N95- 18210

111795
35/596

Effect of Heavy Rain to the Total Received Power

22 April 1994
T. Iguchi

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})

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

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

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

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

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

$$N_{T1} = 3000 \tag{4}$$

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

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

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

$$1.5 \times 10^4 \times 10^{-2} = 1.5 \times 10^2 \text{s}^{-1}. \tag{6}$$

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

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

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. Frietag 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 raingage data, which were presented and discussed.

Some of the problems associated with the capacitance raingage were discussed. Problems with the capacitance raingage 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/hrto 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 that 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, Shiyan #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 were 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 he 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 a 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 a 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 preforms 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@gsfcmail.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@gsfcmail.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: pfru@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:

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
December 1994

3. REPORT TYPE AND DATES COVERED
Conference Publication

4. TITLE AND SUBTITLE
Optical Rain Gauge Performance - Second Workshop on Optical Rain Gauge Measurements

5. FUNDING NUMBERS
RTOP 461-54-15
RTOP 461-56-50

6. AUTHOR(S)
David A. Short, Michael J. McPhaden, and Otto W. Thiele, Editors

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS (ES)
Goddard Space Flight Center
Greenbelt, Maryland 20771

8. PEFORMING ORGANIZATION REPORT NUMBER
95B00023
Code 910

9. SPONSORING / MONITORING ADGENCY NAME(S) AND ADDRESS (ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING / MONITORING ADGENCY REPORT NUMBER
NASA CP-3288

11. SUPPLEMENTARY NOTES
Short and Thiele: Goddard Space Flight Center, Greenbelt, Maryland
McPhaden: NOAA Pacific Marine Environmental Laboratory, Seattle, Washington

12a. DISTRIBUTION / AVAILABILITY STATMENT
Unclassified - Unlimited
Subject Category 47

Availability: NASA CASI (301)621-0390.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

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.

14. SUBJECT TERMS
Rainfall Rate, Rain Gauges, Optical Rain Gauge

15. NUMBER OF PAGES
88

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL