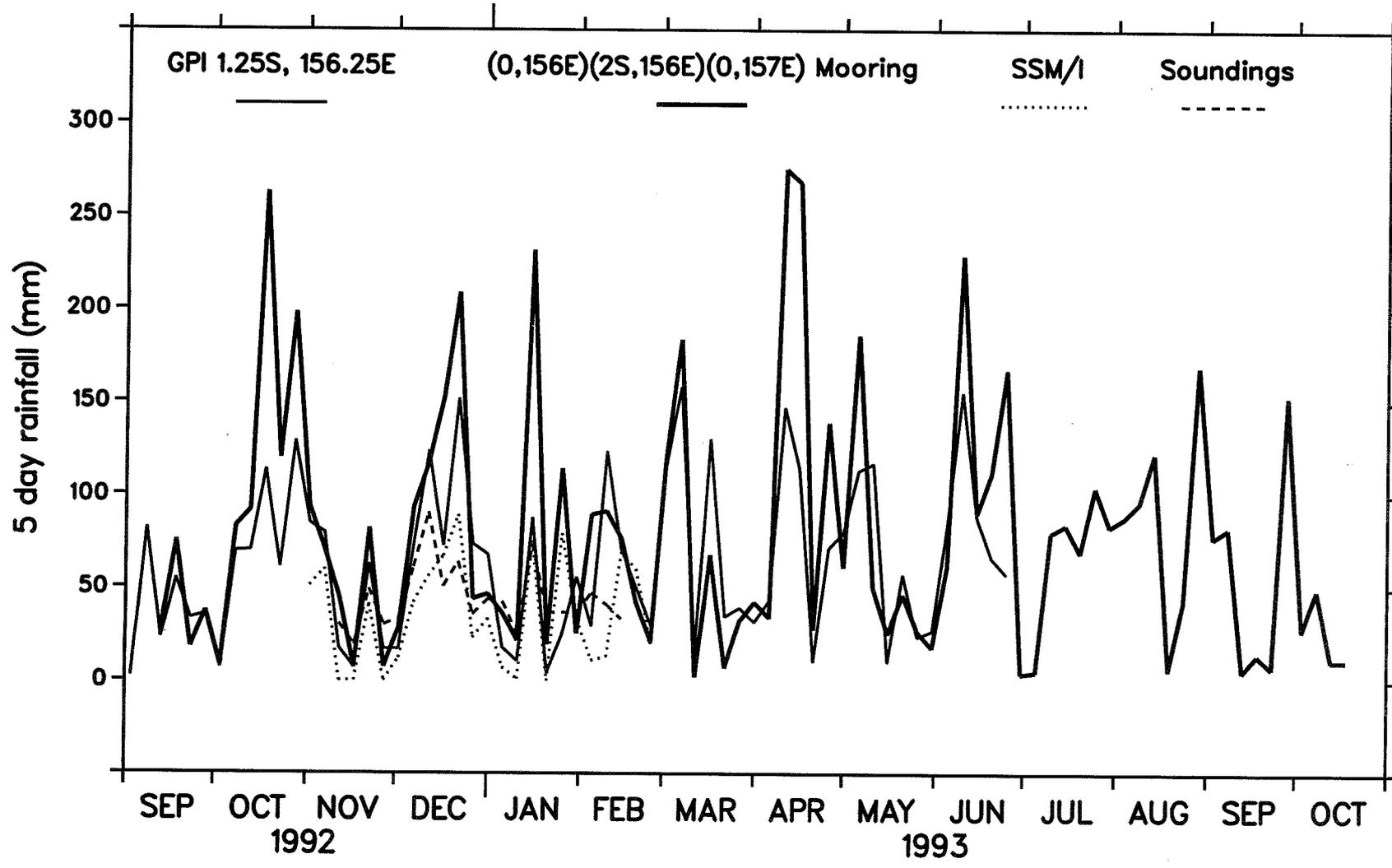


Rain gauge values
2°S-2°N, 154°E-165°E



● 10-day
■ 5-day
▲ 1-day

Solid - Significant at 95% level
Open - Not significant at 95% level



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Second ORG Workshop
April 21-22, 1994
Goddard Space Flight Center, Greenbelt MD

Update on TAO moored ORG Array
H. Paul Freitag
Pacific Marine Environmental Laboratory, NOAA

Present Array Status

During COARE six TAO moorings were equipped with ORGs. In late 1993 moorings deployed on the equator at 154E and 157.5E were recovered and not redeployed as they were augmentations to the TAO array for COARE only. In December 1993, four TAO moorings were equipped with ORGs; One each at 2N, 156E and 2S, 156E and ORG doublets on the equator at 0, 156E and 0, 165E. The 2N, 156E mooring has been lost. By the end of April all sites will have been serviced and six refurbished sensors will again be deployed in the same locations.

COARE comparisons: Moored ORG's with NATSUSHIMA and IMET Buoy

R/V NATSUSHIMA remained within a mile of the 0, 156E mooring for about 6 days in February, 1993. Two major and several minor rain events occurred during the 6-day period. Both moored and shipboard ORG's agreed on the timing of both major and most minor events. The means of all non-zero hourly rainrates differed by 1.6 mm/hr (7.7 vs 6.1 mm/hr). The largest hourly means differed by 14 mm/hr (38 vs 24 mm/hr).

The WHOI IMET mooring returned rain data from a RM Young capacitive rain gauge for 14 days in October/November 1992 and for 9 days in December 1992. The IMET buoy was deployed about 15 miles from the PMEL mooring at 2S, 156E. The IMET and TAO data do not compare as well as the TAO ORG vs NATSUSHIMA ORG data, which may be attributed to the possibility that 15-miles between moorings exceeds the correlation scale for these rain events. Two points may be made about the general character of the IMET vs TAO data: 1) More events occur in TAO time series and 2) The percentage of an hour that the IMET measured rain was a much more noisy time series and had a tendency after major rain events to indicate light rain, while the TAO ORG indicated none. Some of the differences are probably due to different processing methods, but the RM Young sensor may also be more likely to be noisy in a moored buoy environment.

Feb-Dec 93 Array

Due to problems with ship scheduling in the western Pacific, the TAO array of moorings equipped with ORGs deployed in February/March 1993 were not serviced again for up to 10 months, which was significantly longer than the designed deployment length of 6 months. Most of the batteries deployed in February/March 1993 dropped below 11v (the minimum operating voltage specified by STI) within 3 to 5 months. STI has since

informed us that a modification to the sensors had produced a higher current drain than specified in their manual. Seemingly reasonable data were returned long after the sensor battery dropped below 11v, although we have no confirmation that the data are accurate.

Five of the six moorings in the ORG array had signs of vandalism on recovery in December. The majority of damage was done to wind, temperature and humidity sensors, but in one case the infrared transmitter and support rods were missing from an ORG. A second ORG had its rods broken during recovery. The combination of longer than normal deployments, high current drain and vandalism resulted in a data return of only 65%.

Comparison of moored doublets

Time series of hourly data from ORG pairs mounted on the same buoy show coincident events, but values can be significantly different, with one sensor consistently measuring more rainfall than the other. At 0, 156E (Fig. x) the percent (of the hour raining) differed on average by about 6%, indicating a threshold difference. The hourly mean rainfall rates differed by 29%. One of the sensors at 0, 165E had been turned around at sea. Within a few days of deployment it had several events which were much larger than its partner. After that, differences between the two sensors were more like those at 0, 156E. After omitting the first few days the percent data differed by about 6% on average (Fig. y). The hourly mean rainfall rates differed by 55%. All four sensors have been recovered and replaced and will be returned to Wallops for checkout and calibration.

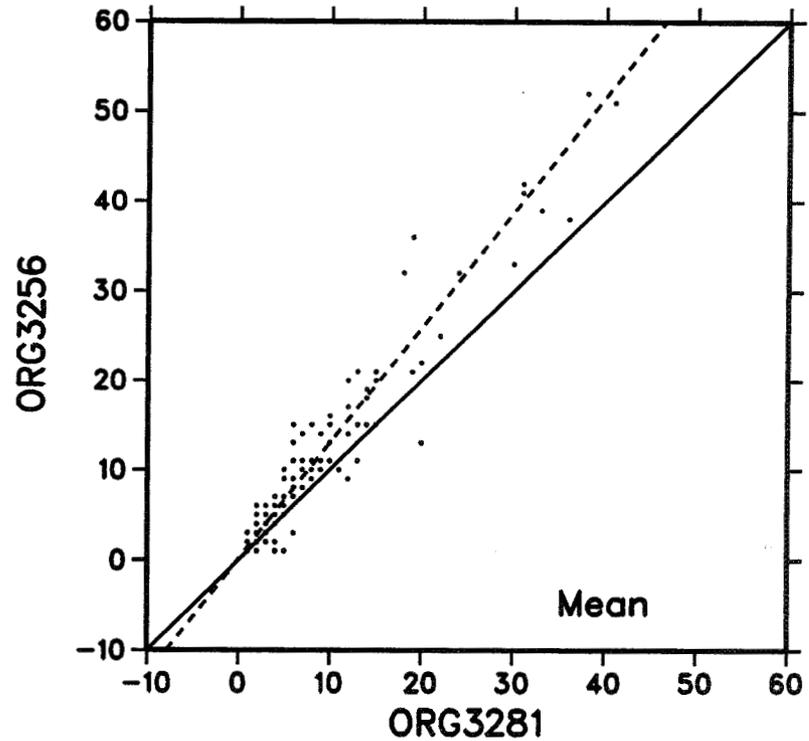
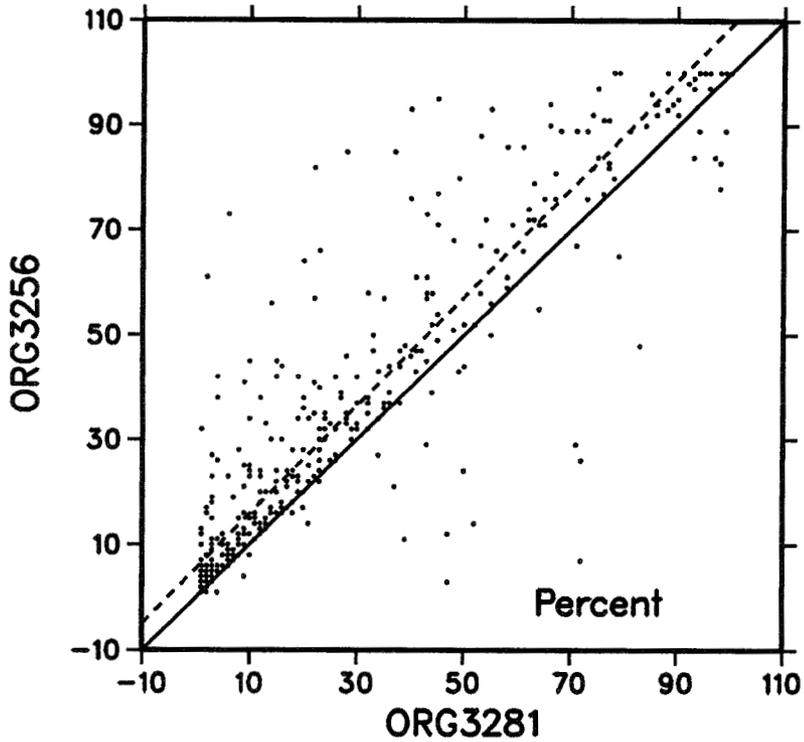
Pre-deployment sensor checkouts

Before the most recent field work two ORGs recently placed at 165E were tested in natural rain conditions for 3 weeks at PMEL before deployment. While several rain events occurred during this period, none had hourly means larger than 3 mm/hr. It appears that rainrates in Seattle are not sufficient for sensor checkout.

Shortly before shipping sensors and electronics for the most recent deployments we were able to test two sensors for 8 days at Quinalt Ranger Station in Olympic National Park. This site was selected because it has an annual rainfall of about 3500 mm (mostly in winter) and is near a regularly manned ranger station. Unfortunately, very little rain fell during the 8-day period. The largest hourly mean was 4 mm/hr and the largest sample was 42 mm/hr (compared to 19 mm/hr in Seattle).

We plan to install a more permanent test facility this fall at Quinalt. We envision several (~6) ORGs, 1 or 2 RM Young capacitive gauges and a weighing gauge being continuously monitored by a PC. We hope to have phone communications to the PC over which data can be transferred to PMEL on a daily basis. We welcome advice on hardware selection and sampling and processing schemes and hope to draw upon the experience of both the Wallops and AOML test facilities.

Mooring TC2: 0°, 156°E



FROM 0000 19 DEC 93 TO 0000 13 APR 94

FROM 0000 19 DEC 93 TO 0000 13 APR 94

	MIN	MAX	MEAN	STD DEV
x:	1.000	100.000	33.118	31.447
y:	1.000	100.000	39.766	32.439

	MIN	MAX	MEAN	STD DEV
x:	1.000	41.000	5.294	6.980
y:	1.000	52.000	6.953	8.923

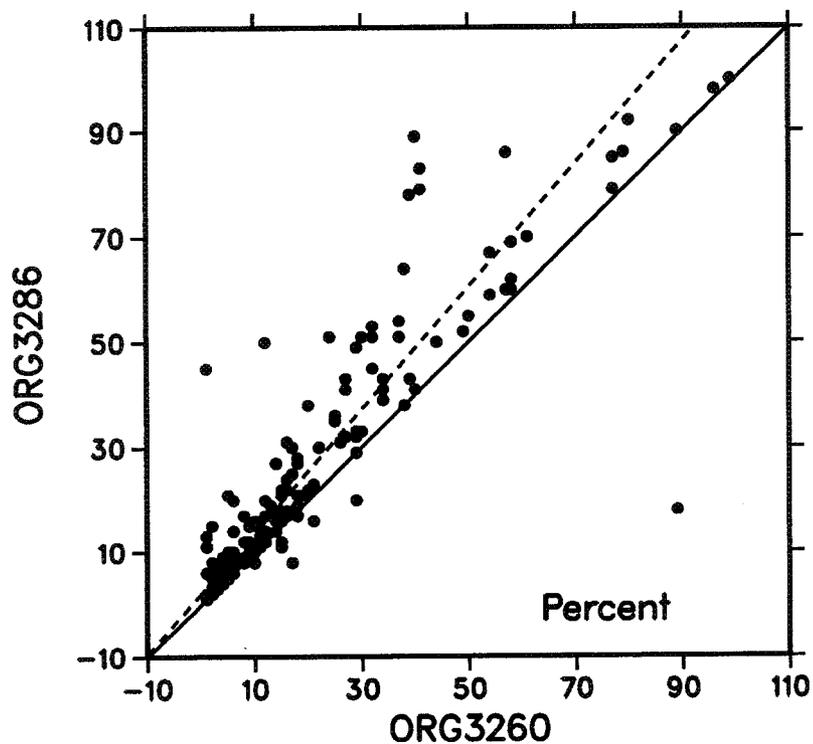
n: 389 r: 0.91

n: 235 r: 0.97

y = a + bx: a = 5.50 , b = 1.03

y = a + bx: a = 0.135 , b = 1.29

Mooring TC1: 0°, 165°E

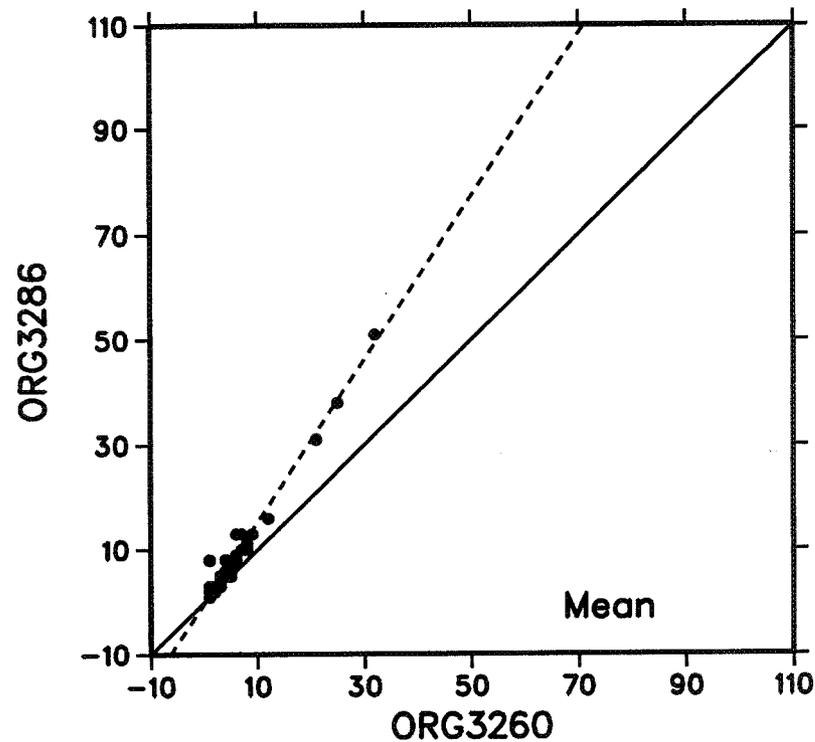


FROM 0000 1 JAN 94 TO 0000 13 APR 94

	MIN	MAX	MEAN	STD DEV
x:	1.000	99.000	20.802	21.052
y:	1.000	100.000	26.475	24.176

n: 162 r: 0.89

$y = a + bx$: $a = 2.17$, $b = 1.17$



FROM 0000 1 JAN 94 TO 0000 13 APR 94

	MIN	MAX	MEAN	STD DEV
x:	1.000	32.000	3.356	4.827
y:	1.000	51.000	5.000	7.442

n: 90 r: 0.99

$y = a + bx$: $a = -0.200$, $b = 1.55$

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Inter-Comparison of Automatic Rain Gauges

Jeffrey A. Nystuen
Cooperative Institute for Marine and Atmospheric Studies
University of Miami, Miami, Florida
and
Ocean Acoustics Division
Atlantic Oceanographic and Meteorological Laboratory
Miami, Florida

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 instrument. 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 ($\lambda = 0.85 \mu\text{m}$ 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 choosing 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 $\pm 20\%$. 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 $\pm 20\%$. 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 $\pm 20\%$ 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 $[(\text{ORG-105 minus Weighing})/\text{Weighing}]$ of the mini-ORG compared to the weighing rain gauge. During the initial minutes (Min 2-8) of the event, the error is $\pm 50\%$. During the heaviest rainfall rates (Min 8-20), the error is $\pm 20\%$. During the light drizzle (Min 21-100), the relative error can be very high ($\pm 300\%$), 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:

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

where $\text{dsd}(D_i)$ 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 ($r \sim 0.95$).

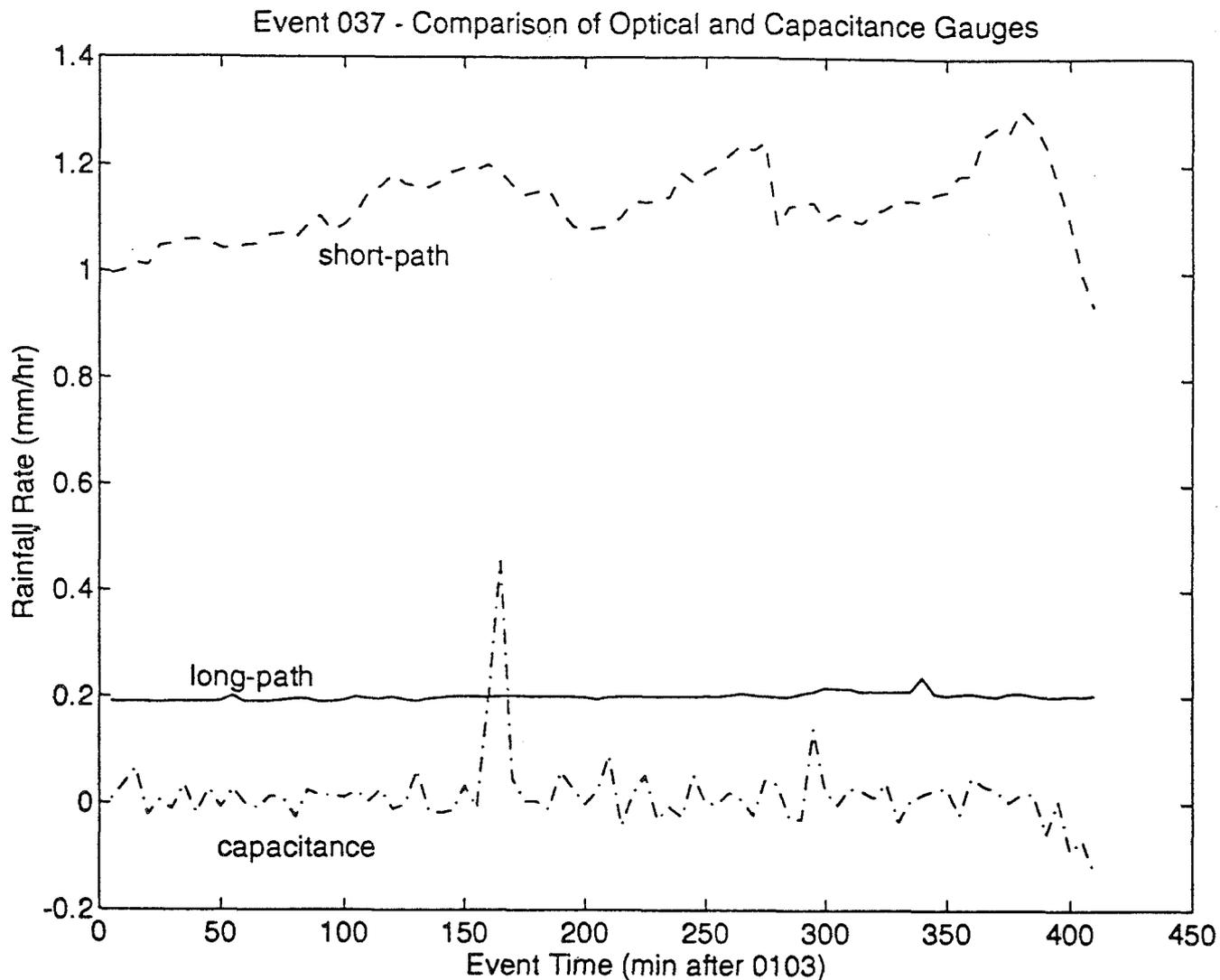


Figure 1. A time series showing the temporal variation in the equivalent rainfall rate due to background turbulence and electronic noise. The ORG-105 (short-path) is reading above 1 mm/hr. ScTI suggests that dew collecting on the receiver lens causes the AGC circuit to amplify the background noise levels. 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.

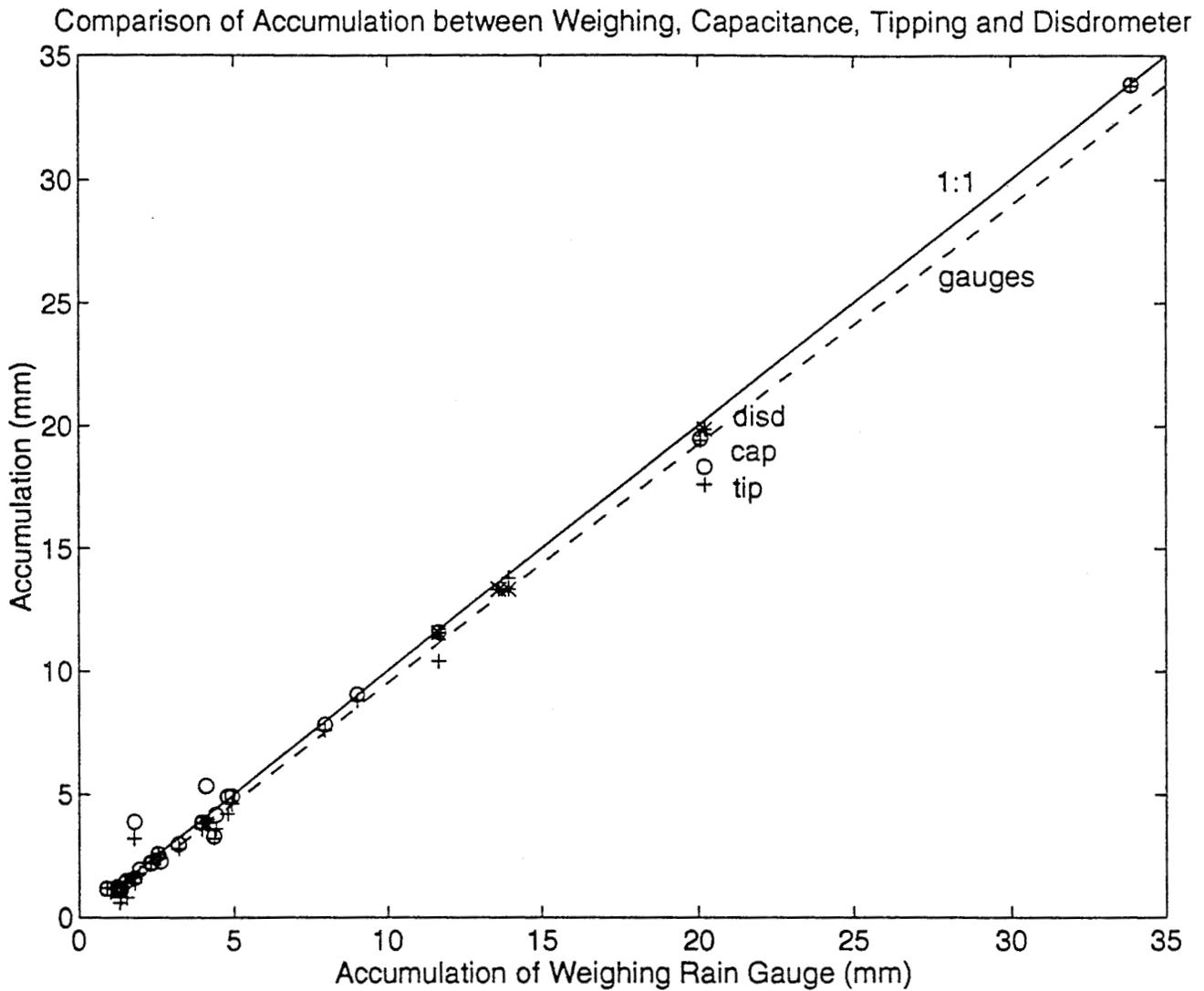


Figure 2a. A comparison of accumulation totals for 33 rainfall events in September and October 1993. The regression slope between the weighing rain gauge and the disdrometer (disd, *), capacitance (cap, 0) and tipping bucket (tip, +) rain gauges is 0.97.

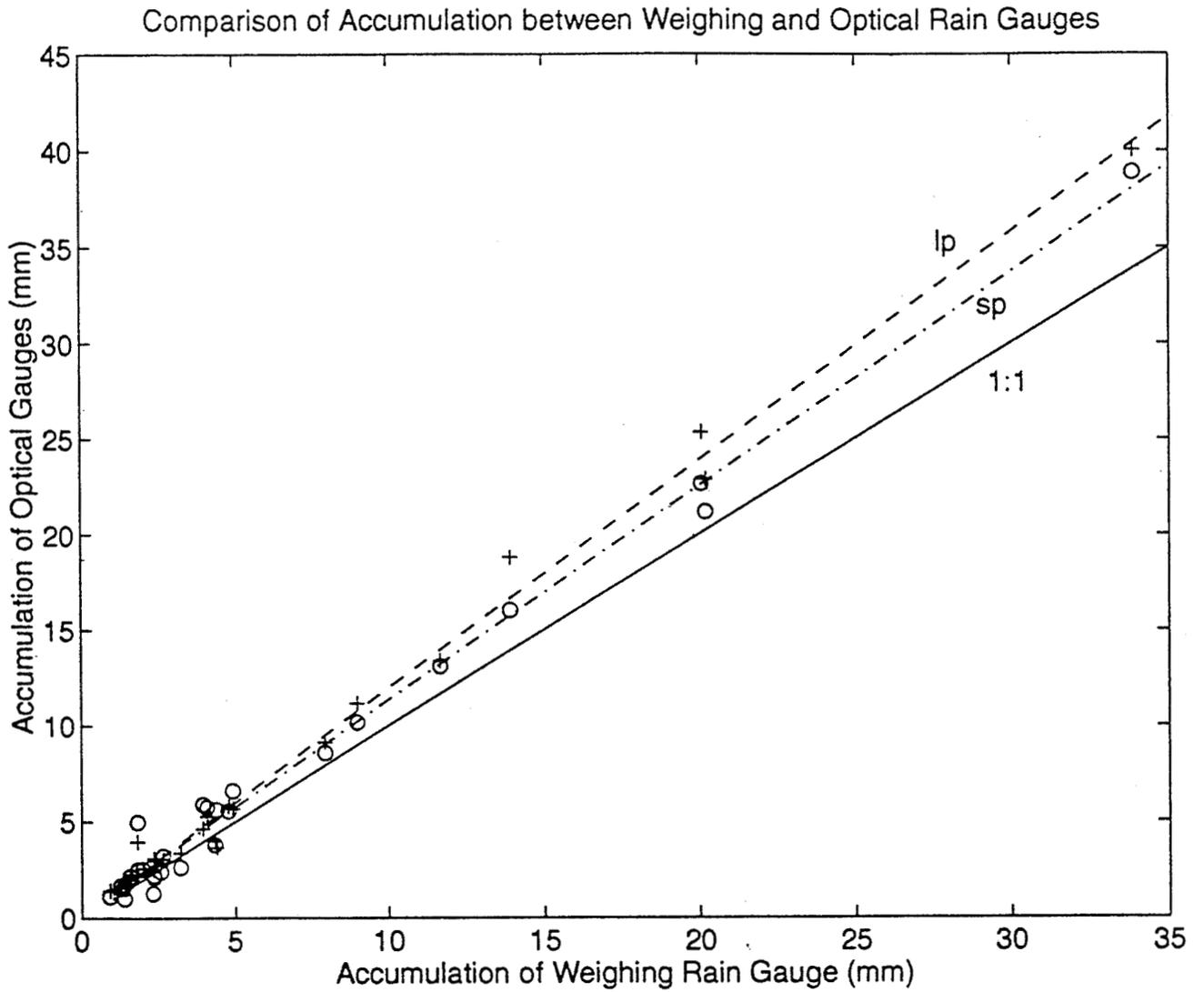


Figure 2b. A comparison of accumulation totals for 33 rainfall events in September and October 1993. The regression slope between the weighing rain gauge and the ORG-105 (sp,0) is 1.12 and for the ORG-705 (lp, +) is 1.19.

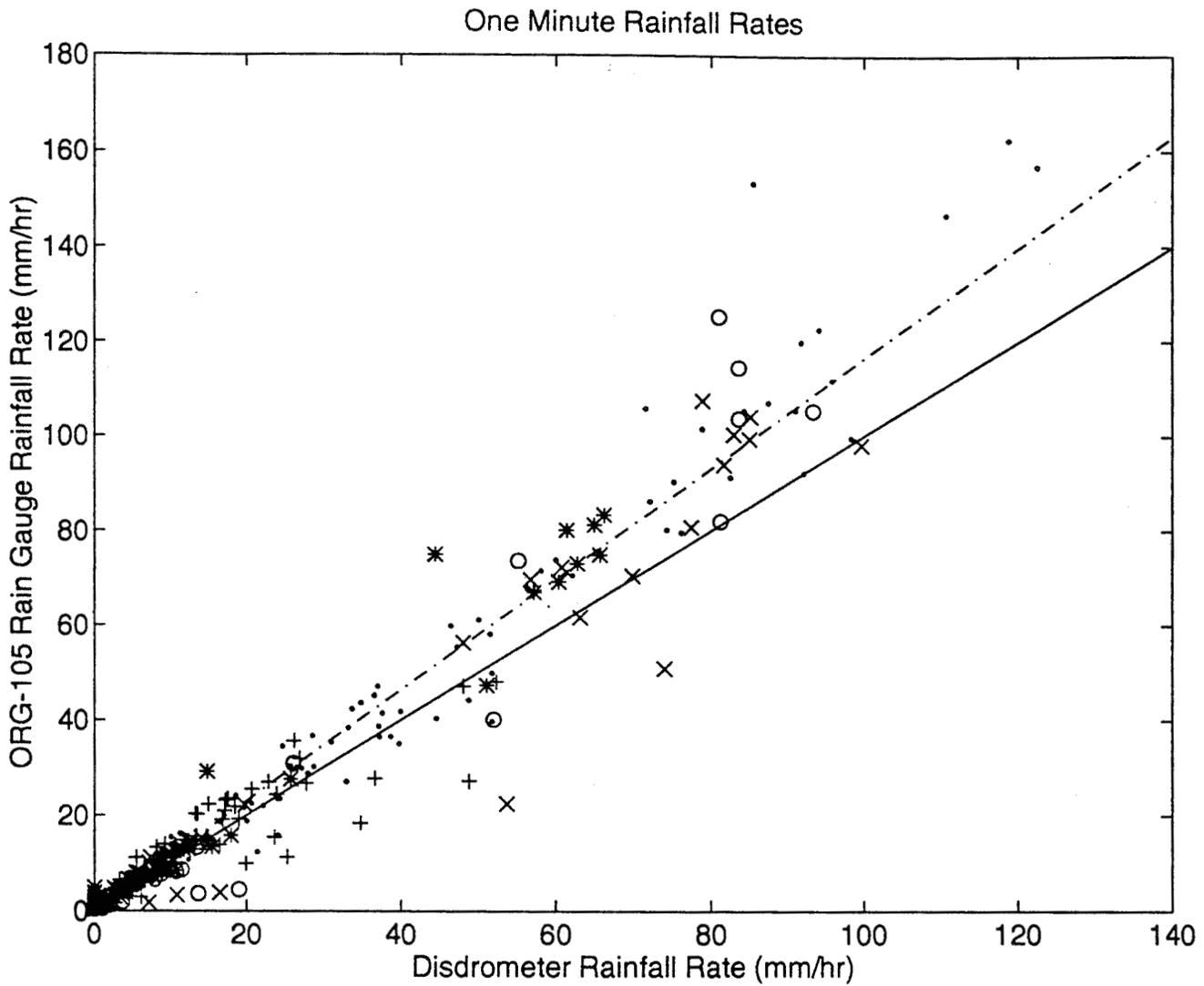


Figure 3. One minute rainfall rate estimates from the disdrometer and the ORG-105 optical rain gauges. The first order regression (dash-dot line) is shown. Data from five events (Event 271, *; Event 272, o; Event 275, x; Event 287, +; Event 289, •) are shown. Note the high correlation ($r = 0.98$) and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

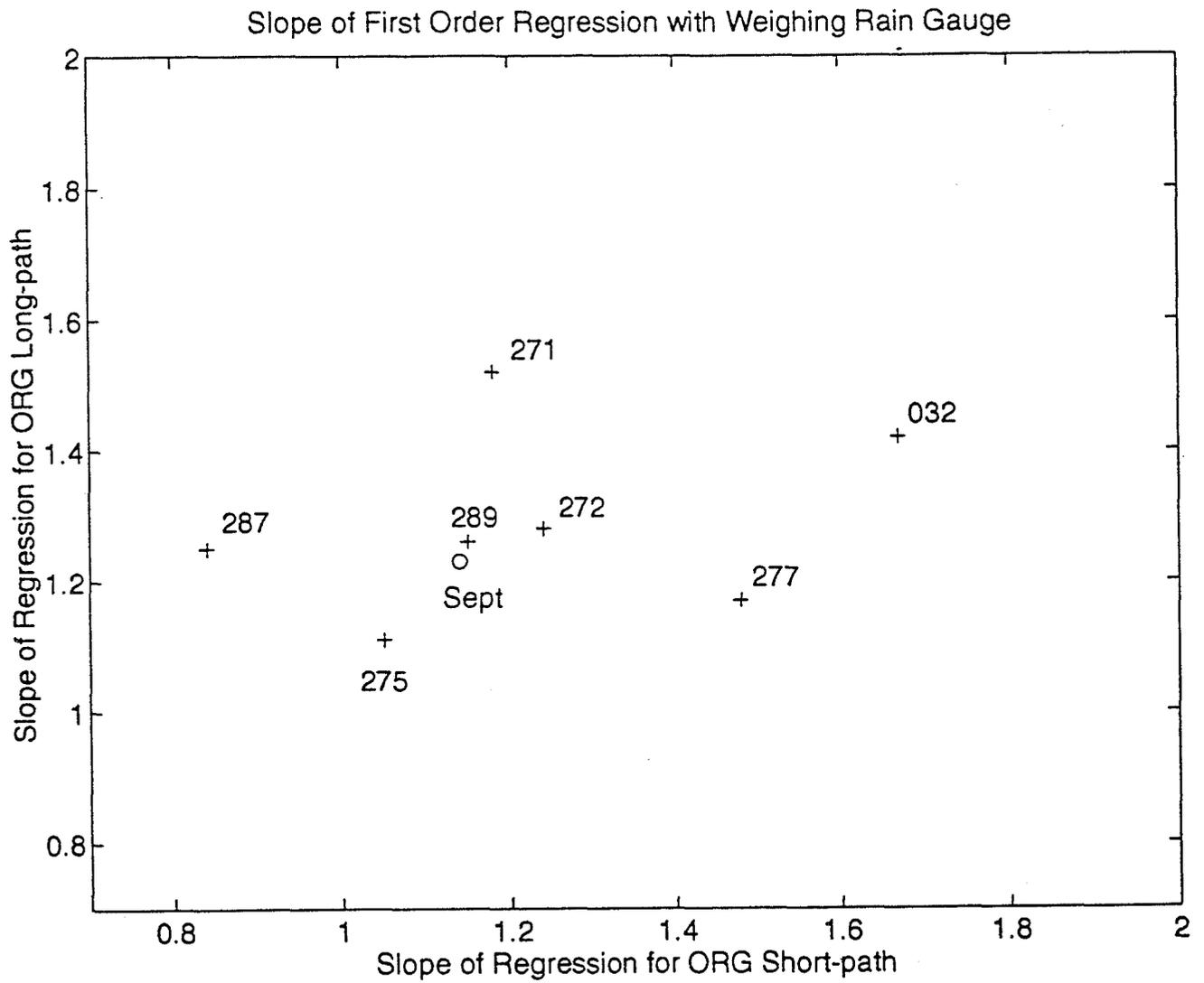


Figure 4. The slope of the first order regression between the weighing rain gauge and the ORG-105 (abscissa) and the ORG-705 (ordinate) for individual rain events. The events are identified by Julian date. The event on JD 032 (1994) is a light rainfall event (maximum rainfall rate 5 mm/hr). The other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

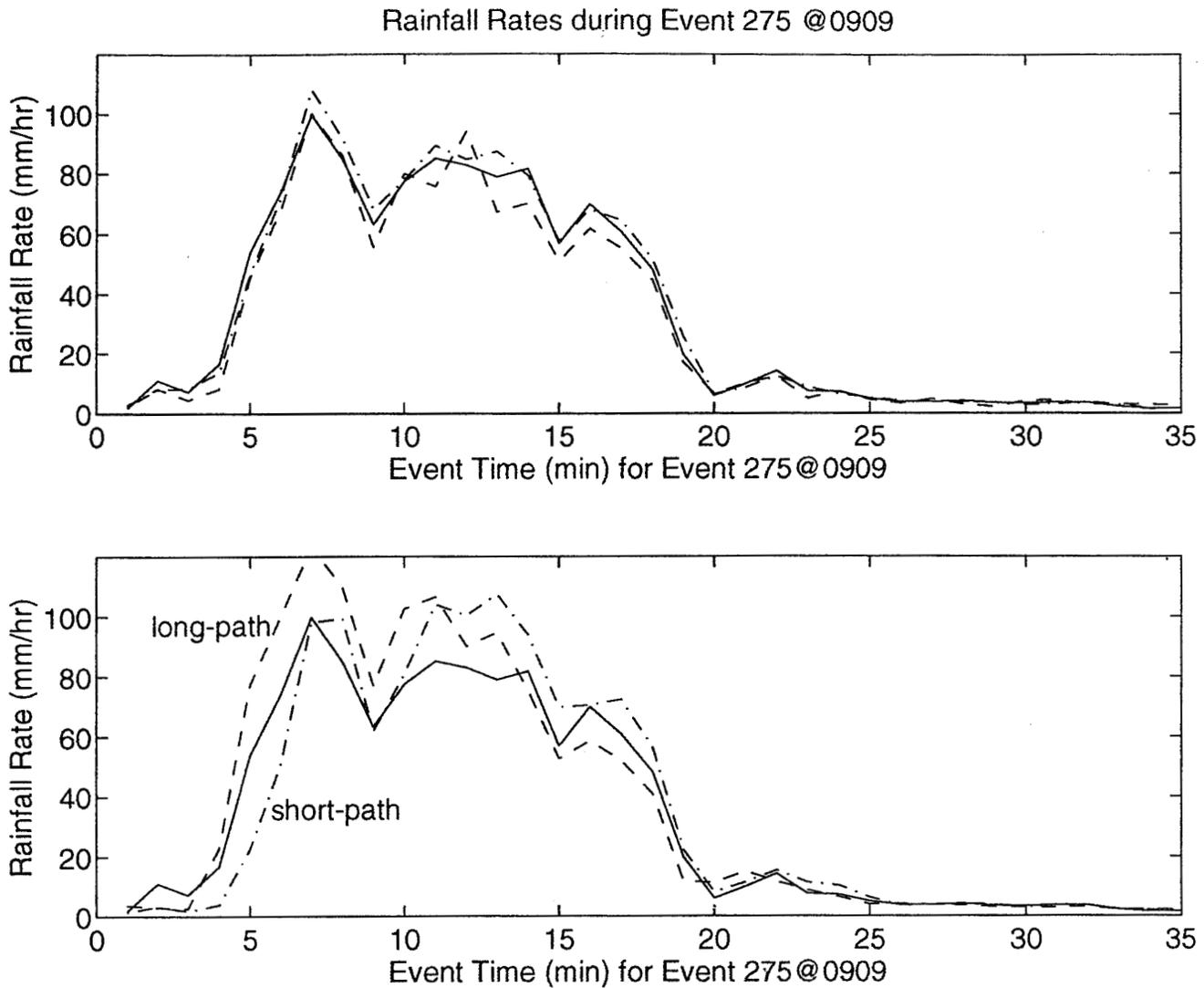


Figure 5. One minute rainfall rate estimates during Event 275. The upper panel shows that the rainfall rate measurements from the disdrometer (solid line), the capacitance rain gauge (dashed line) and the weighing rain gauge (dash-dot line) are in excellent agreement. The lower panel shows the rainfall 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.

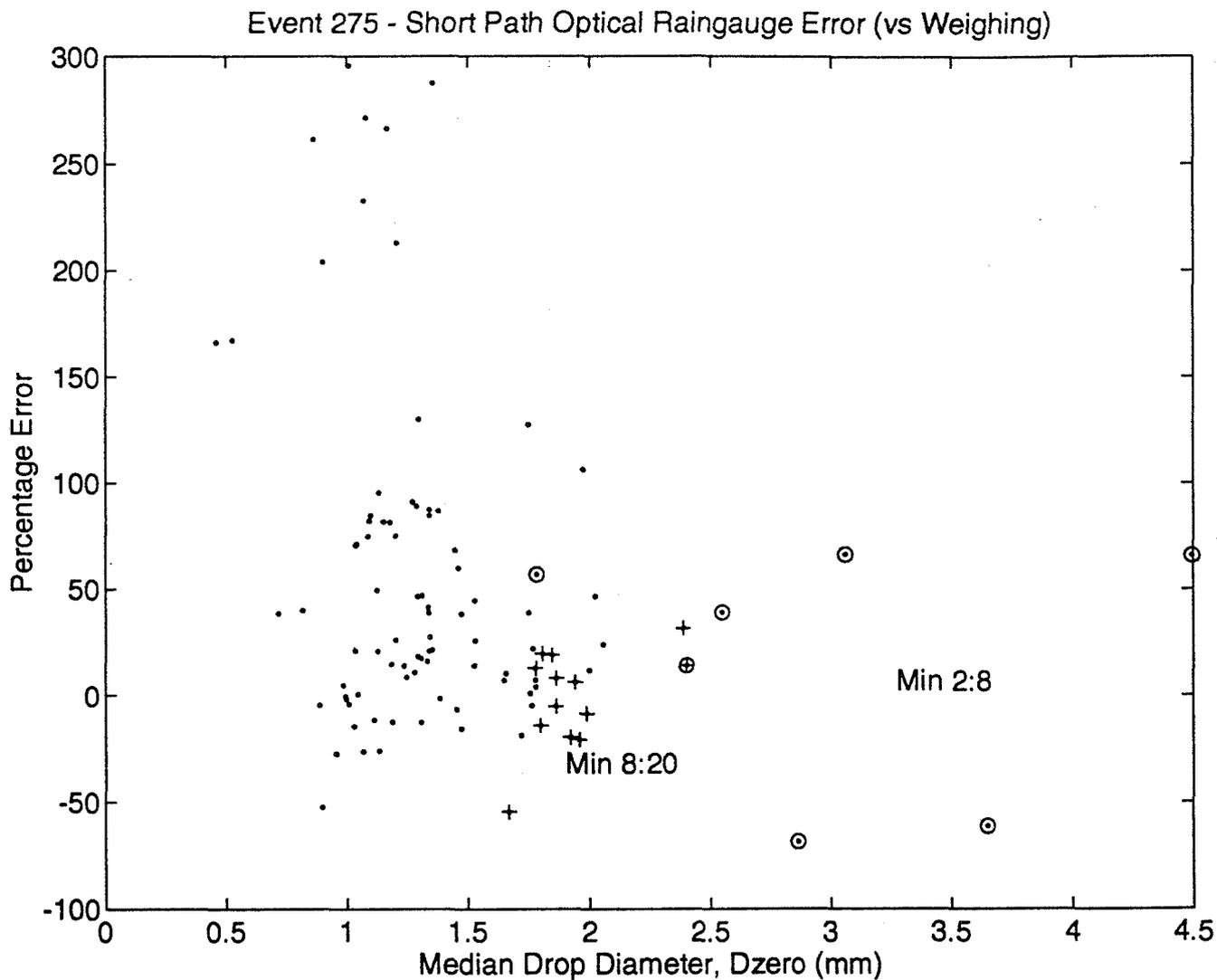


Figure 6. The percentage rainfall rate error between the ORG-105 (short-path) and the weighing rain gauge. The abscissa shows the median drop size (by liquid water volume, D_0 , calculated from the disdrometer data. During minutes 2-8 (⊙ symbol), the rainfall rate is increasing and the rain contains 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) (○ symbol), the rainfall rate is low (stratiform rain). No clear trend is evident in the percentage error values.

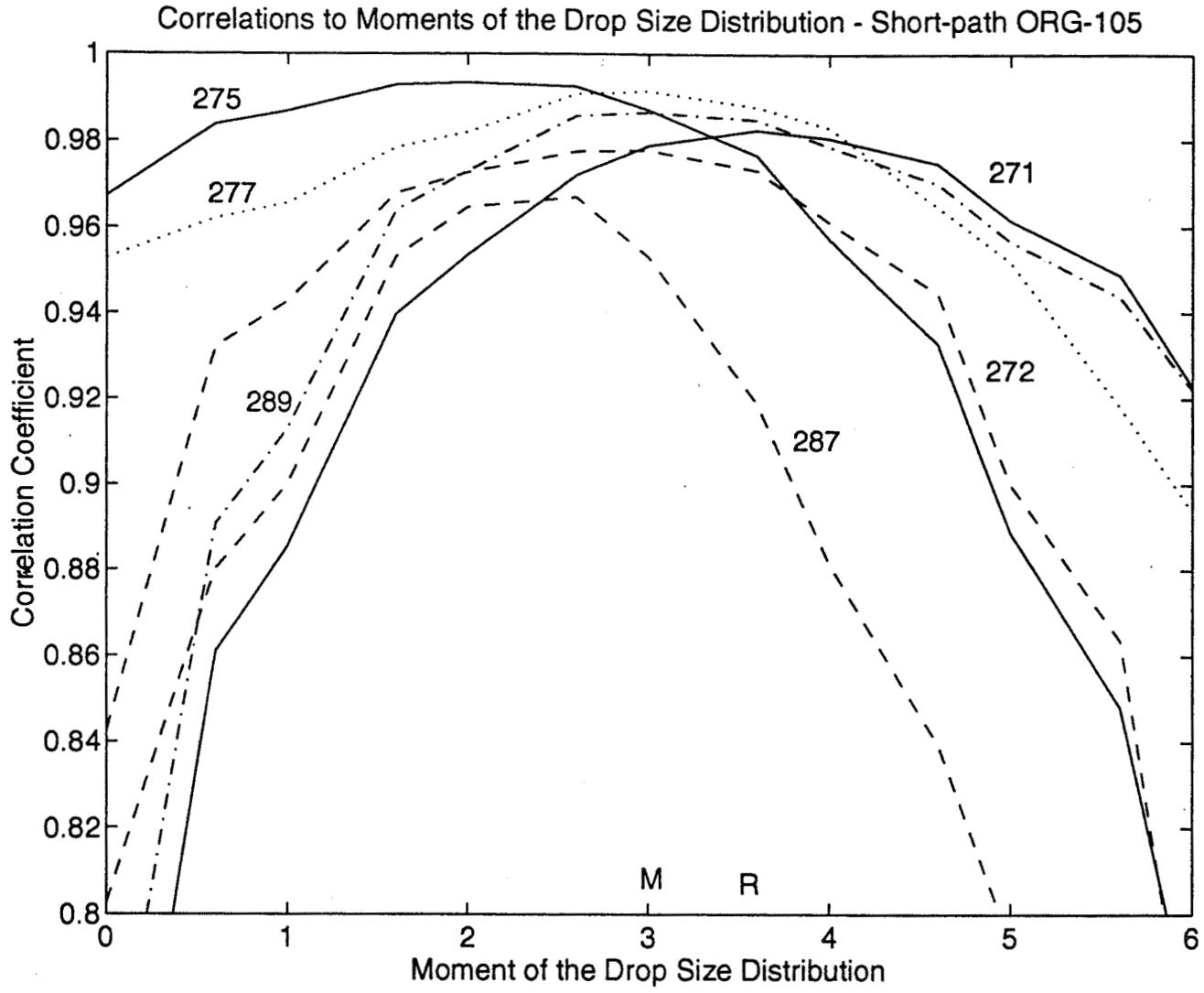


Figure 7. Correlation between the moments of the drop size distribution and the ORG-105 (short-path) rainfall rate estimate for 6 individual rain events. The rain events are identified by their Julian date. The highest correlation tends to be at a moment of the distribution that is less than rainfall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

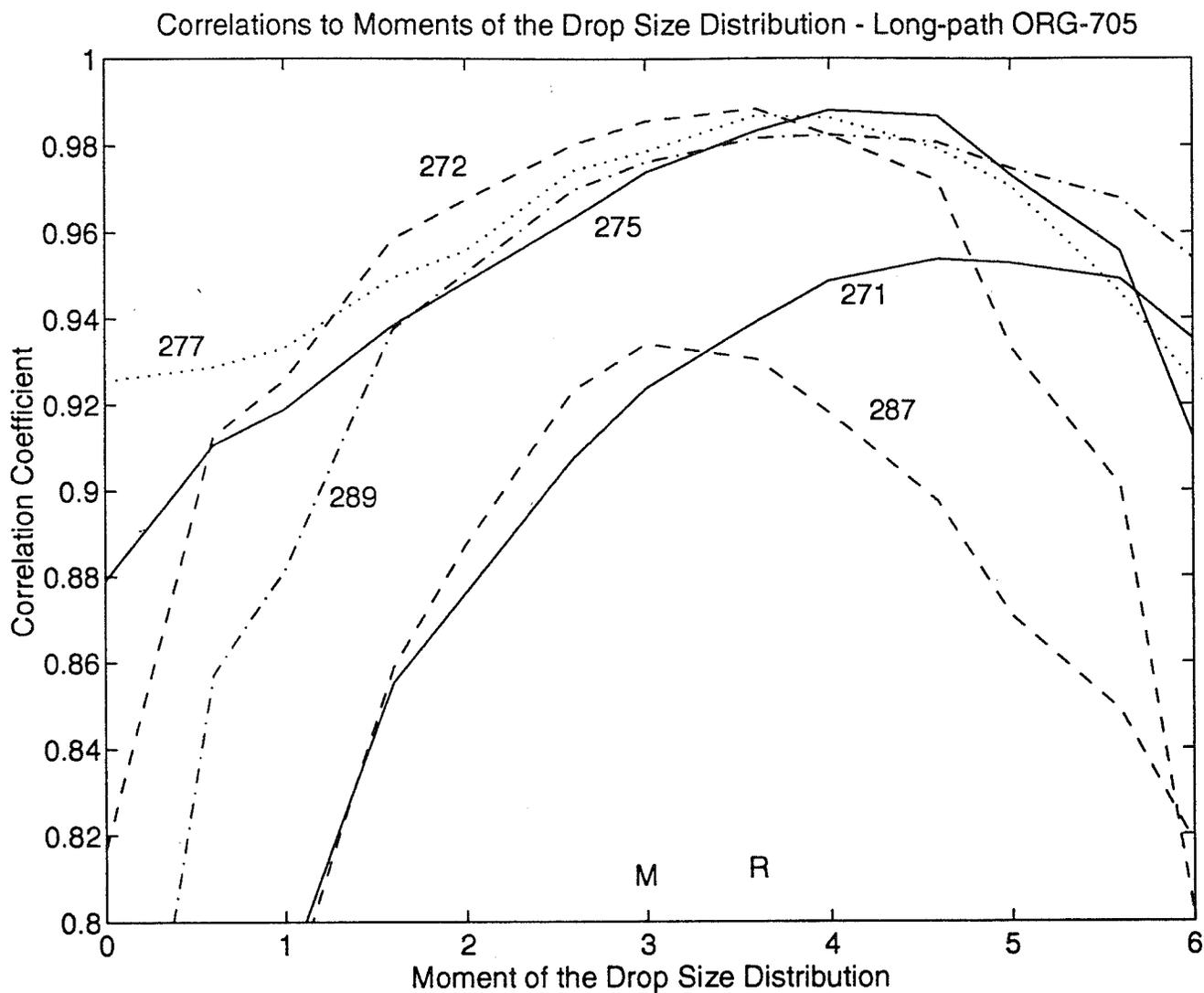


Figure 8. Correlation between the moments of the drop size distribution and the ORG-705 (long-path) rainfall rate estimate for 6 individual rain events. The rain events are identified by their Julian date. The highest correlation tends to be at a moment of the drop size distribution that is higher than 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.

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**WALLOPS ISLAND NATURAL RAIN
DATA ANALYSIS**

by Ting-i Wang, ScTI

ScTI has performed a detailed analysis of four (4) ORG-105 sensors tested by Wallops Island on 5/8/92. The four ORG's tested were S/N 2236, 2237, 2239, and 2241. Figure 1 shows a 30 minute time series of the individual ORG's, the ORG average, and the weighing gauge. The sensors tracked well with rainrates (RR) up to 45 mm/hr for the period. Figure 2 shows a plot of accumulated rainfall over the same period. It can be seen that even though the ORG's tracked well, some ORG's tended to read higher and some read lower during the event.

The individual ORG's were normalized to the ORG average and plotted again in Figure 3. The normalized coefficients are:

ORG S/N	Coefficient
2236	1.397
2237	1.108
2239	1.138
2241	0.997

Figure 4 shows the accumulated rainfall for the normalized ORG data. As can be seen by the very tight fit of the data, the application of a simple coefficient is sufficient to correct the data over the entire event with rainrates up to 45 mm/hr.

Figures 5 - 8 are graphs of the "percent difference" between each individual normalized sensor and the ORG average. The calculation of the percent difference was made as follows:

ORG average RR < 10 mm/hr

$$(\text{individual sensor RR} - \text{ORG average}) / 10$$

ORG average rainrate \geq 10 mm/hr

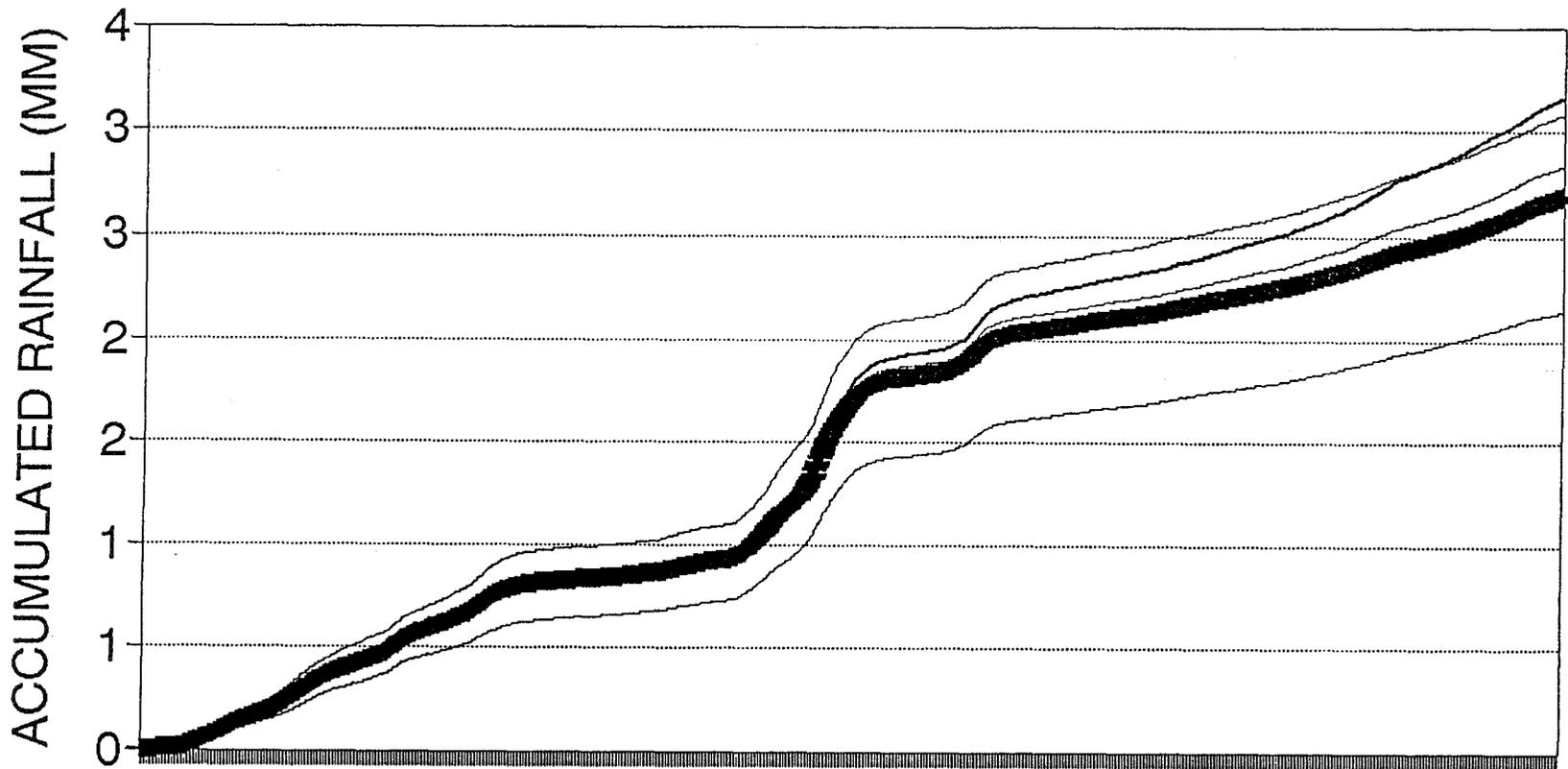
$$(\text{individual sensor RR} - \text{ORG average}) / \text{ORG average}$$

Most of the data is within +/- 10% with a standard deviation of less than 5%. Because of the ORG time resolution of 10 seconds, we believe that most of the fluctuations are caused by the fine space structure of the rain cell.

The final graph shown in Figure 9 is the percent difference of the weighing gauge to the ORG average. It shows more scatter than any of the ORG's. Unfortunately other meteorological data such as wind were not available for further studies.

WALLOPS ISLAND NATURAL RAIN

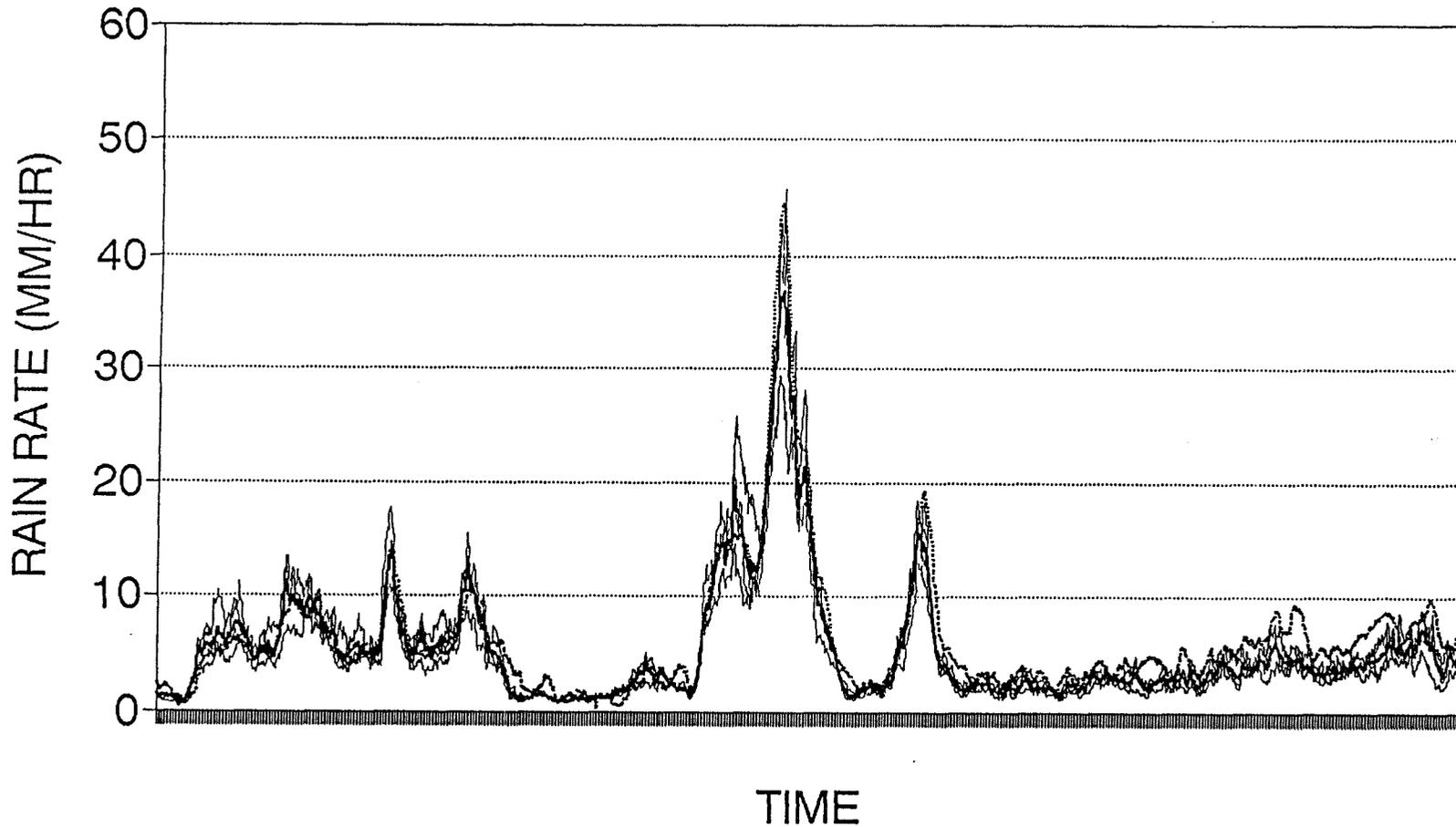
A331-62(05/08/92 05:34:23)



— ORG's (RAW) + ORG AVG — WG

WALLOPS ISLAND NATURAL RAIN

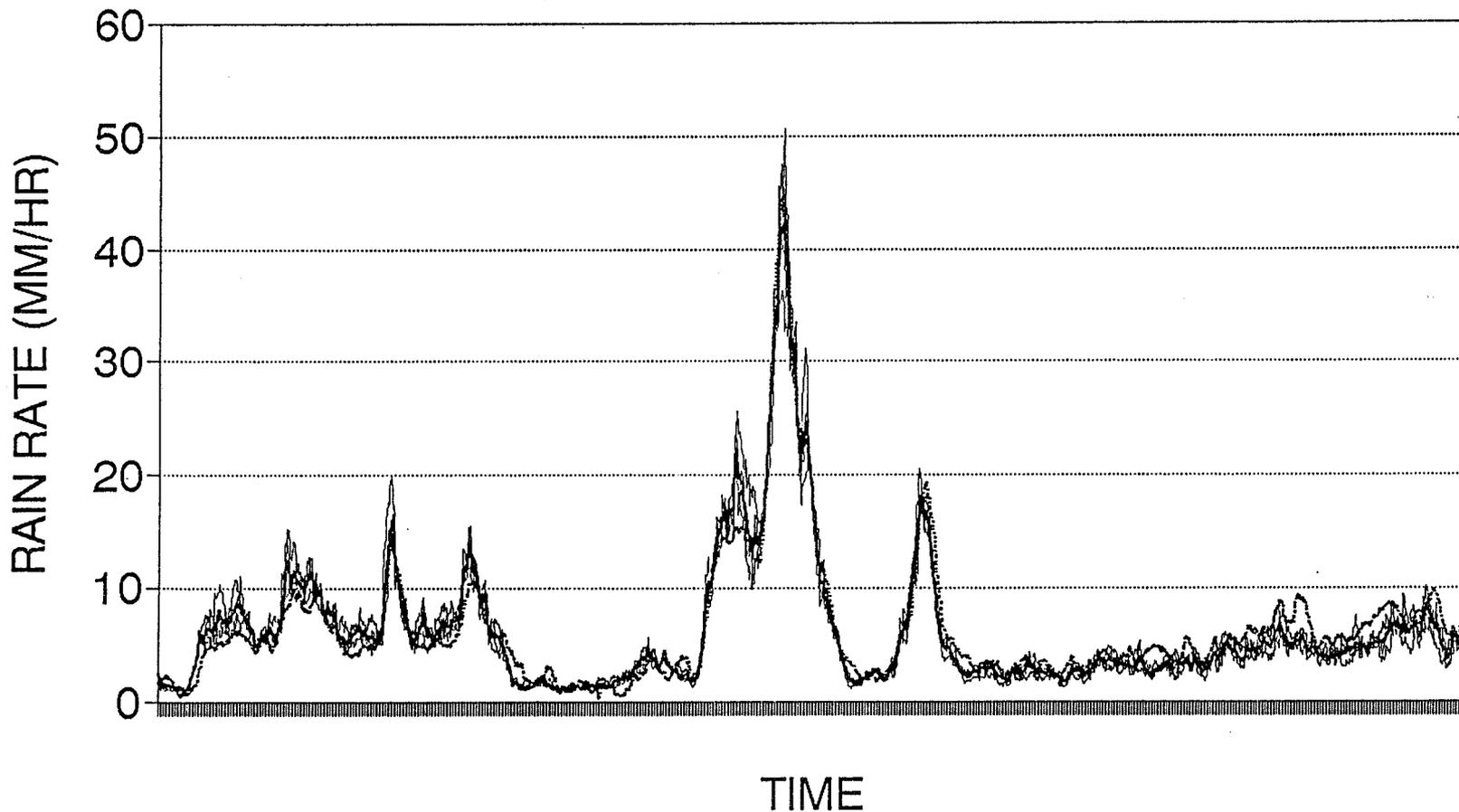
A331-62(05/08/92 05:34:23)



— ORG's (RAW) — ORG AVG WG

WALLOPS ISLAND NATURAL RAIN

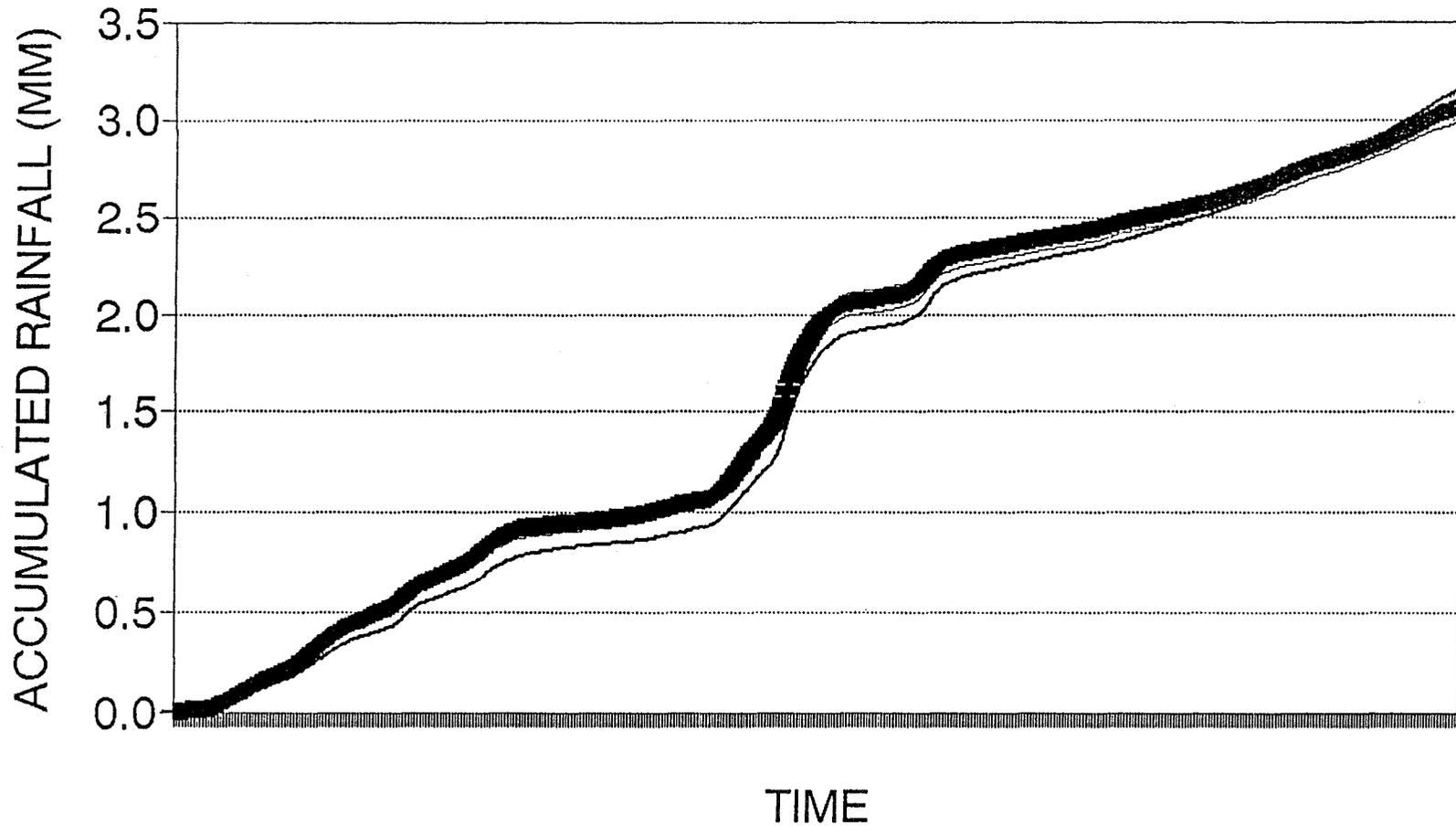
A331-62(05/08/92 05:34:23)



— NRMLZED ORG's — ORG AVG WG

WALLOPS ISLAND NATURAL RAIN

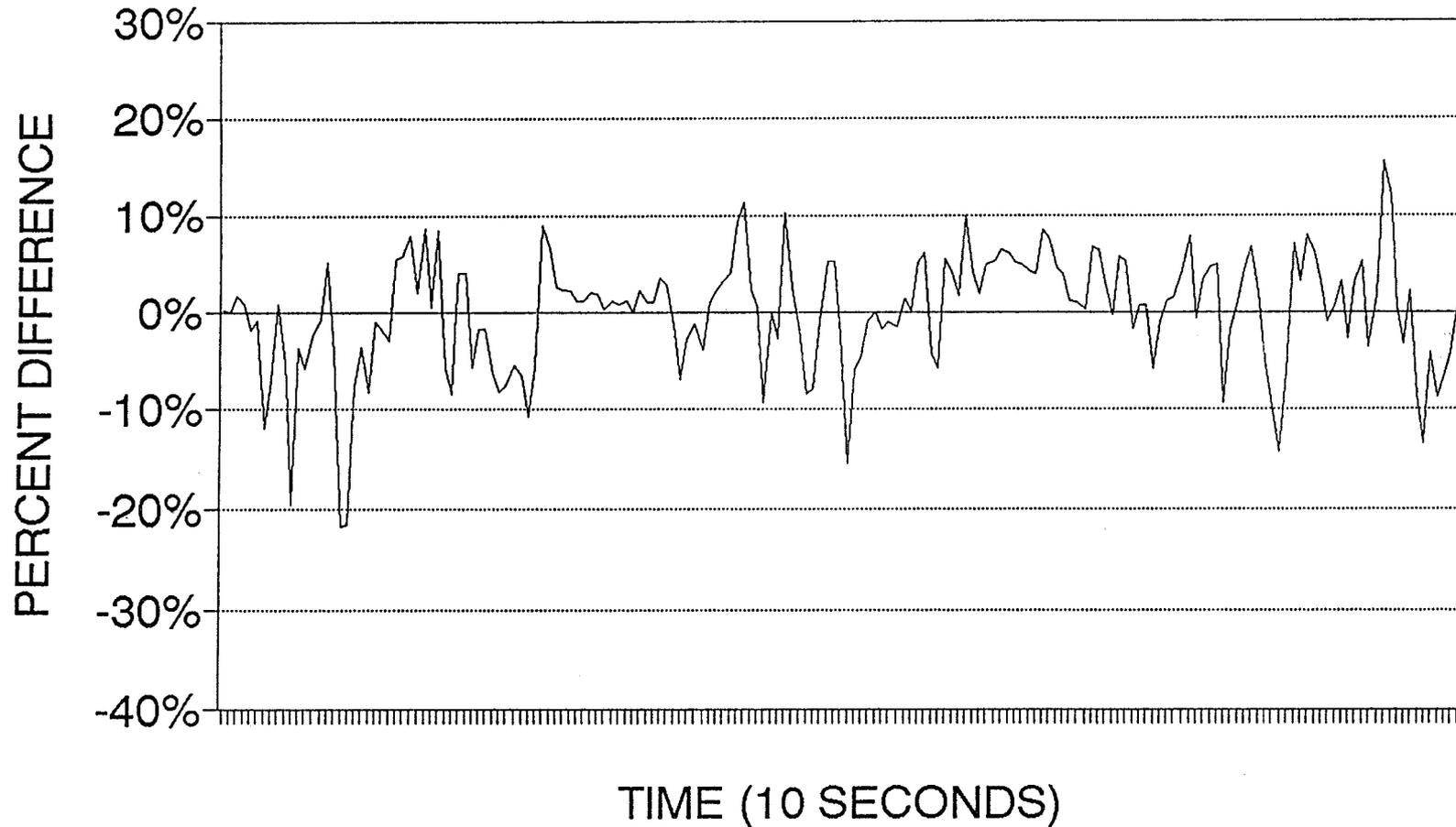
A331-62(05/08/92 05:34:23)



— NRMLZED ORG's + ORG AVG — WG

WALLOPS ISLAND NATURAL RAIN

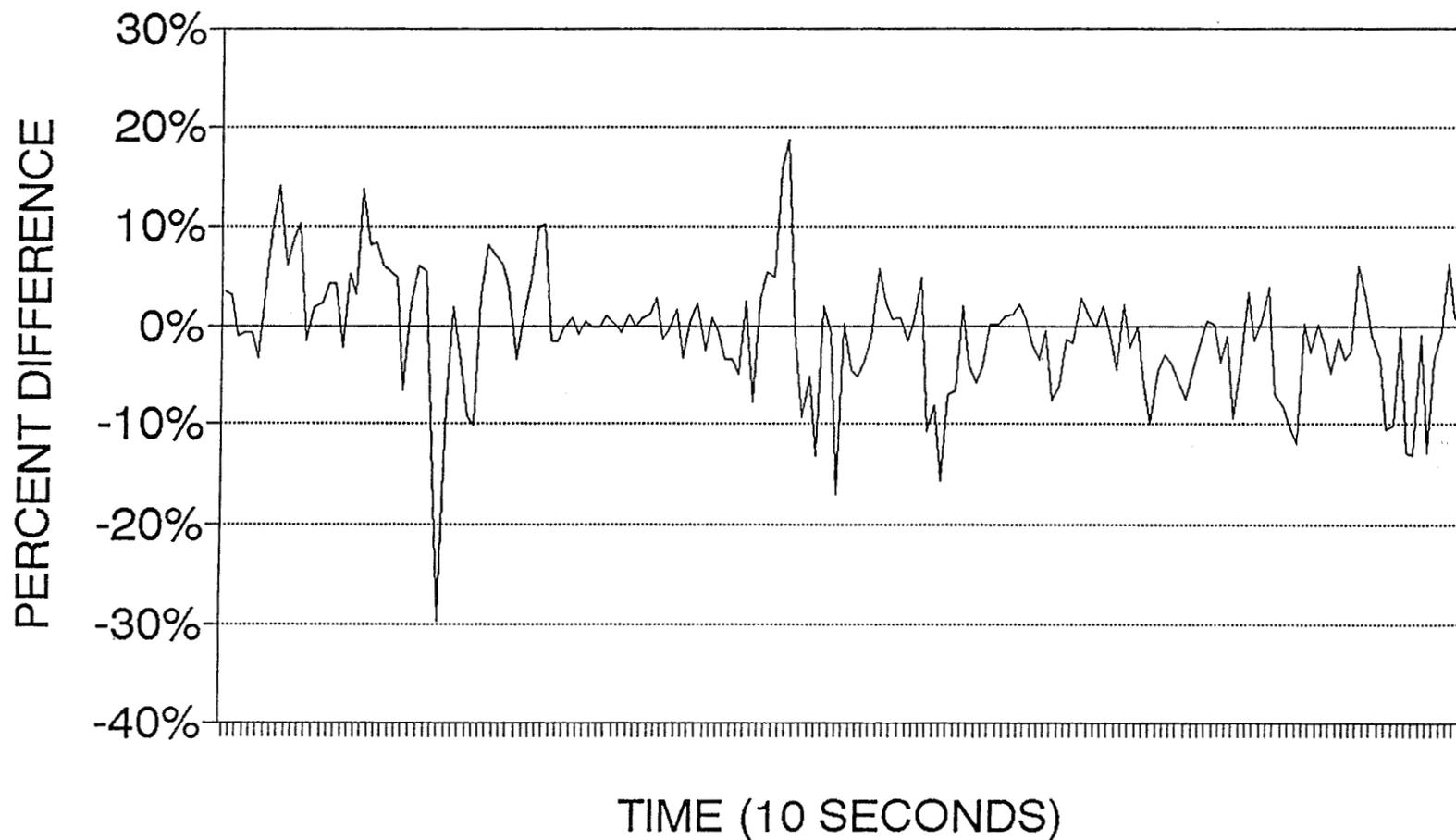
A331-62(05/08/92 05:34:23)



— 2239(NORMALIZED)

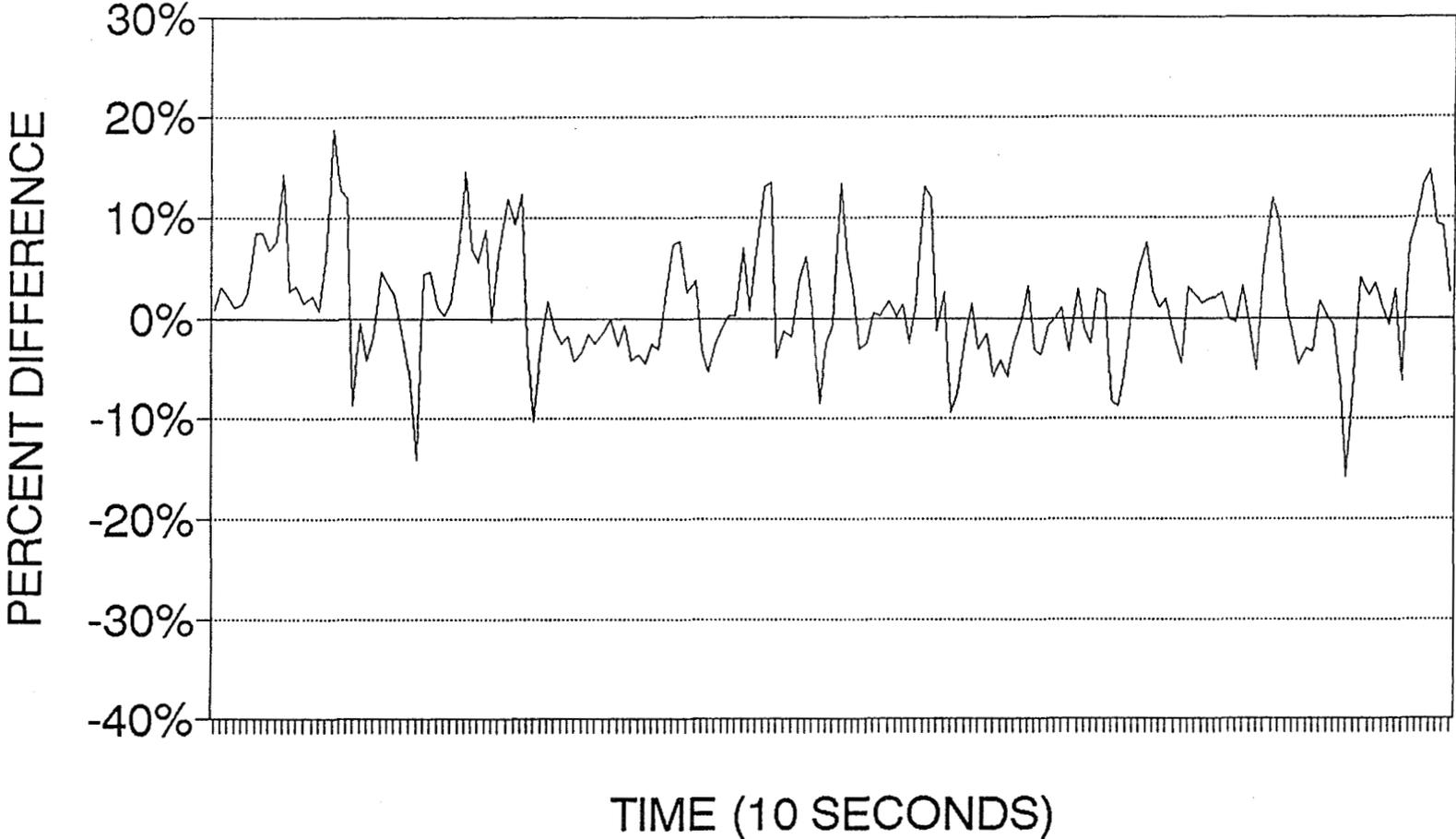
WALLOPS ISLAND NATURAL RAIN

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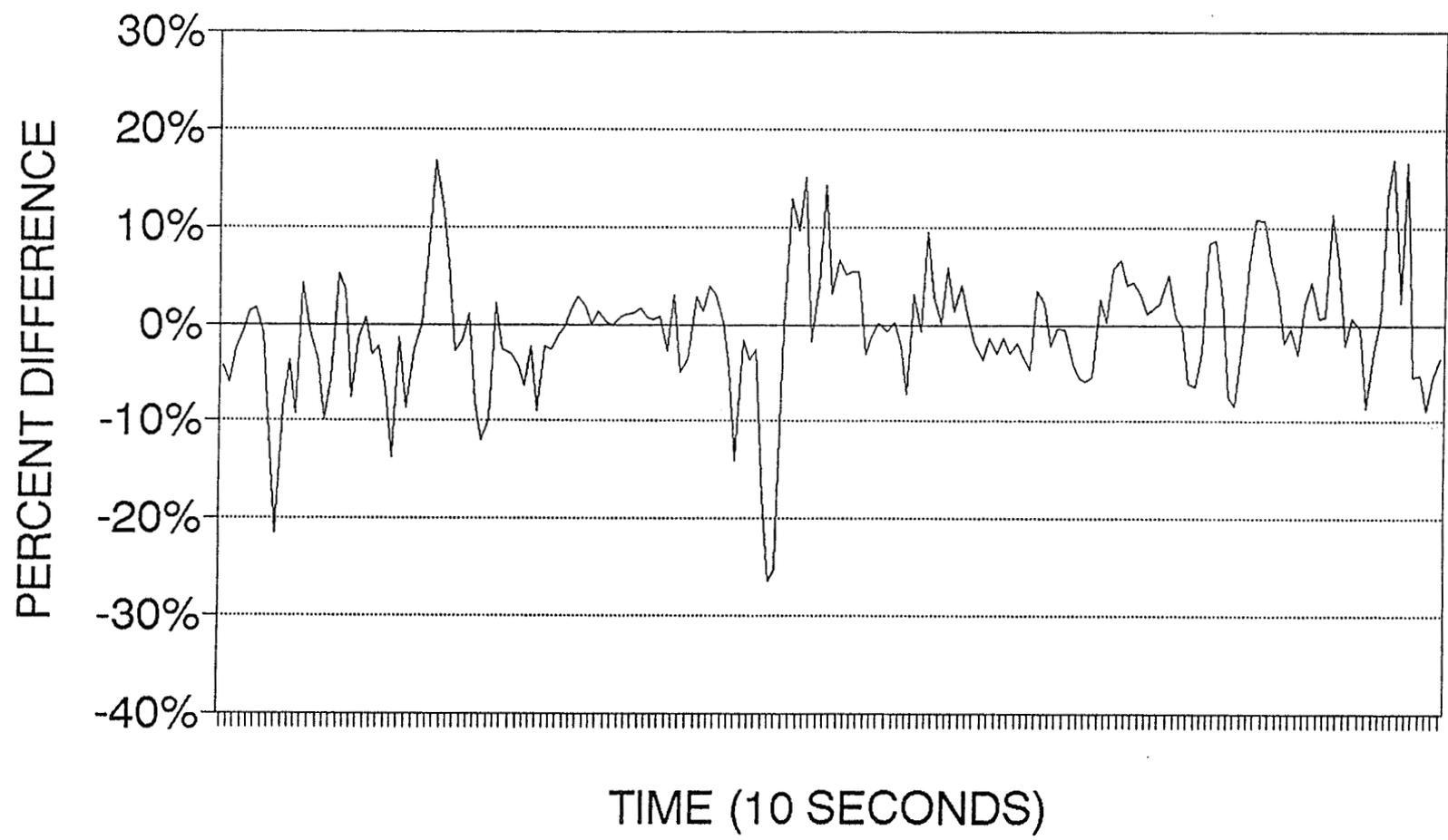
WALLOPS ISLAND NATURAL RAIN

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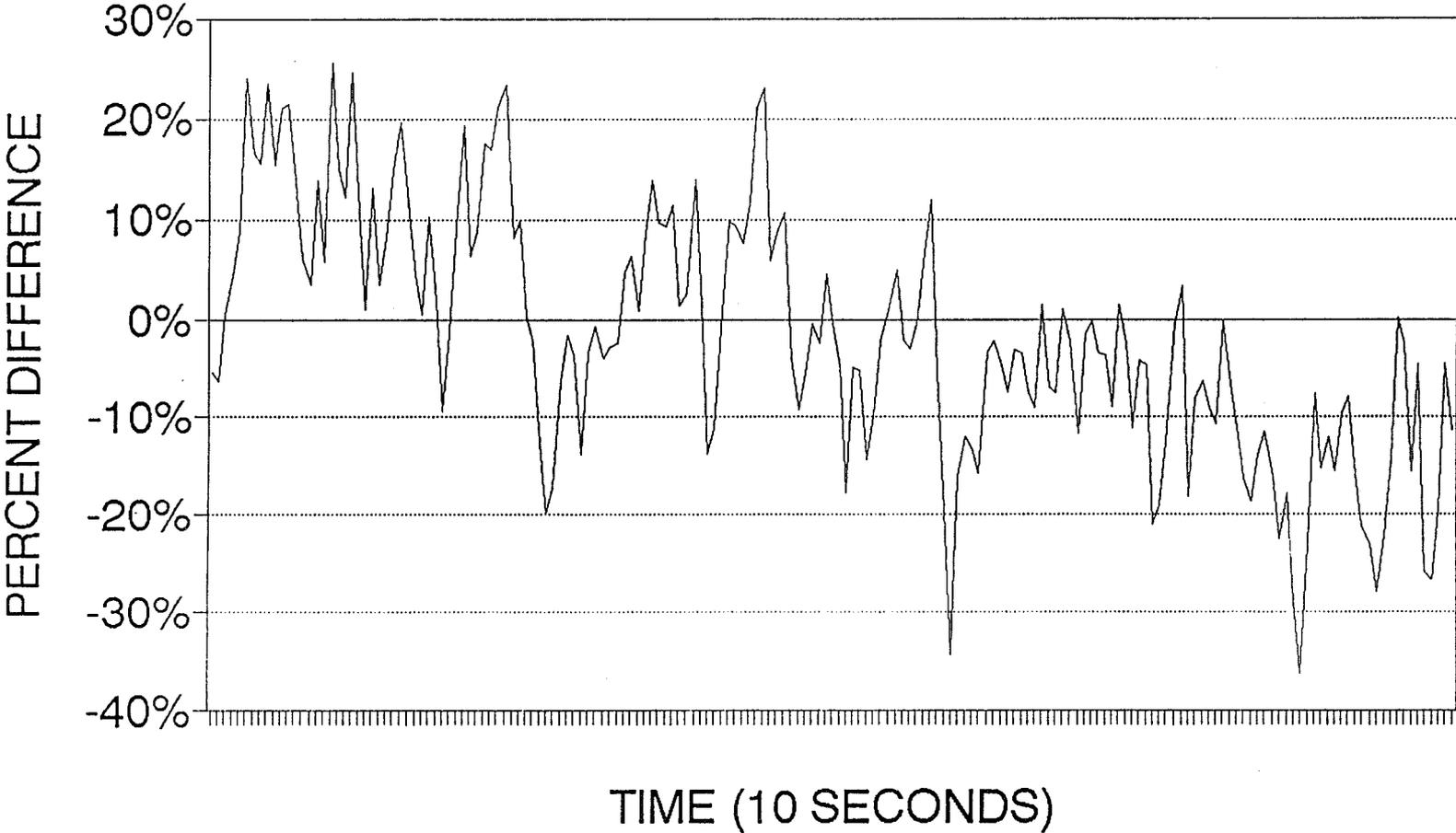
WALLOPS ISLAND NATURAL RAIN

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WALLOPS ISLAND NATURAL RAIN

A331-62(05/08/92 05:34:23)



— WG

Vibration (?) Spikes During Natural Rain Events

David A. Short
TRMM Office
NASA/Goddard Space Flight Center
Greenbelt, Maryland

Limited analysis of ORG data from shipboard and ground based sensors has shown the existence of spikes, possibly attributable to sensor vibration, while rain is occurring. An extreme example of this behavior was noted aboard the PRC#5 on the evening of December 24, 1992 as the ship began repositioning during a rain event (Fig. 1) in the TOGA/COARE IFA. The spikes are readily evident in the one-second resolution data, but may be indistinguishable from natural rain rate fluctuations in sub-sampled or averaged data. Such spikes result in increased rainfall totals.

The PRC#5 ORG data are being re-analyzed to isolate events observed while the ship was drifting from those observed while underway and to examine rain rate statistics for the two subsets.

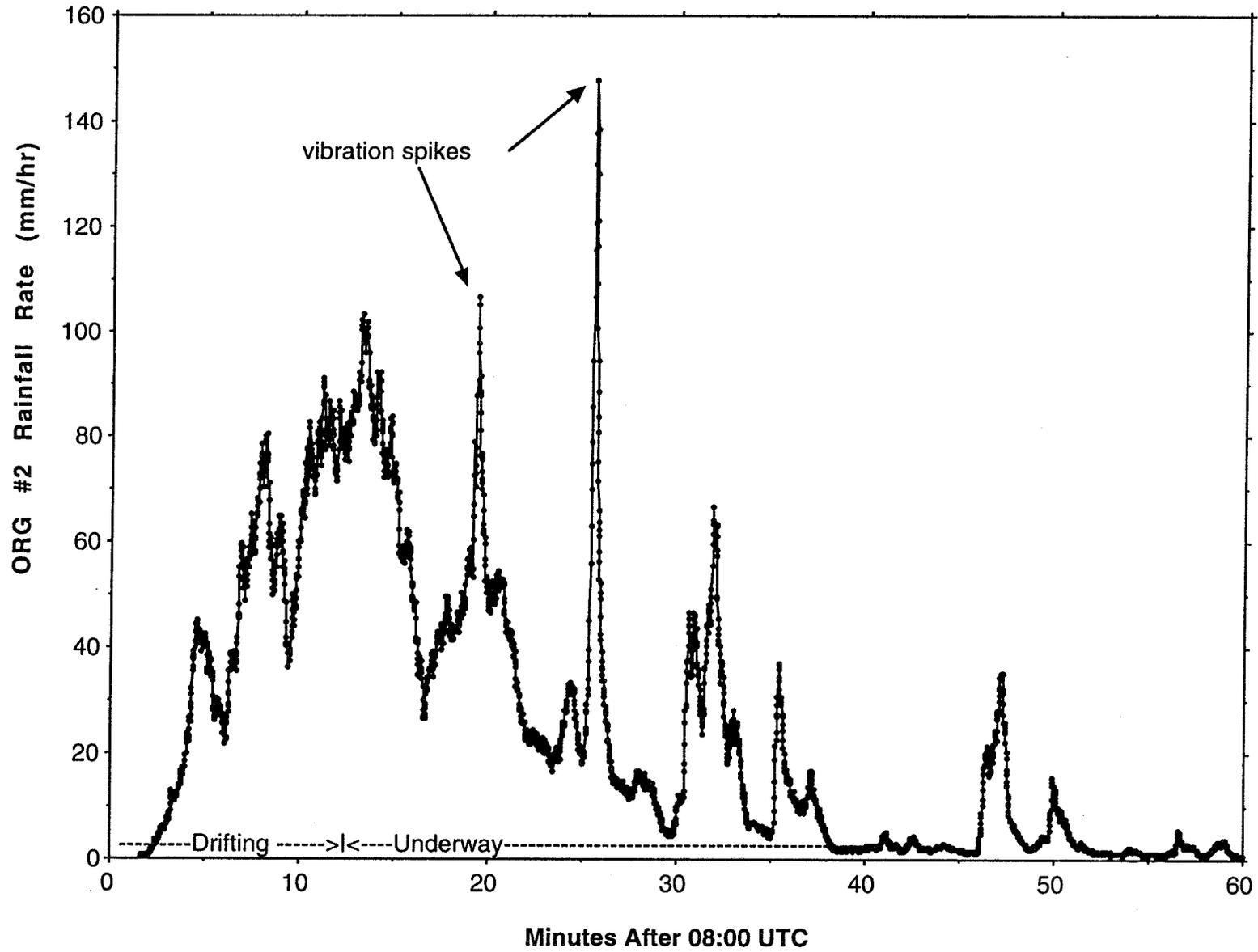
Figure 2 shows another example of spikes reported by the ORG aboard the RV Franklin on November 27, 1992, also during TOGA/COARE. The Franklin data were recorded every 5 seconds.

Such erratic behavior appears to be exceedingly rare when the sensors are land based. However, Fig. 3, showing an inter-comparison of rain rates reported by 6 ORGs at Wallops Flight Facility, indicates that one sensor was reporting rapidly fluctuating, high rainfall rates while the other sensors showed almost nothing. The wind speed was about 10 m/s and all the sensor were mounted on the same platform.

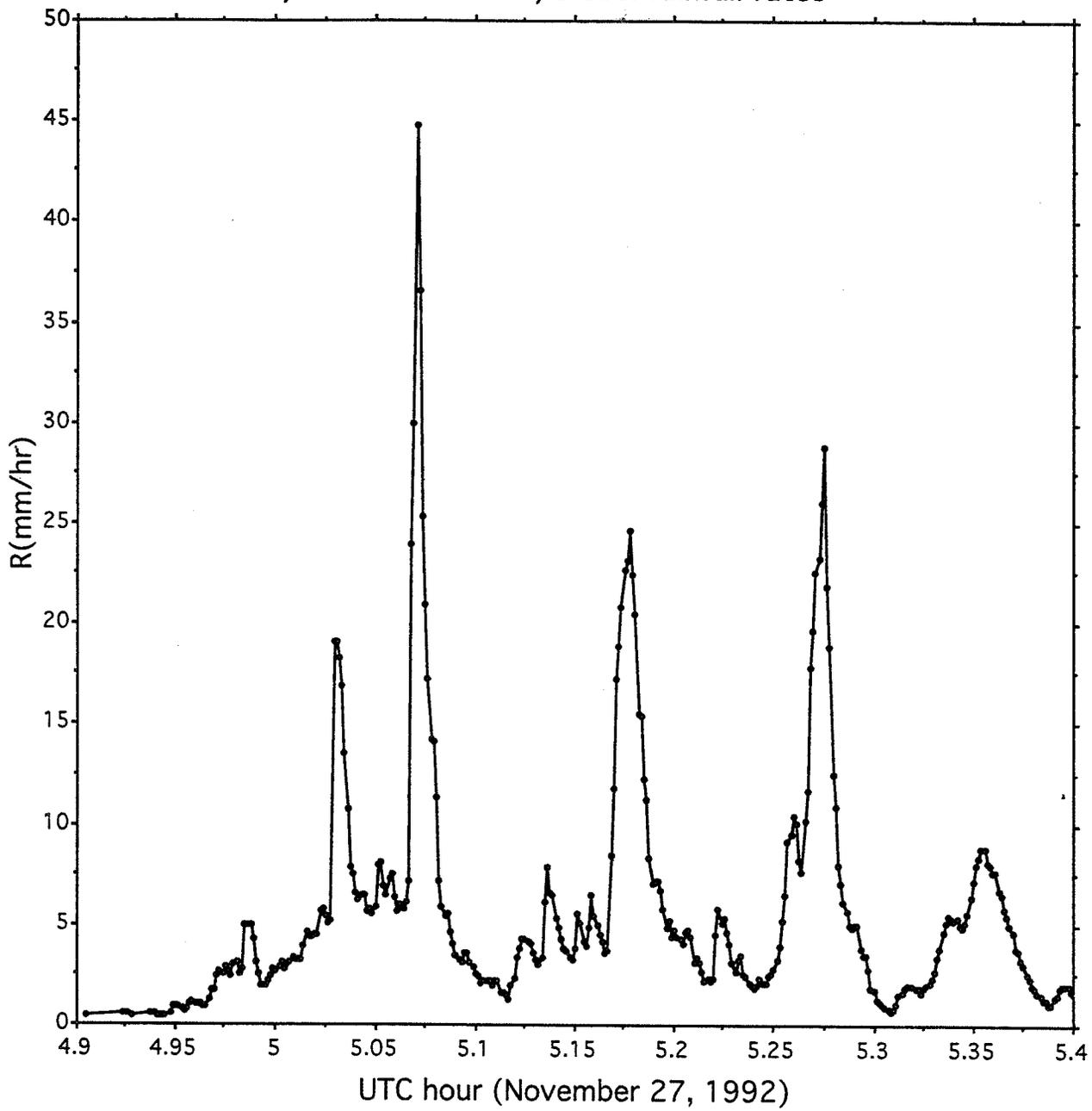
It is not known at this time whether such spikes affect rainfall reports from the ORGs deployed on buoys, as data transmission constraints limit reports to hourly statistics, as computed by an on-board processor.

Pre- and post-COARE calibration studies with land-based ORGs in natural rain have given good indications of reliable performance, with some need for a sensor-dependent, calibration offset, as reported elsewhere during the workshop. Fig. 4 shows a typical example of rain totals from natural rain events recorded by the RV Franklin and PRC#5 ORGs, compared to totals from a precision weighing gauge at the Wallops test facility after the TOGA/COARE IOP.

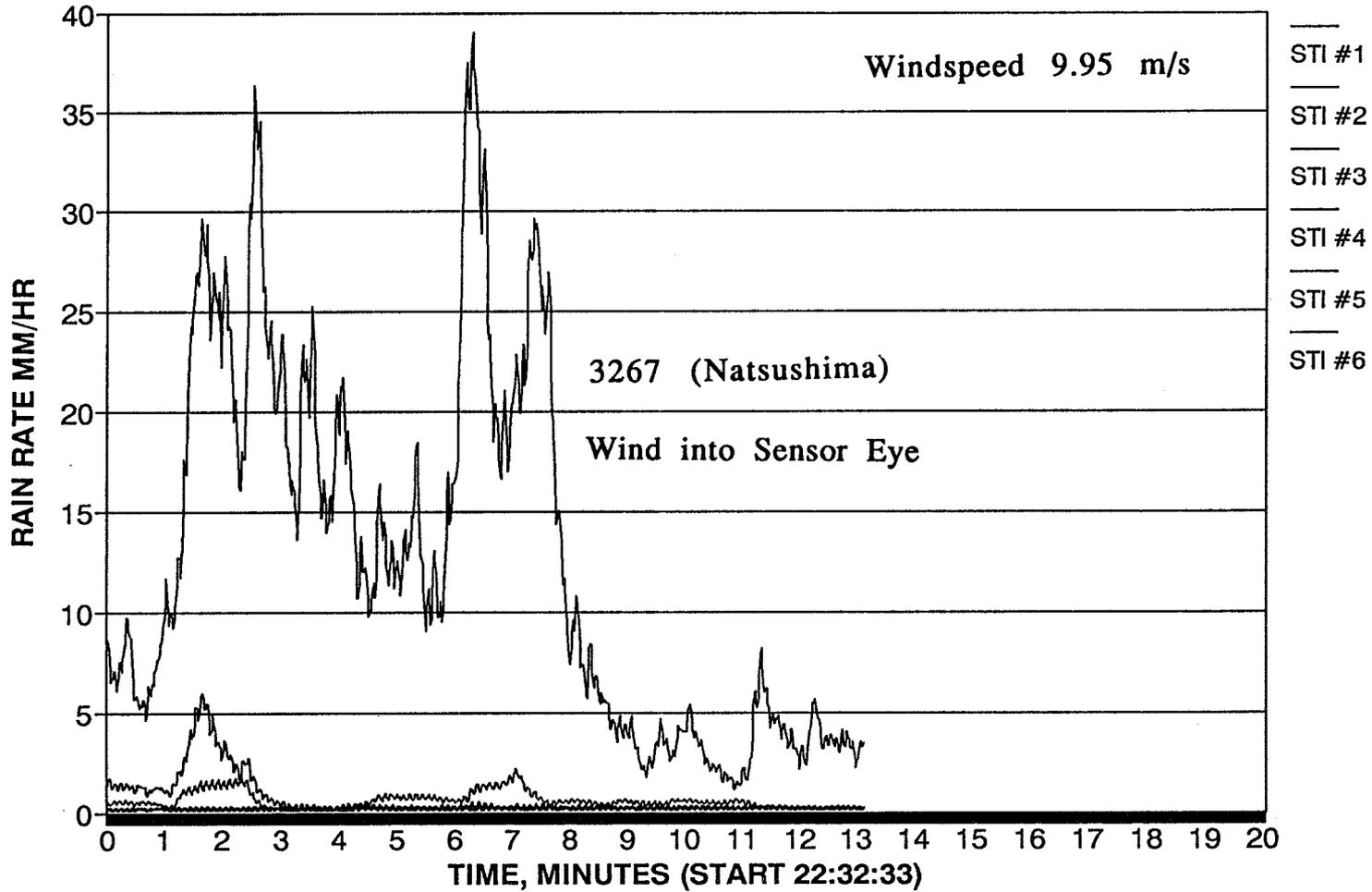
PRC#5, 24 December 1992, {2° 5' S, 155° 15' E}, TOGA/COARE IFA



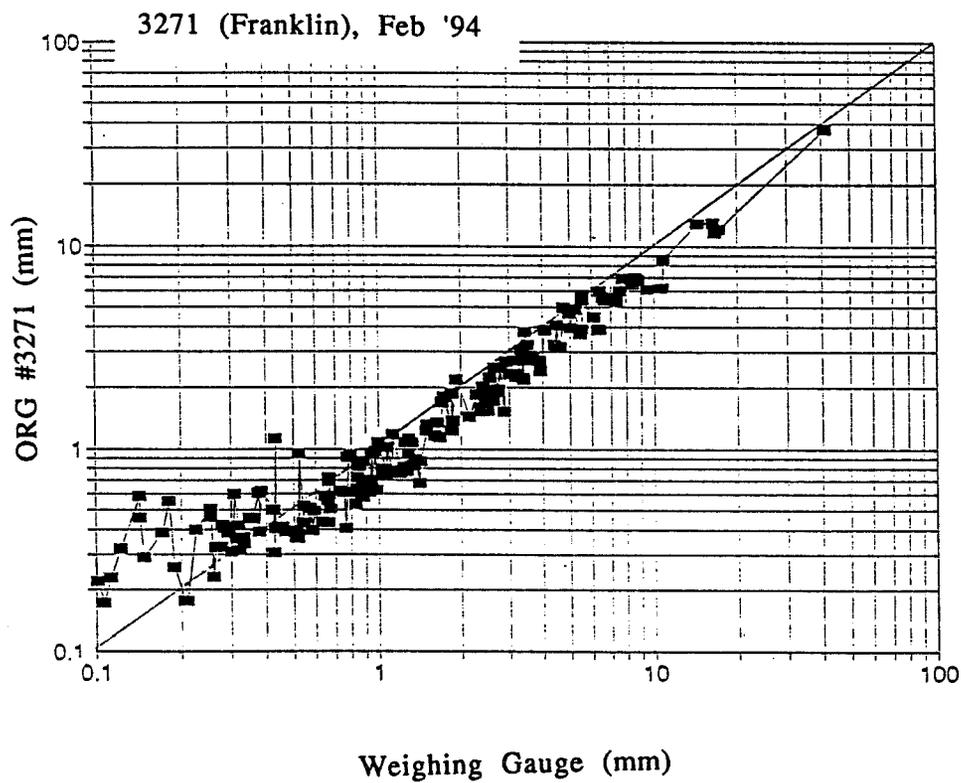
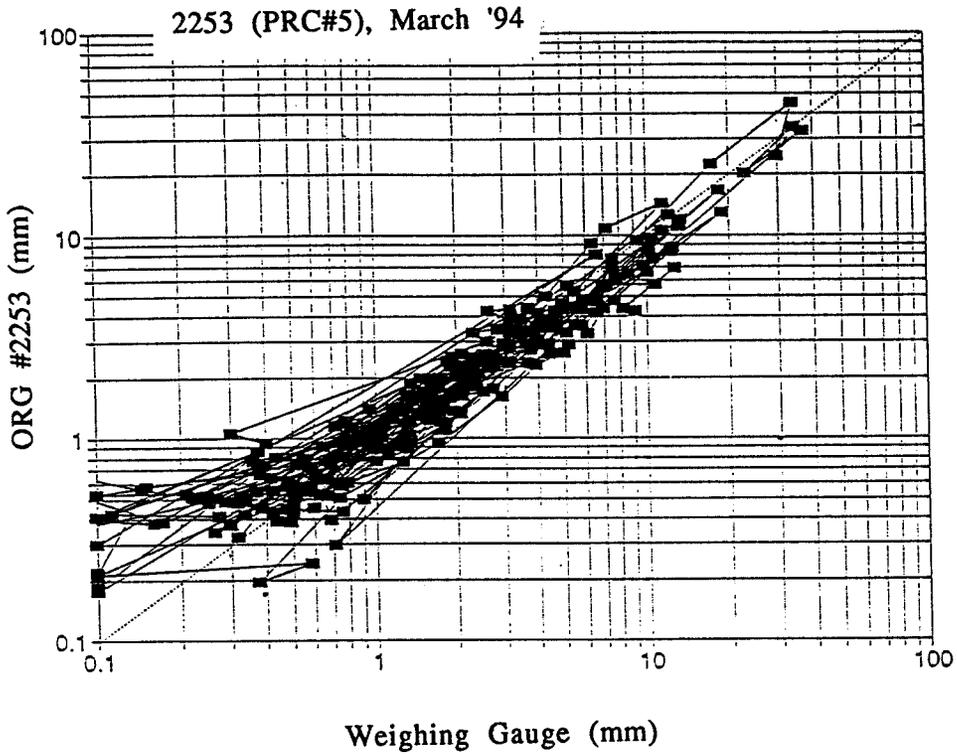
RV Franklin, mini-ORG #3271, 5 sec. rainfall rates



NATURAL RAIN .03/02/94
1-6 STI'S FILE A764_47



Natural Rain Events at the NASA/Wallops Flight Facility



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61

A Comparison of Optical Rain Gauge and Radar Data from
TOGA/COARE

Linda Galusha
Atmospheric Sciences Group
Texas Tech University
Lubbock, Texas

A comparison between raingage data and radar data from TOGA/COARE was studied. The raingage data from an echo that passed over the Xiangyanghong #5 on December 24, 1992 was compared to what the MIT radar saw at this location from the R/V Vickers, 103.4 km to the east. The precipitation measured by the raingage peaked at 108 mm/hr 92 seconds into the period before tapering off 11 1/2 minutes later. This sharp gradient was evident in a PPI plot of the radar reflectivities and the percentage area-rainfall for the radar data statistics. The percentage area curve was converted to rainrates using a GATE Z-R ($Z=230R^{1.25}$) and compared to a percentage time curve of rainrates according to the raingage. A four minute running average applied to the raingage rates improved the comparison of peak rates between the raingage and radar. Differences in peaks between rainrates observed by the raingage and reflectivities observed by the radar could be due to variations in rainfall rates within a single radar data bin. For example, two measurements of reflectivity such as 37 and 47 dBZ within the same bin would result in a 44 dBZ average. This range in rates from 12 mm/hr to 74 mm/hr is observed in 30 seconds by the raingages within the first two minutes of the radar echo passage.

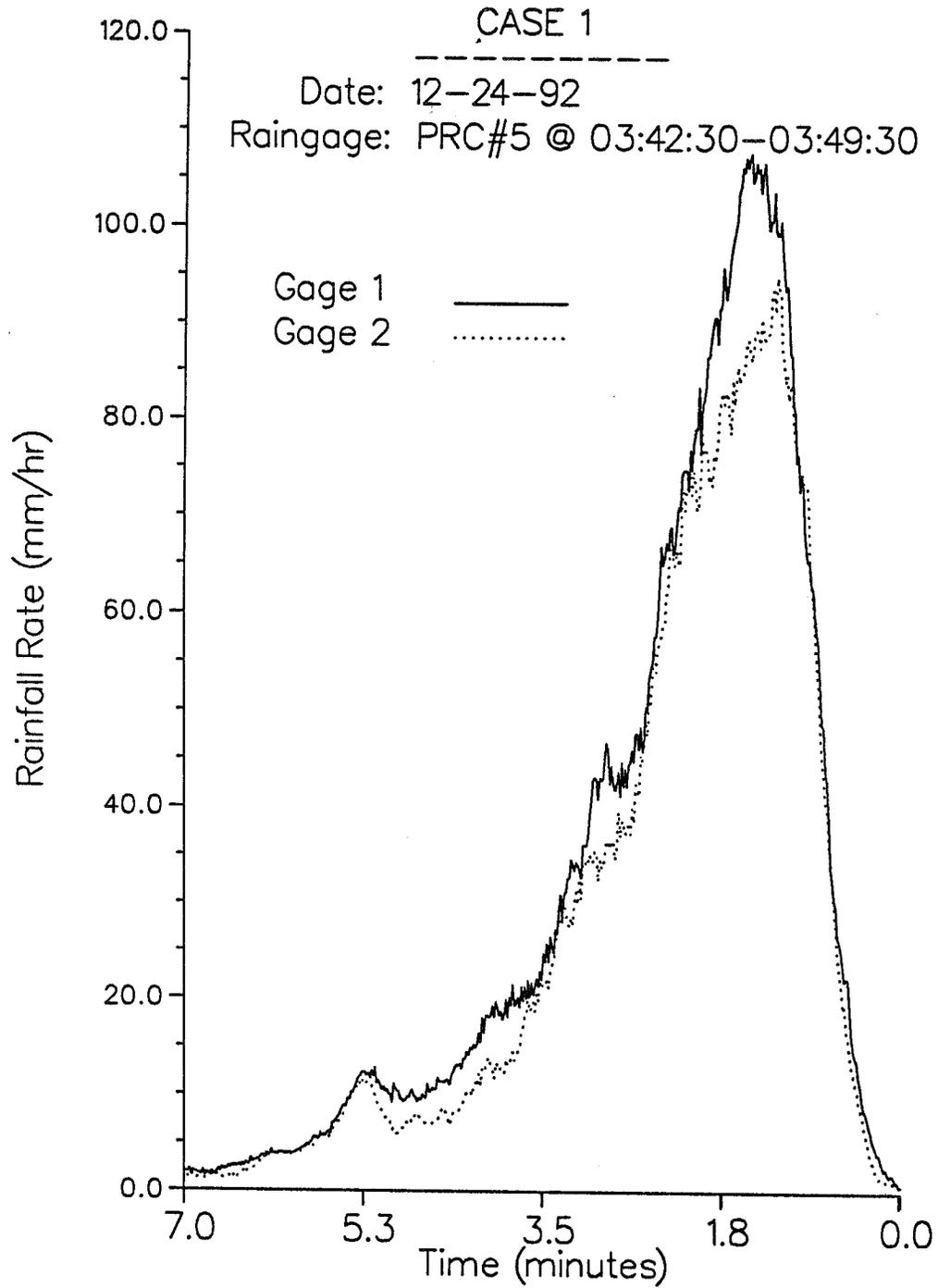


Figure 4.1. Case 1: Rainfall rate as a function of time from both PRC #5 raingages on 24 December 1992 from 03:42:30 to 03:49:30.

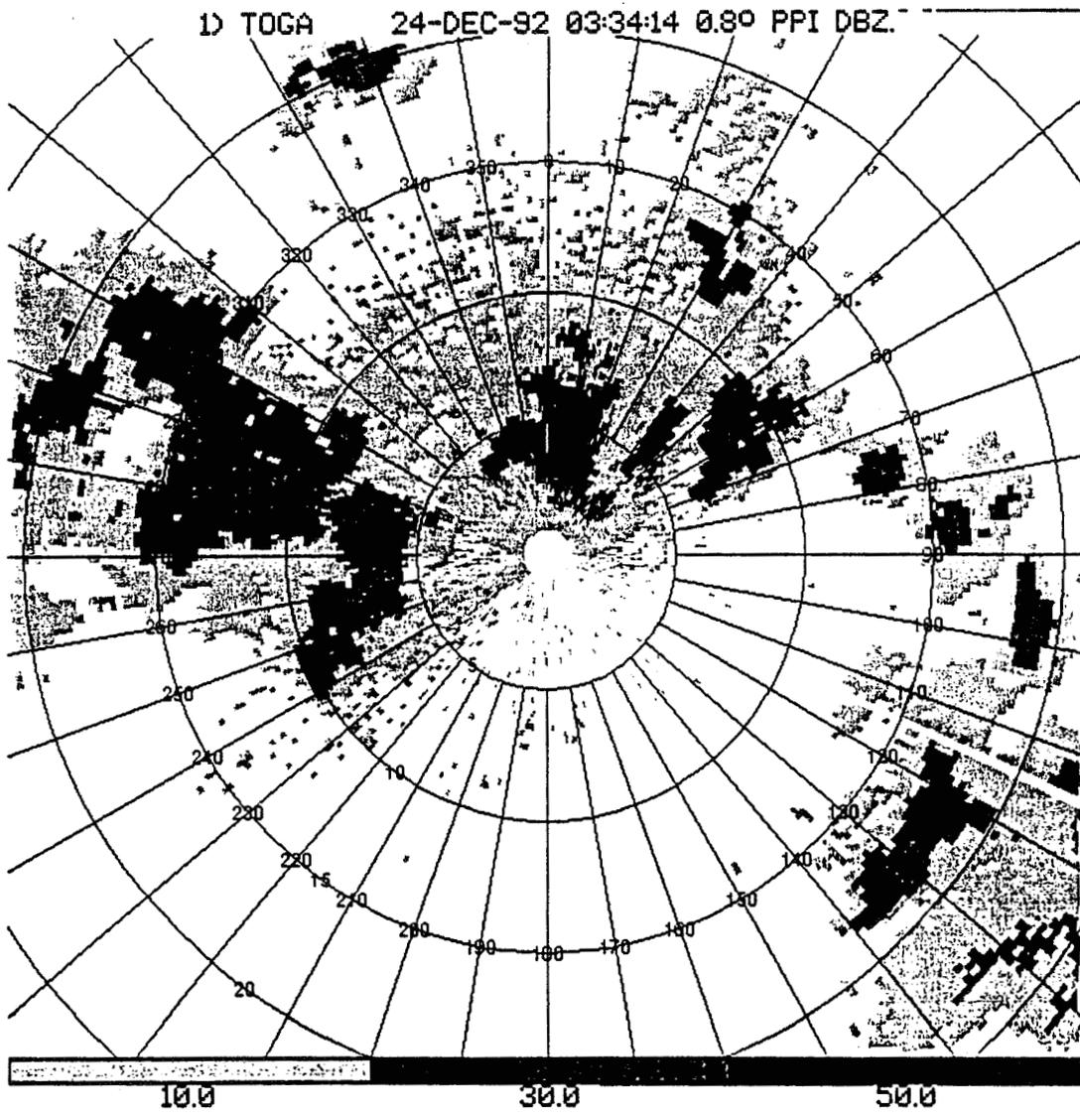


Figure 4.2. Case 1: PPI display of radar reflectivity from the TOGA radar for 0334 UTC 24 December 1992. The echo of interest lies along azimuth 258° with the most intense echo at a range of 7 km.

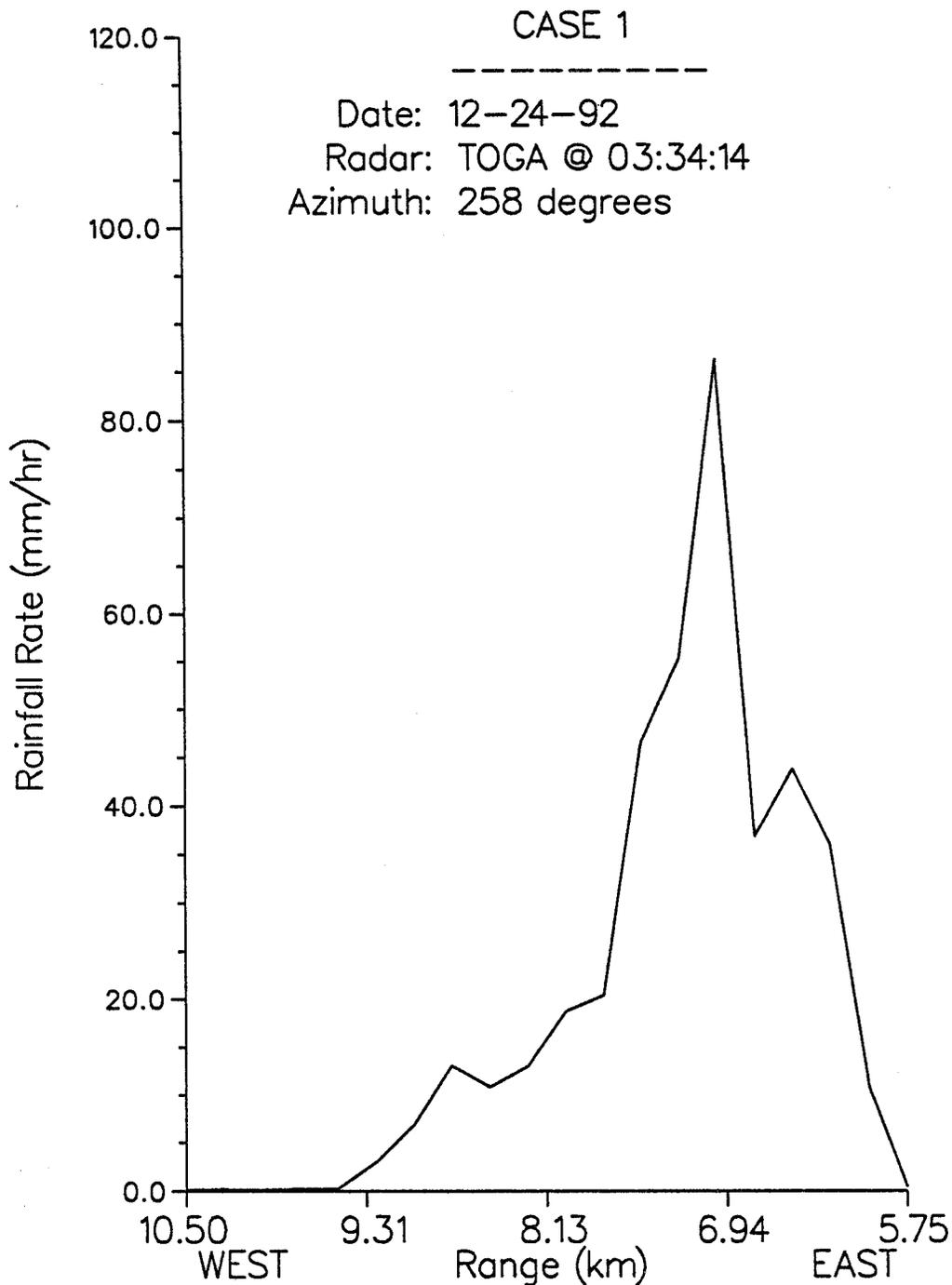


Figure 4.3. Case 1: Rainfall rate as a function of range from the TOGA radar for 0334 UTC 24 December 1992. The curve represents bin-by-bin radar data from azimuth 258°.

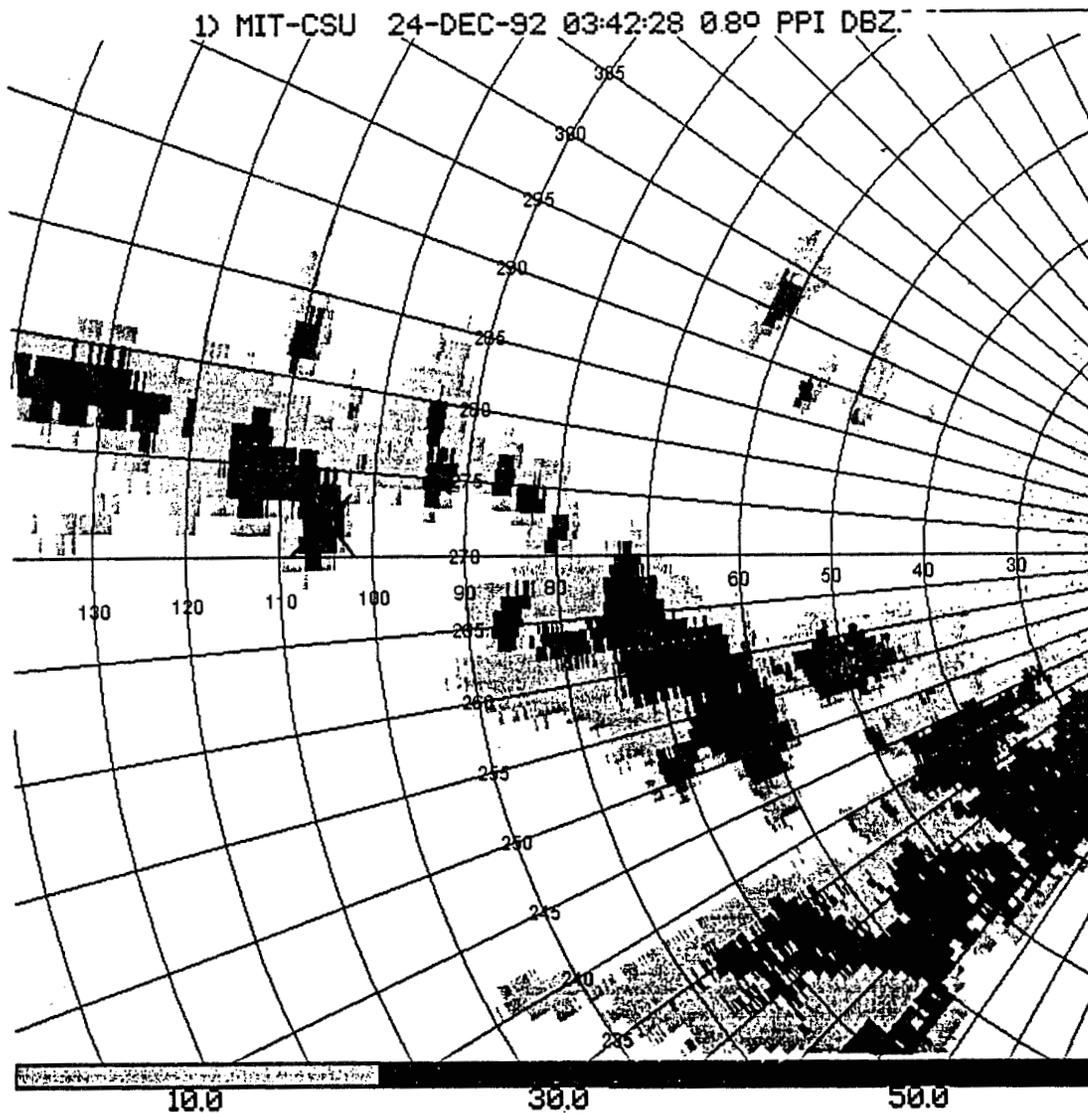


Figure 4.6. Case 1: PPI display of radar reflectivity from the MIT radar for 0342 UTC 24 December 1992. The "X" indicates the location of the PRC #5.

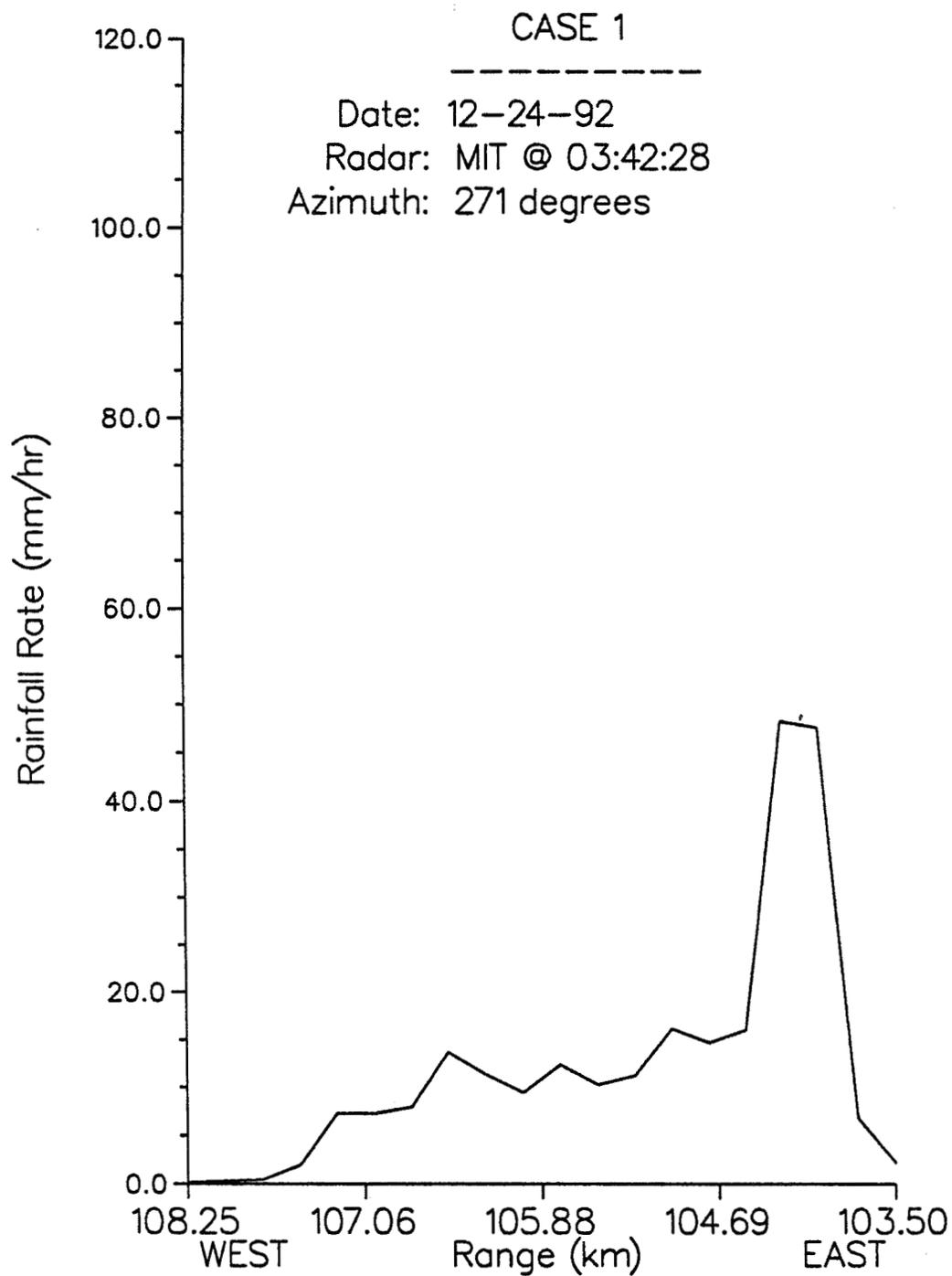


Figure 4.7. Case 1: Rainfall rate as a function of range from the MIT radar for 0342 UTC 24 December 1992. The curve represents bin-by-bin radar data from azimuth 271°.

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Can Salt on an Optical Rain Gauge Lens Affect Performance?

Larry F. Bliven
Laboratory for Hydrospheric Processes
NASA/GSFC

The optical rain gauge (ORG) by ScTI is designed to be tolerant to reduction of infrared beam intensity due to a 'dirty' lens. The system electronics includes an automatic gain control circuit (agc) which compensates for dirty lens effects. So with reasonable care and in suitable operational conditions, data from the optical rain gauges do not require adjustment for variations in the beam strength.

Recently there is interest in long term use of optical gauges onboard buoys at sea. Because of logistics, these systems are serviced infrequently, i.e. every several months. Due to the proximity of the gauges to the sea surface, salt can be expected to be deposited on the lens. As inhabitants of northern climates who drive their cars in the winter months know, it is wishful thinking to expect that rain will effectively rinse the salt off. Thus although rain may help wash off the gauge optics, it can not be expected to keep the lens clean. In fact, inspection of gauges that have been deployed on buoys reveals some abnormal pitting of metallic surfaces. Salt is probably coating the optics too.

To obtain an indication of the potential for dirty lens to affect the ORG calibration, a simple experiment was conducted using a translucent piece of plastic. Although scientific assessment of the optical properties of the plastic mask were not obtained at the time of the experiments, copies were made on 'xerox' machines with the mask over a portion of text. On one machine the mask appeared as a slightly smudged area, but on the other machine the mask was not apparent. This test shows that whereas the optical properties of the mask are constant, the effect of the mask is dependent upon the particular system. So it is interesting to see what effect, if any, the mask has on an ORG. Two simple experiments were conducted.

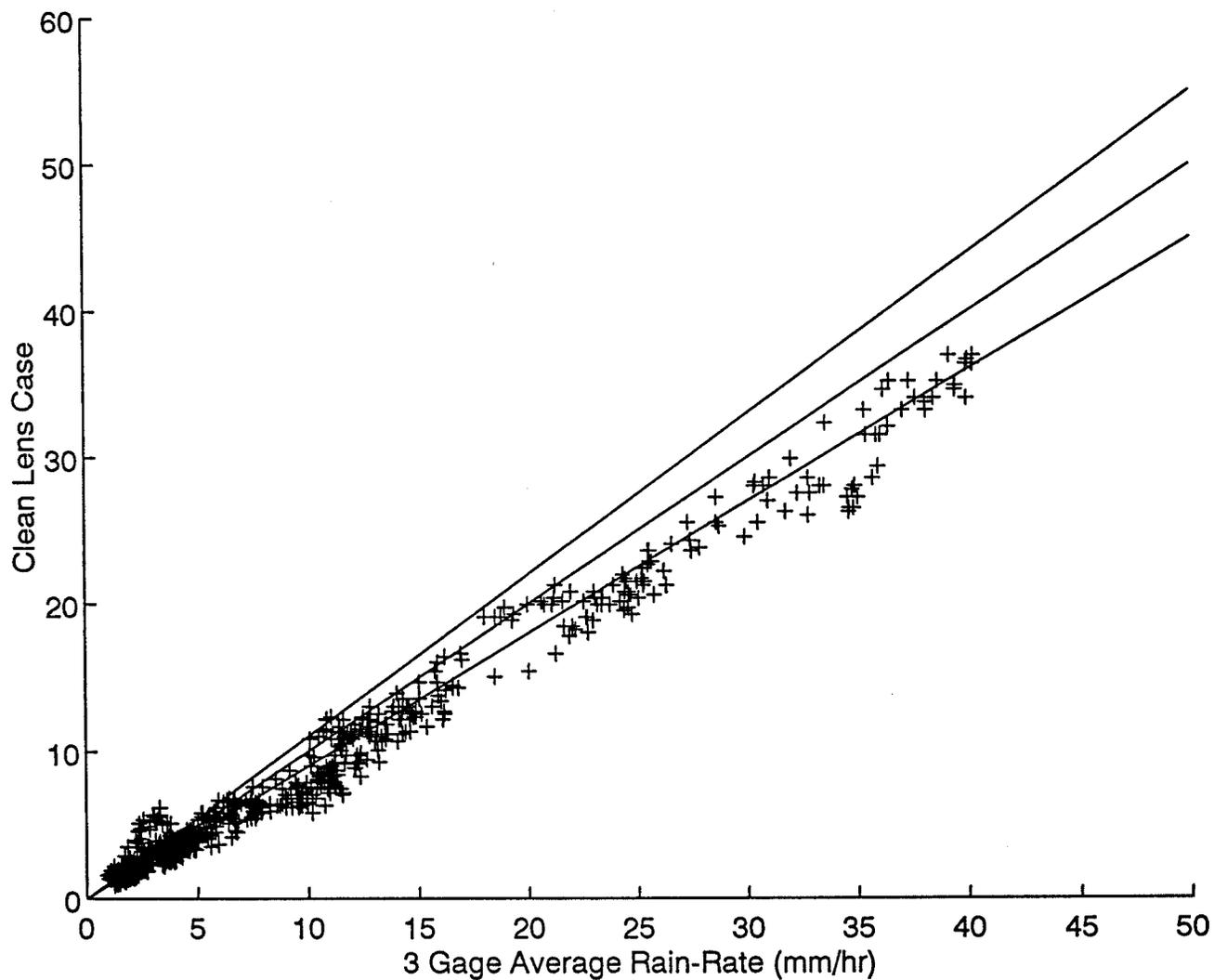
In the control experiment, a sample ORG was compared to three other ORGs during natural rain events. The results of that experiment are shown in Figure 1, which reveals that the

unperturbed gauge measurements fall within 10 % of the average from three other ORGs. Thus the sample ORG is within specifications when operated under normal conditions.

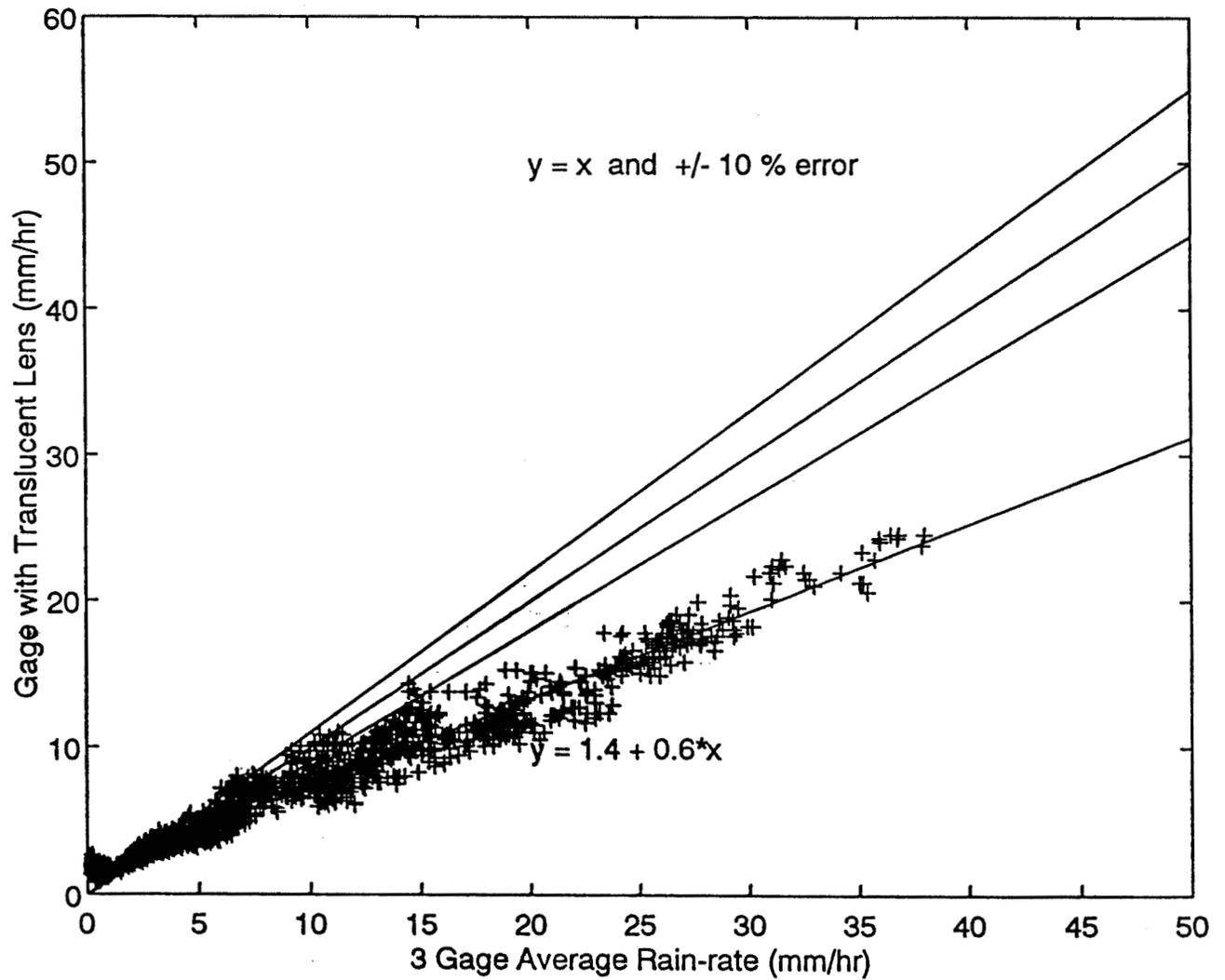
Next the mask was placed on the transmitter lens of the sample ORG and again data were collected under natural rain conditions. The data from the perturbed ORG are plotted in comparison with the three other ORGs in Figure 2, which shows that the mask reduced the gain of the perturbed ORG by about 30%. The perturbed ORG operated rather well in that the mask only causes a change in the gain and does not cause data drop out at low rain rates. However, the reduced gain would seriously impact an assessment of rain statistics.

The concern for buoy applications is sea salt - not plastic masks. In discussions with workshop participants, the need to study potential salt effects was recognized because no data are available on this topic and the effects of sea salt on ORG calibration are unknown. Hopefully this simple but inconclusive experiment will motivate potential users of ORG data from buoys deployed at sea to ensure that sea salt is not significantly contributing to errors. Because of the robust operation of the ORG with the plastic mask, it is likely that sea-salt is not a real concern for normal deployment. Studies with sea-salt are needed to confirm this intuitive feeling.

Unperturbed Gage Comparison



Simulation of Sea Salt on Rain Gage Lens



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Rain Gauge Calibration and Testing

John Wilkerson
NOAA/NESDIS Satellite Research Laboratory
Camp Springs, Maryland 20746

Abstract

Rain Gauge Testing

Prior to TOGA-COARE, 42 Model 100 series optical gauges were tested in the rain simulator facility at Wallops Island before shipment to the field. Baseline measurements at several rain rates were made simultaneously with collector cans, tipping bucket and a precision weighing gauge and held for post-COARE evaluation with a repeat set of measurements that were to be recorded after the instruments were returned. This was done as a means of detecting any calibration changes that might have occurred while deployed (Figure 1). Although it was known that the artificial rain in the simulator did not contain the required exponential distribution for accurate optical rain gauge rate measurements, use of the facility was necessary because it was the only means available for taking controlled observations with instruments that were received, tested, and shipped out in groups over a period of months. At that point, it was believed that these measurements would be adequately precise for detecting performance changes over time. However, analysis of the data by STI now indicates that this may not be true. Further study of the data will be undertaken by Short and Wilkerson to resolve this.

During the pre-COARE period, there were two short intervals when the opportunity existed for checking the manufacturer's calibration accuracy in natural rain. Ten gauges were set up to monitor rainfall simultaneously with the precision weighing gauge. Results, presented at last year's workshop by Wang showed that above 10 mm/hr and for rates up to 100 mm/hr, these optical gauges agreed to within 20% of the weighing gauge. It was also shown that if recalibrated using the weighing gauge as a standard, agreement could be improved to within 10%. Further, by this normalization process, measurement differences between optical gauges could be held to 5%. At present, this method of determining a calibration correction factor for each instrument is all that is available for dealing with the inaccuracies of the STI calibration and for the subsequent reprocessing of the TOGA CARE data set. Natural rain data for this purpose now exists at Wallops where over 400 rain events have been recorded since the return of instruments. Still lacking, however, are sufficient events above 100 mm/hr. Since the probability of heavy rainfall is greater in south Florida, 4 gauges from Wallops are being transferred to AOML for monitoring events there during the next six months.

The distribution of TOGA COARE optical gauges by platform is shown in Table 1. Gauge mountings on ships were typically well clear of superstructure when not located on a bow mast forward of all obstructions (Figure 2). Those on TOGA buoys were located 4 m above the ocean surface and clear of the other instruments. However, at the remote island site on Kapingamarangi, rain gauge and disdrometer were placed on the beach as no other area was properly cleared of vegetation. This location proved disastrous when storm surge caused

flooding at the site and damage to the instruments. The gauge was later replaced but no substitute for the disdrometer was available.

Of the 42 optical gauges used in COARE, sixteen were returned inoperative (4 of these were unrepairable). Causes of failure were corrosion of electronics due to water leaks (8); parts failure (6), and on buoys, vandalism (2). Some of the corrosion failures appear to have been caused by field technicians who opened the instrument for inspection. Lid seals, once broken, do not remain water tight when reused in all cases, even when tape or sealant is applied. While field personnel had been instructed not to attempt repairs, it was not always practical. Replacements for defective gauges were dispatched from Wallops immediately to ports of call when connections could be made in time. But that was not always possible and those in the field were faced with the choice of attempting a repair or missing an installation. The STI redesign of the gauge housing should eliminate leaking seals, but the problem still remains for those units we have. A better seal needs to be found.

Based on a report by Nystuen prior to the workshop, that background noise levels of the AOML optical gauge (100 series #2234) exceeded 1mm/hr in the absence of rain (see his Figure 2), it was decided to test a number of instruments at Wallops to determine if this was a common condition. Seven 100 series Wallops gauges were monitored for 450 minutes during no-rain periods with the result that none recorded rates higher than about 0.2 mm/hr (see Figure 3). This suggests that if dew on the receiver lens was the cause, as Nystuen believes, differences in local weather conditions at the times of monitoring is the explanation. Gauge #2234 is now being shipped back to STI for examination and a calibration check. The planned transfer of additional Wallops gauges to AOML will allow this tests to be repeated there with these instruments.

Disdrometer Manufacture

The need for drop size distribution measurements in the study of underwater sound generated by rain resulted in the purchase of a Joss-Waldvogel disdrometer from Distromet Ltd. This instrument, known worldwide, is the only commercially available disdrometer in its class considered reliable. Its cost of \$15,000, however, limits the number that could be considered for TRMM. So with funding from TRMM, NESDIS began the manufacture of disdrometers of an APL design. The APL disdrometer consists of a 3-inch diameter plastic block housed in a brass cylinder with base plate (Figure 4). The impact of drops falling on the beveled surface of the plastic are sensed by a piezoelectric transducer fixed to the bottom of the block. The output analog signal is amplified and digitized using two circuit boards. The digital data is then feed to a PC. This rugged sensor appears much less prone to corrosion and subsequent failure - a problem experienced with the Joss instrument.

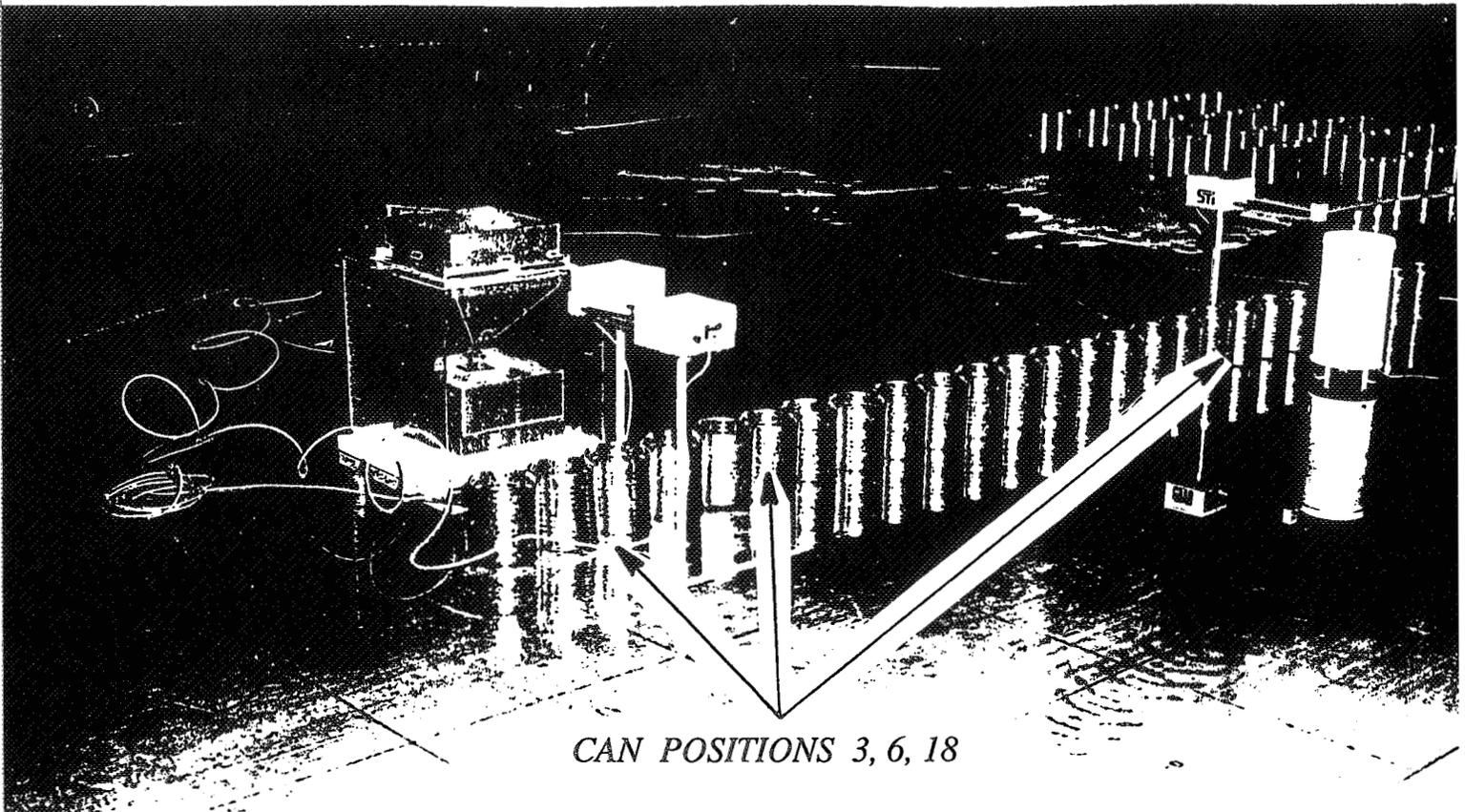
To date, fourteen disdrometer sensors have been assembled at NESDIS and one set of circuit boards for testing has been fabricated at Wallops. One of the fourteen sensor and the set of boards were sent to AOML for calibration and checkout. Calibration was achieved by monitoring sensor output voltage levels while water drops of known size struck the sensor head at terminal velocities. But before monitoring rainfall, AOML implemented design changes in one of the boards for enhanced performance. These changes are now being tested for expected

improvement using the Joss disdrometer as a standard.. When testing is completed, the remaining electronic board components will be built and the instruments assembled. APL distrometers will be provided to Wallops, KSC, PMEL, and AOML.

NESDIS is also investigating a second disdrometer sensor concept. Because of their size, the Joss and APL sensors require 1- minute sampling for stable distribution estimates. For monitoring underwater sound level changes during rainfall however, a 6-second sampling rate is required. Since the acoustic signal levels are directly proportional to the drop size distribution, a sensor capable of higher sampling is needed. Pressure-sensitive foils appear to offer a solution. The piezoelectric foil transforms the mechanical force of drop impacts to electrical impulses that are an order of magnitude greater than the responses of the APL disdrometer and produce almost no ringing. By using an area 10 times that of the APL and Joss 3-inch diameter sensor, sampling rates of 6-seconds should be possible. For testing this concept, foil sections with 3-inch and 9.5 inch diameters have been purchased for mounting as shown in Figure 5. The mounting plates are adjustable so that optimum pitch of the surface to accommodate runoff during rainfall can be determined. A separate circuit design is not required as the signal processor boards for the APL disdrometer can be used with this sensor. Once proven, this instrument should be highly suited for buoy use because of its physical simplicity. Used as a rain gauge at sea, it should also be capable of differentiating between convective and stratiform rain by keeping count of periods when sampled distributions contain drops no larger than about 2 mm in diameter. Field testing will be carried out at the AOML facility as soon as the ongoing circuit board study is completed and production of boards is resumed at Wallops.

Artificial Rain Facility Measurements

NASA, WALLOPS



CAN POSITIONS 3, 6, 18

1/2 Inch Nozzle Means
1992 vs 1993

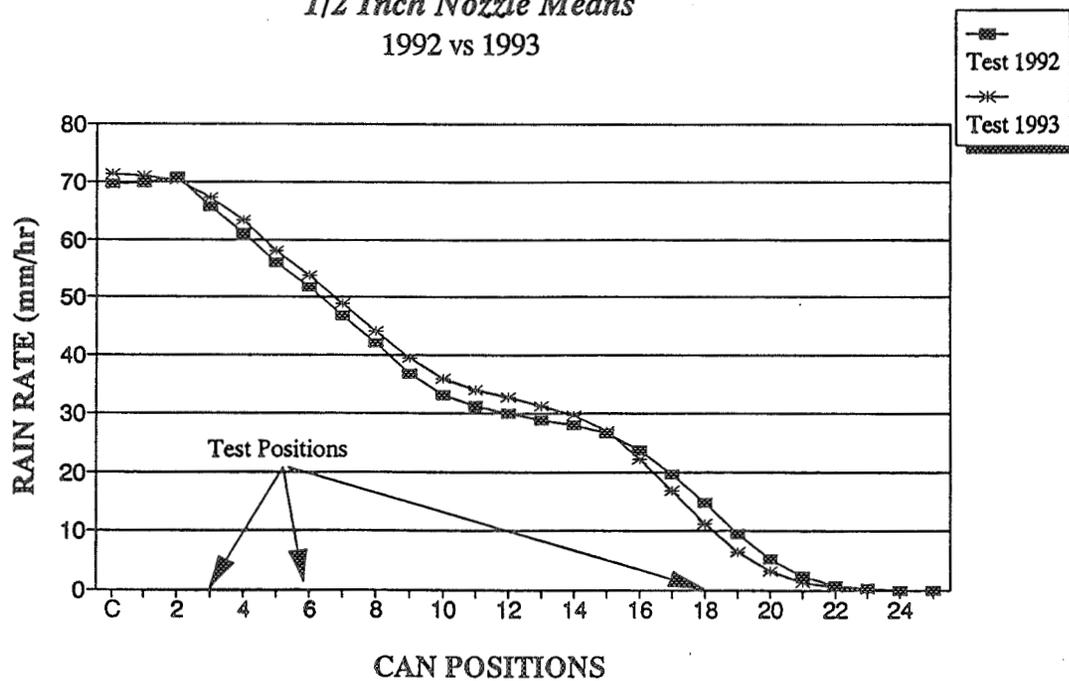
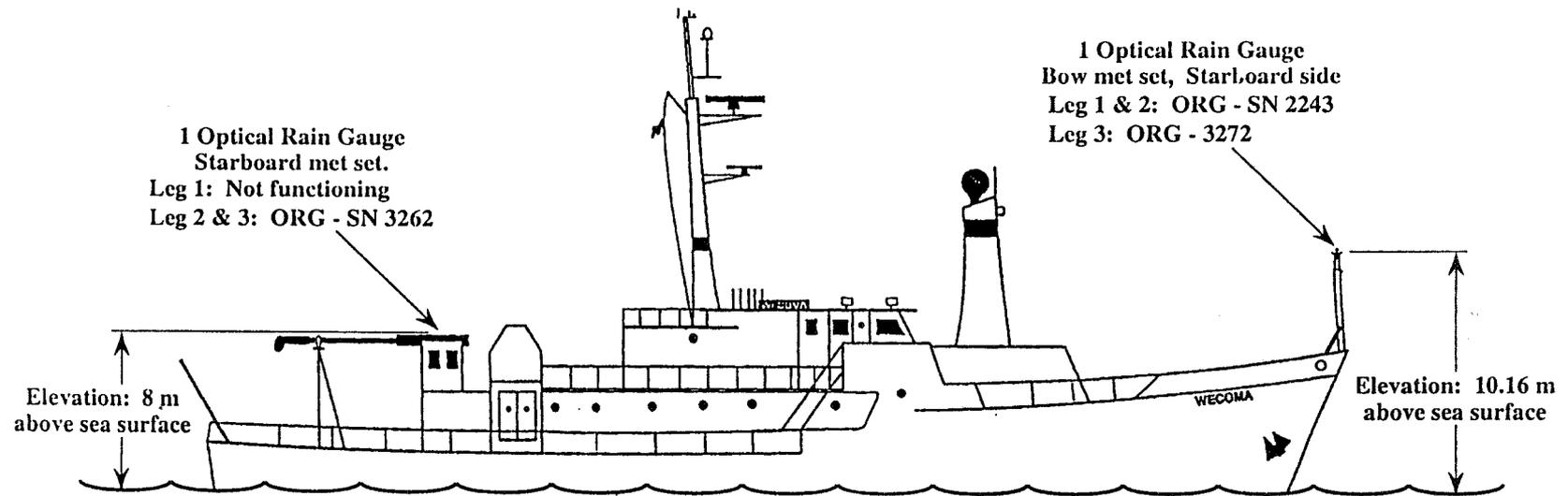


Figure 1. Measurement setup at the NASA, Wallops, rain simulator. Optical gauges were placed at three locations under the nozzle spray to record measurements at three separate rain rates. The spatial variation of rain rates with collector can separation is shown in the lower figure.



R/V WECOMA (Oregon State University)

Figure 2. Typical optical rain gauge installation on ships participating in TOGA COARE.

TABLE 1. STATUS OF SHIP/BUOY RAINGAUGES FROM TOGA COARE

April 1, 1994

SHIPS	Rain Gauge Serial#	Number Shipped	Number Returned	Not Returned	Number Returned Damaged	Pre and Post Calibration Performed	Pre or Post Calibration Performed	Sent to STI For Repair
VICKERS	(3260)(3261)	2	2		2	** (3260)	** (3261)	(3260)(3261)
WECOMA	(3272)(2243)	2	2		1		(2243)(3272)	(2243)
M. WAVE	(3268)(3269)	2	2			*(3268)*(3269)		
NOROIT	(2121)(2241)(3286)	3	2	(3286)	1	(2121)		(2241)
ALIS	(3266)	1	1			(3266)		
KIEFU	(3264)	1	1			(3264)		
HAKUHO	(3265)	1	1			(3265)		
NATSUSHIMA	(3267)	1	1			(3267)		
FRANKLIN	3271(Darwin)	1	1			(3271)		
KE #1	(2236)(2251)(3289)	3	2	(3289)	2		(2236)(2251)	(2236)(2251)
SH #3	(2237)(2252)(2238)(3290)	4	3	(3290)	2	(2238)	(2237)(2252)	(2237)(2256)
XI #5	(2239)(2253)(3291)	3	2	(3290)		(2239)(2253)		
MALAITA	(3273)(3274)	2	2		1		(3273)(3274)	(3273)
<u>BUOYS</u>								
0°, 157.5°E	(3258)	1	1			(3258)	(3258)	
0°, 165°E	(2245)	1	1		1			(2245)
0°, 156°E	(2113)	1	1		1		** (3303)	(2113=3303)
2°N, 156°E	(3256)	1	1		1		** (3256)	(3256)
2°S, 156°E	(3257)	1	1				(3257)	
0°, 154E	(3259)	1	1				(3259)	
SPARES	(2254)(3281)(3282)(3285)(3262)	5			1		(3262)	(2254)
Unrepairable (Vandalized)	(2244)(2246)				2			(2244)(2246)
<u>SHORE SITES</u>								
KAPINGA	(2255)(3270)	2	1	*** (3270)	1		(3270)(3308)	(2255=3308)
WALLOPS	(2235)(2240)(3263)	3					(2240)(3263)	
TOTALS		42	29	5	16	13	21	16

OTHER TRMM OPTICAL GAUGES

WALLOPS (100159)****(100165)****
 KFC (2242)(3262)(3288)
 NDBC (2108)(2109)(2123)
 AOML (2234)(2252)(100117)****
 NWS (Melbourne) (3274)

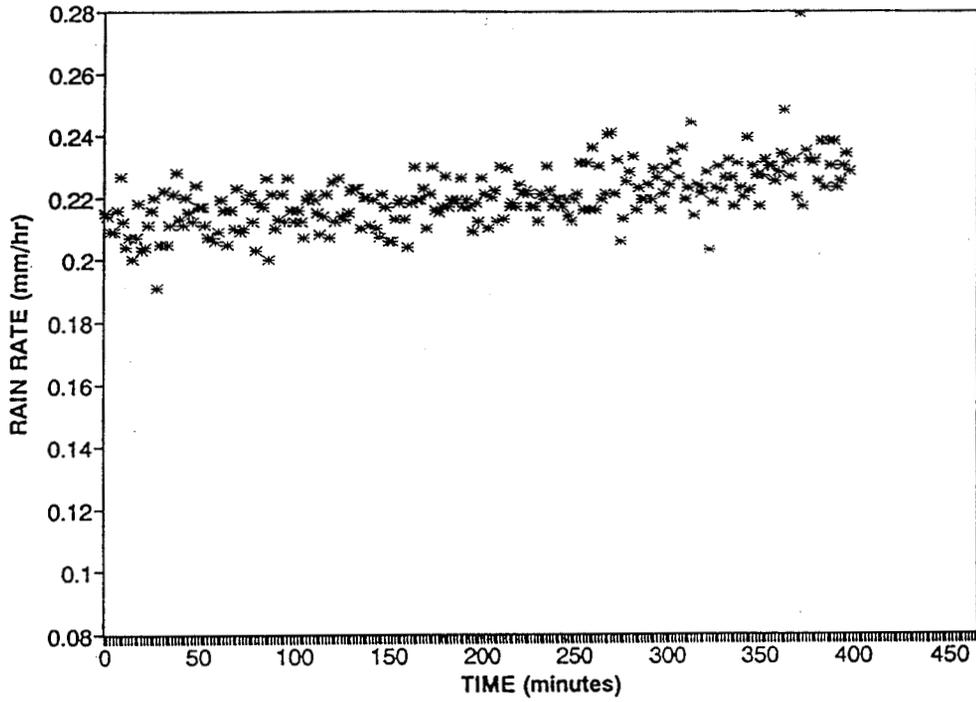
* Sent to KSC. Gauge 3268 was struck by lightning and replaced by 3288 which failed shortly thereafter. It in turn was replaced by 3269.

** Sent to PMEL as spares to replace gauges returned for post-COARE calibration checks.

*** Lost during return shipment from Kapingmarange

(ser#1=ser#2) Repair of ser#1 was not possible so new rain gauge ser#2 replaced it.

COMPARISON OF OPTICAL GAUGES
CLEAR SKY - SER# 3267 (04/14/94)



CLEAR SKY - SER# 3265 (04/14/94)

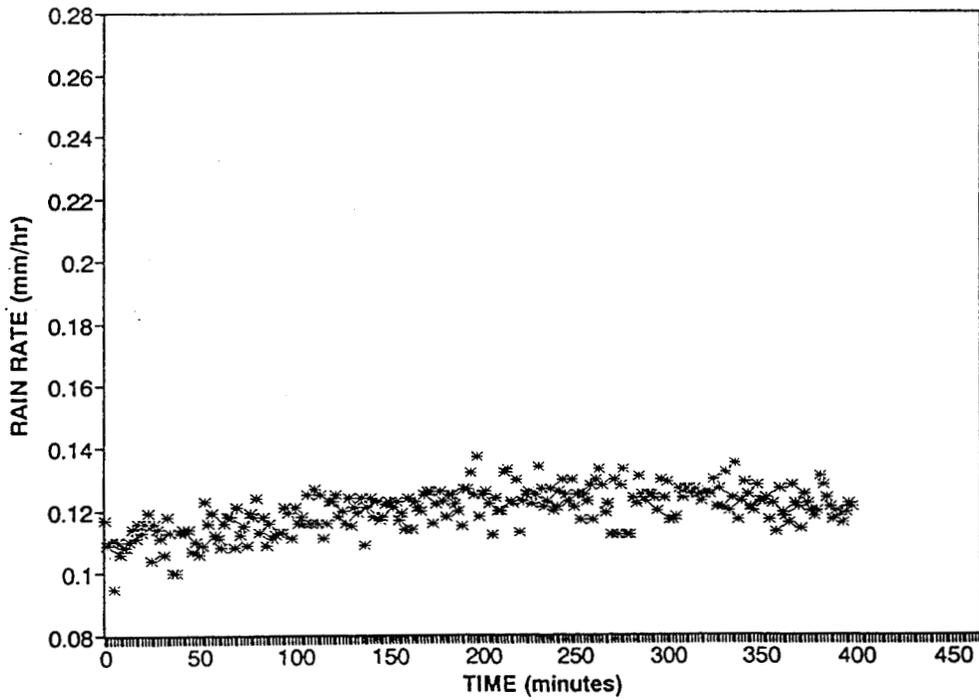


Figure 3. Typical examples from tests of seven gauges showing temporal variations in background noise levels during periods of no rain.



Figure 4. The APL disdrometer sensor dismantled, left, and assembled, right.

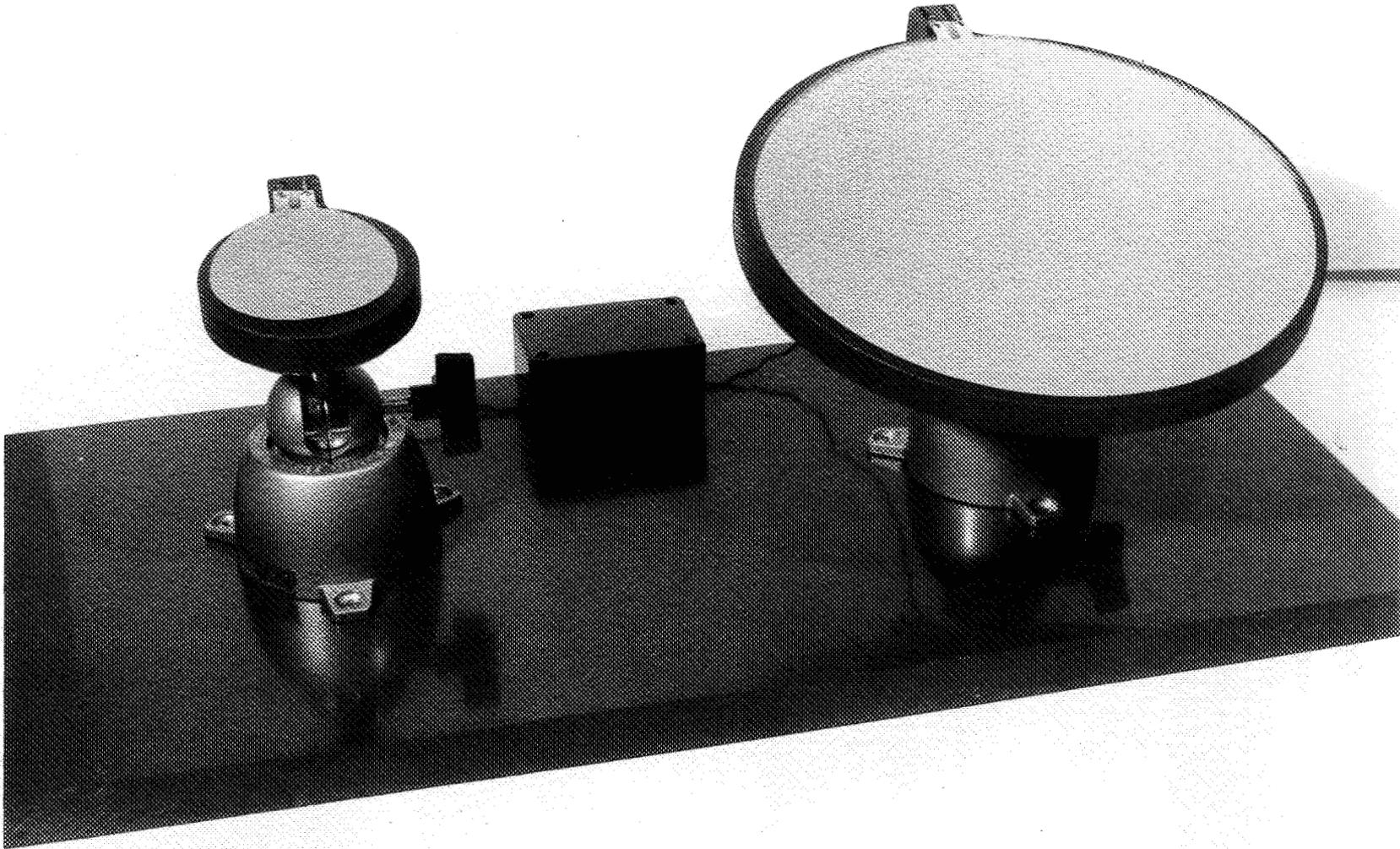


Figure 5. The NESDIS foil disdrometer sensors of 3-inch and 9,5-inch diameter mounted for testing. Mounting plates are adjustable to permit the correct pitch for water runoff.

Effect of Heavy Rain to the Total Received Power

111795
351590
22 April 1994
T. Iguchi *IGP*

If the average power at the receiver is substantially reduced by heavy rain, the AGC (Automatic Gain Control) circuit will try to compensate this reduction by increasing the gain. If this happens, then the pulses created by rain drops are amplified more than they should be and the rainfall rate may be over-estimated.

In what follows, I will roughly estimate the average reduction of received power for a heavy rain case.

D : Diameter

D_0 : Median diameter

D_M : Maximum diameter

$N(D)$: Drop size distribution (particles $m^{-1} mm^{-1}$)

N_T : Total number density (particles m^{-1})

N_{T1} : Total number density of particles $> 1mm$ (particles m^{-1})

$$N_T = \int_0^{D_M} N(D)dD = \int_0^{D_M} N_0 \exp(-3.67D/D_0)dD \quad (1)$$

$$N_{T1} = \int_1^{D_M} N_0 \exp(-3.67D/D_0)dD \quad (2)$$

Suppose $D_0 = 3.67$ mm or $\Lambda = 1$ for simplicity. (This diameter is rather large but not exceptionally large.) We also approximate the upper limit of integration D_M by infinity (∞). Then

$$N_{T1} = N_0 \int_1^{\infty} \exp(-D)dD = \frac{N_0}{e} \quad (3)$$

If we assume $N_0 = 8154 = 3000e$, then

$$N_{T1} = 3000 \quad (4)$$

Suppose the average falling velocity v is 5 m/s (a rather conservative estimate). The total number of drops (> 1 mm) that pass a horizontal area of $1 m^2$ is

$$N_{T1} \times v = 3000 \times 5 = 1.5 \times 10^4 m^{-2} s^{-1} \quad (5)$$

The area of the optical beam that is sensitive to the water drops is about $2 \text{ cm} \times 50 \text{ cm} = 0.01 = 10^{-2} m^2$. The number of drops (> 1 mm) that cross this area is

$$1.5 \times 10^4 \times 10^{-2} = 1.5 \times 10^2 s^{-1}. \quad (6)$$

If each particle produces a 5 ms pulse, the total time in which the beam is partially blocked by rain drops is

$$5ms \times 1.5 \times 10^{-2} = 750ms = 0.75s$$

per second. This number indicates that the beam is almost always partially blocked by rain drops. In other words, the receiver does not receive the full power most of the time.

If the effective diameter (blocking efficiency) of a particle is 2 mm and if the beam width is 2 cm, each particle will reduce the received power by 10% when it crosses the beam. Since the beam is blocked by water drops 75% of the total time according to the above calculation, the total received power may be reduced by 7.5%. To compensate this reduction to the reference value, the gain of amplifier will be increased by 8.1%. This increase of gain will increase all pulse sizes by the same fraction and result in the overestimate of the rainfall rate.

Second Workshop on Optical Rain Gauge (ORG) Measurements
NASA/Goddard Space Flight Center
Building 22, Room 365
April 21-22, 1994

Minutes from Meeting:

0900 Introduction

Otto Thiele gave the opening remarks and presented a general outline of the structure for the second ORG workshop.

0915 Brief Overview of First ORG Workshop

Michael McPhaden gave an overview of the first workshop that was held in Seattle, WA from 31 March 1993 to 1 April 1993. He displayed the key points of the first meeting. The meeting focused on instrument performance, and some conclusions were that the ORG's were in error by +/- 20%, there were possible outliers in the data, the ORG's overestimated by 20-30%, and sources of error included: Drop Size Distribution (DSD) differences, and sea spray.

The recommendations from the last meeting were discussed next. A few of the recommendations included: post-calibration checks for all ORG's at NASA/Wallops, more calibrations in natural rain, and NASA/Wallops were to include disdrometer data into the calibrations.

The next topic of discussion was the climatic impacts of rainfall and the issues in measuring rainfall. Rainfall has significant impact on the measure of latent heat release and is a source of buoyancy in the upper ocean. The measurement issue was how to accurately quantify rainfall in short time and space scales of individual rainfall events using platforms such as ships, islands, satellites.

The last figure presented by McPhaden showed the location and number of moorings in the TAO array for April, 1994 and December, 1994. This array could be used to validate the TRMM radar.

Discussion from this talk included a inquiry on how many ORGs failed in TOGA COARE. They had a 25% failure rate that was caused by moisture in the electronics.

0930 Instrument Comparisons in Natural Rain

I. Paul Frietag showed comparisons of different ORG's in the TAO array. His first slide displayed the location of the TAO moored buoys with ORGs in 1993 and location of ORGs in 1994. Also, he showed a figure that gave the location of the ORG on a typical moored buoy.

The next set of slides showed examples of comparisons of data from ORGs that were located on buoys and ships. The first comparison was with the ORG on the Natsushima and the ORG on a moored buoy stationed at 0, 156 E. This comparison showed that the two gauges were in disagreement by about 25%.

The next two figures showed comparisons of the ORGs from the IMET and ATLAS buoys for October and December 1992. These comparisons indicated differences between the gauges. Freitag attributed the differences to the physical separation between the gauges (~15 miles).

The next set of results compared the sensor voltage and rainfall rate over time for 1993. It showed that the ORGs gave reasonable data for voltages above 11V but tended to lose intensity when voltages dropped below that value.

Comparisons between two ORGs on the same moored buoy was presented for moored buoys located 0, 156E and 0, 165 E. The comparison at 0, 156E showed the ORGs differed by 3% in the percent time raining and by 30% in the mean rainfall. For the ORG at 0, 165E, the percent time raining varied by 17% and the mean varied by 55% between the two ORGS. The differences between the ORGs was attributed to instrument and calibration differences. The scatter seen in the plots was caused by low rainfall rates. It was determined that the percent raining at low rainfall rates was not a very good parameter to use.

The last figure showed the results of a comparison between two ORGs that were set up in Seattle. This study didn't show anything conclusive because the rainrates in Seattle were so low. PMEL was going to try to set up a site in a rainy location in the mountains for calibration purposes.

I. Jeffery Nystuen of AOML presented results from the comparison of a weighing rain gauge, RM Young Model 50202 Capacitance Rain Gauge, ORG-705 Long-Path Optical Rain Gauge, ORG-105 Optical Rain Gauge, Belfort Model 382 Tipping Bucket Rain Gauge and a Joss-Waldvogel Disdrometer.

The locations of each raingauge that was used in the comparison study at AOML was shown. Also, the description and characteristics of each gauge were presented in the talk.

A comparison was made on how different smoothing techniques affected the instantaneous data. Weighing gauge data were smoothed for 10 sec, 1 min, and 5 min averages for a variety of events. Also, different filters were applied to the raingauge data, which were presented and discussed.

Some of the problems associated with the capacitance raingauge were discussed. Problems with the capacitance raingauge included spikes in the data, draining, and drips. Most of the erroneous signals were removed by proper smoothing of the data.

The drawbacks of each raingage were eventually discussed and finally the gauges were compared with the Joss-Waldvogel Disdrometer. The disdrometer was considered the standard and all the raingauges were compared against it.

A summarization of the conclusions of this extensive study is presented below. The exact details can be found in Nystuen's handouts. Some of his conclusions were: The equivalent rainfall rate derived from background voltage of the ORG's varied from 0.2 mm/hr to over 1 mm/hr. It was concluded that rainfall rates below 1 mm/hr can not be trusted. Also, in heavy rain events, the ORGs tend to overestimate rainfall when compared to more traditional raingauges such as weighing gauges. Furthermore, in light rainfall events, the ORG's tend to overestimate the rainfall rate. When compared to disdrometer data, weighing, capacitance, and tipping bucket rain gauges are well correlated where as the ORG's are biased high by 10-20%. The error in rainfall rate using the ORG-105 does not depend on the assumption of a M-P distribution. Finally, the study found that the ORG-105 is more highly correlated with moments less than the rainfall rate, and the ORG-705 is more highly correlated with moments higher than the rainfall rate.

III. T. Wang from STI presented results from his studies using ORG data in natural rain. The data was recorded at Wallops Island (he handed out his overlays to the group). He concluded that even when there were large differences in the drop-size distribution, the calibration in the ORG's was almost identical. Also, in his conclusions, he stated that sea spray had no effect in the amount of rainfall recorded by the ORGs. The size of the sea spray droplets were so small that they made no contribution to the rainfall.

1130 Meeting adjourned for lunch

1245 Meeting resumed

Dave Short gave a review of the morning session.

1250 IV. Dave Short presented his results from his study with the ORG data that was obtained from Wallops Island.

The first figure presented showed the schematic of the raingage setup at the Wallops Island facility. The following figure showed a listing of the gauges that were used in TOGA COARE and the corresponding serial numbers if they were available.

The set of figures showed examples of how the ORGs compared to a weighing gauge, which was considered the standard. From the data, there seemed to be some correlation between spikes in the data and high wind events. The discussion that followed indicated that the spikes may have been caused by vibration effects on the ORG performance and underestimation of rainfall by the weighing gauge in high winds.

The last comparison presented in the talk was between the ORGs that were located on Moana Wave, Shiyun #3, etc. during TOGA COARE. The results showed that some of the gauges were in excellent agreement. A few of the ORGs differed in comparison. It was discussed that these gauges could be corrected by a constant offset. T. Wang indicated that the ORGs that were in disagreement could have incorrect calibrations.

0115 V. Larry Bliven of Wallops Is presented results from a study he performed at Wallops Island using a plastic filter to measure the effects of masking the lens of an ORG. His study showed that a semi-transparent sheet of plastic reduced the rainfall rate by 20-30%. It was discussed if this study was representative of an ocean environment where sea spray deposited salt on the lenses. He indicated that he would repeat this experiment by masking the lens with salt water instead of plastic film.

1330 Field Experience (TOGA COARE, others)

I. Michael McPhaden gave a presentation on the results from the TAO mooring instrumentation during TOGA COARE. He showed data from the moored buoy located at 0, 156 E for December, 1992. He displayed data that showed the ocean had responded differently to rainfall under a variety of conditions. He showed that a wind speed of about 10 m/s removes the diurnal cycle of mixing in the ocean. From the data, he indicated that mixing of freshwater depended on the wind speed and buoyancy at the ocean surface.

He also compared ORG data to incoming radiation measurements taken from the moored buoy. This result showed lower amounts of incoming radiation corresponded to a higher occurrence of rainfall. This was a reasonable result because lower incoming radiation was an indication of cloudier skies, convergence, rainfall, etc.

Satellite data were also compared with ORG data. The Goes Precipitation Index (GPI) was used in comparison. It uses a 2.5x2.5 deg grid. It uses IR data and is based on the areal percentage of cloud tops colder than 235 K. The study found that this comparison was poor for periods of warm IR temperature. During TOGA COARE, there were many observations that indicated that significant amount of rainfall occurred from warm, shallow clouds. The study indicated that ORG rainfall was greater than the GPI rainfall estimations by a factor of 2.1. This analysis was applied to SSM/I data. The result was that SSM/I underestimated rainfall by a factor of two when compared to ORG data. It was suggested that the large footprint of the SSM/I was not able to resolve the small, intense convective cells seen in TOGA COARE.

II. Dave Short presented some of the preliminary radar-raingauge studies that are being performed at Goddard. A rainfall image of the combined MIT and TOGA radar reflectivity scans was compared to rainfall rates from ORGs located on R/V Franklin, R/V Moana Wave, and from the IMET buoy. This comparison showed that the radar indicated rain at the time and location of the ORG data. It was mentioned further comparisons between the ORGs and radars will be performed after the quality control of the radar data is finished.

III. Linda Galusha presented preliminary results from her thesis work. The study compared the reflectivity data from the MIT radar and the ORG data collected on the PRC #5. A case study was presented for an echo that passed over PRC #5 around 1245 UTC 24 December 1992. The reflectivity data was converted to rainfall rates using the GATE Z-R, Darwin convective Z-R, and Willis and Jorgenson Z-R. These data were compared to the rainfall rates of the ORGs. The data was analyzed by comparing the percentage of area above a given rainfall rate from 1 mm/hr to the highest rainfall rate observed in the echo. This study showed the rainfall rates derived from the Z-R relationships didn't agree very well with the ORG data. It was suggested in discussion that a new Z-R relationship could be developed from this type of study.

1500 John Wilkerson gave a presentation on instrument performance and calibration. First, he showed pictures of the different ORGs that were used in TOGA COARE. In some cases, the pictures showed the location of the ORG's on the ships during TOGA COARE. He explained how the ORGs were calibrated at Wallops Island. He showed some results from data collected in natural rain events. Also, he presented calibration results from data collected in the rain barn. Finally, he displayed and discussed the principles of the disdrometer they had developed at Wallops Island.

1510 Dave Atlas made a short presentation. He presented figures that showed how different raindrop distribution affected the rainfall and reflectivity field.

1515-1530 Break

1530 Data Archives

There was discussion on how each institution would make their data available to the scientific community. It was suggested that each group would write simple instructions on how to access the data. Most of the data will be available by anonymous ftp or by contacting the principle investigator in each group.

1545 Design/Fabrication/Reliability

I. Paul Freitag gave a presentation on the reliability of the gauges. He concluded that the original design was not meant for sea. The reason for this conclusion was because the ORGs that were returned from sea had corrosion around the lens area. Also, some of the ORGs had water in the electronics case. He made some suggestions for improvement. First, ORGs should have an interface to allow precalibration of the instrument.

II. T. Wang discussed some of the problems that still exist with the ORGs. He mentioned that calibration was still a problem. Also, he said the optics had a poor focal length. He explained some of the improvements being made to the next version of the ORG. The newest ORG should be available in 6 months.

III. John Wilkerson showed another instrument that they had designed at Wallops. It was a foil type device that was made in two different sizes. He said that this material could be used to make disdrometers.

1700 Dave Short gave summary of the day's events and concluded the meeting for the day.

22 April 1994

0900 Meeting Resumed

Dave Short gave an overview of yesterday's meeting and presented the agenda for the rest of the meeting. Also, Otto Thiele suggested that each group write up suggestion on how to improve rainfall measuring.

0915 Future Plans/Potential Improvements

Michael McPhaden presented the recommendations from the 1st Raingauge Workshop. The group discussed each key point addressed at the previous meeting. They discussed what problems have been solved and what still needs to be improved.

There was discussion on what would be the best data to transmitted from the buoys. Currently, the following parameters are being saved: mean hourly rainrate, standard deviation, the percent time raining in a hour, maximum rain rate. Otto Thiele suggested that 4 maximum rainrates (every 15 min) should be saved during each hour. Another suggestion was that there should be flags to indicate when it starts and stops raining.

1030-1100 Break

1100 Wrap-up discussions

Dave Short put up an overlay that showed the location of the different data archives. The data available and who is in charge are listed below:

GSFC: TOGA COARE ship data, disdrometer data

WFF: Calibration data

PMEL: ATLAS buoy data, intercomparison data

AOML: Multiple gauge study, disdrometer data

1111 T. Wang invited anyone who was interested to visit STI.

1115 Dave Short showed plot of location of the ATLAS buoy that was centered at 2S, 156E. The plot showed that the buoy never varied more than 2km anchored position. Dave also mentioned that the data from the buoy will eventually be compared with the radar in a time series.

1120 Future plans

Michael McPhaden suggested that they continue to keep buoys in the Pacific to assure long time series of the climatology of the area, especially the sites with the ORGs installed. Presently, there are 4 buoys in the Pacific with ORGs.

He also suggested that everyone who gave a presentation should submit a 1-2 page abstract of their work. In the abstract, there should be section that describes the participant's current work and a section for future work. The format of the abstracts should be the same as the abstracts from the first workshop.

The report format was discussed in the meeting. The group decided to have the following sections:

3-4 page summary of the meeting which will include conclusions and recommendations.
Abstracts from the presenters and a few overlays with the most important information.

Also, there was a listing of who should submit a abstract for the write up. The following people should submit a abstract by 29 April 1994:

M. McPhaden
D. Short
P. Freitag
J. Wilkerson
O. Thiele
J. Gerlach
G. Furness
J. Nystuen
L. Galusha
T. Wang

Besides the report, it was discussed and decided that John Wilkerson and Dave Short would compile a listing the platforms, dates, serial numbers, and calibration summary of the ORGs that were used in TOGA COARE. Also, John Gerlach and Brad Fisher were given the task of generating a database that included the name of each ORG, the performance of each ORG, and a time history of times when the ORG was running.

Otto Thiele mentioned that he would compose a report that described TRMM's need for ORG data. Furthermore, he said that he would like someone to investigate to see if there were other ORG's in use that could be added to the raingauge database.

Michael McPhaden showed an overhead that listed the conclusions from the 1st Workshop. He went over each issue and summarized the main points that had come out of this meeting.

In the last section of the meeting, the group discussed and listed the new recommendations to be addressed in the future. The recommendations are listed below and also can be found on a overhead:

2nd Workshop Report -- Recommendations

1. Review of 1st workshop recommendations: action, progress
2. ORG: Move some of the gauges from Wallops to KSC and AOML in the summer of 1994. Furness and Nystuen will be in charge of the move.
3. PMEL: Setup Calibration site on the Olympic Peninsula
4. When the new ORGs come out, tests will be performed using the new ORG along side of the mini-ORGs. This comparison will be performed by McPhaden, Furness, and Nystuen.
5. Field calibration: retrofits? This will be done by PMEL, WFF
6. Test the sample rate on buoys: re-examine the statistics from the remote ORGs and determined if more statistics can be added . Nysteum, Krajewski, and Short are in charge of this task.
7. Check the Low-end sensitivity; analog vs. digital. Determine if the dynamic range of the ORG can be set between 0.5 and 1000 mm/hr.
8. See how Salt on lens affects the optics. Also, the effects of dew, fog, etc. WFF will perform these tests.
9. Determine the effects of different Drop Size Distributions. Nystuen, Short, and Wang will look into this subject.

10. Check the performance of the Automatic Gain Control (AGC) and how it performs in high rainrates. These tests will be done at PMEL, WFF, and AOML.

After the recommendations were completed, there was some wrap-up discussions and some talk of plans after the meeting. It was decided that the first cut of the report would be to a small group of people. The second version would be sent out to everyone that had included their mailing address. Finally, the people writing abstracts were asked to include their email address and phone number along with their abstracts.

1215 Meeting ended

ATTENDANCE LIST AT ORG WORKSHOP APRIL 21-22, 1994

Name	Affiliation	Telephone/FAX #'s
Arkin, Phillip	NOAA/NWS Washington, DC	Phone: (301) 763-8317 FAX: (301) 763-8434 Internet: parkin@sgi17.wwb.noaa.gov OMNET: P.ARKIN
Bliven, Larry	NASA/WFF Wallops Island, VA	Phone: (804) 824-1057 FAX: (804) 824-1036 Internet: fbliven@gsofcmail.nasa.gov
De Oliveira, Victor	University of Maryland College Park, MD	Phone: (301) 405-5139 FAX: (301) 314-0827 Internet: vdo@math.umd.edu
Freitag, Paul	NOAA/PMEL Seattle, WA	Phone: (206) 526-6727 FAX: (206) 526-6744 Internet: freitag@noaa.pmel.gov
Furness, Gene	NASA/WFF Wallops Island, VA	Phone: (804) 824-1159 FAX: (804) 824-2146 Internet: gfurness@ccmail.gsfc.nasa.gov
Galusha, Linda	Texas Tech. University Lubbock, TX	Phone: (806) 742-3417 FAX: (806) 742-0100 Internet: x9cal@ttacs1.ttu.edu
Galusha, Linda	Texas Tech. University Lubbock, Texas	Phone: (806) 742-3417 FAX: (806) 742-0100 Internet: x9cal@ttacs1.ttu.edu
Gerlach, John	NASA/WFF Wallops Island, VA	Phone: (804) 824-1188 FAX: (804) 824-2303 Internet: jgerlach@gsofcmail.nasa.gov
Gruber, Arnold	NOAA/NESDIS Camp Springs, MD	Phone: (301) 763-8127 FAX: (301) 763-8108 OMNET: A.GRUBER
Han, Daesoo	NASA/GSFC Greenbelt, MD	Phone: (301) 286-9414 FAX: (301) 286-1626 Internet: han@trmm.gsfc.nasa.gov
Iguchi, Toshio	CRL Tokyo, Japan	Phone: (81 423) 27-7551 FAX: (81 423) 27-6666 Internet: iguchi@crl.go.jp
Jones, Linwood	FIT Florida	Phone: (407) 867-8256, (407) 768-8000 x6151 FAX: (407) 867-9127 Internet: ljones@ee.fit.edu
Kedem, Ben	University of Maryland College Park, MD	Phone: (301) 405-5119 FAX: (301) 314-0827 Internet: bnk@math.umd.edu
Kucera, Paul	NASA/GSFC Greenbelt, Maryland	Phone: (301) 286-1594 FAX: (301) 286-1626 Internet: kucera@trmm.gsfc.nasa.gov
Lim, Hyo-suk	NASA/GSFC Greenbelt, MD	Phone: (301) 286-1540 FAX: (301) 286-1626 Internet: lim@trmm.gsfc.nasa.gov

Name	Affiliation	Telephone/FAX #'s
McPhaden, Michael	NOAA/PMEL Seattle, WA	Phone: (206) 526-6783 FAX: (206) 526-6744 Internet: mcphaden@noaa.pmel.gov OMNET: M.MCPHADEN
Michelena, Ed	NOAA/NDBC Stennis Space Center, MI	Phone: (601) 688-1715 FAX: (601) 688-3153 Internet:
Nystuen, Jeffrey	University of Miami Miami, FL	Phone: (305) 361-4328 FAX: (305) 361-4402 Internet: Nystuen@tsai.aoml.erl.gov
Pfeiffer, Ruth	University of Maryland College Park, MD	Phone: (301) 405-5178 FAX: (301) 314-0827 Internet: pfriu@math.umd.edu
Proni, John	NOAA/AOML Miami, FL	Phone: (305) 361-4312 FAX: (305) 361-4402 Internet:
Short, David	NASA/GSFC Greenbelt, MD	Phone: (301) 286-7048 FAX: (301) 286-1626 Internet: short@trmm.gsfc.nasa.gov
Thiele, Otto	NASA/GSFC Greenbelt, MD	Phone: (301) 286-9006 FAX: (301) 286-1626 OMNET: O.THIELE Internet: thiele@trmm.gsfc.nasa.gov
Tokay, Ali	NASA/GSFC Greenbelt, Maryland	Phone: (301) 286-9175 FAX: (301) 286-1626 Internet: tokay@echo.gsfc.nasa.gov
Wang, Ting-I	STi Gaithersburg, MD	Phone: (301) 948-6070 FAX: (301) 948-4674 Internet:
Wharton, Larry	NASA/GSFC Greenbelt, MD	Phone: (301) 286-3486 FAX: (301) 286-1663 Internet: wharton@eosdata.gsfc.nasa.gov
Wilkerson, John	NOAA/NESDIS Camp Springs, MD	Phone: (301) 763-8231 FAX: (301) 763-8020 OMNET: J.WILKERSON
Winter, Don	NOAA/NWS	Phone: (301) 713-0675 FAX: (301) 713-0662 Internet:

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