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# Improved Meteorological Measurements from Buoys and Ships (IMET): Preliminary Comparison of Precipitation Sensors.

by

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**Technical Report**

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**Approved for Distribution:**

Robert C Beardsley

**Robert C. Beardsley, Chairman**
Department of Physical Oceanography

# Abstract

Rainfall data obtained from an optical rain gauge and a capacitive siphon rain gauge are analyzed and discussed. These sensors were developed for unattended use and are being considered for use at sea on ships and buoys.

# Table of Contents

# 1 Introduction and Motivation

Very little is known about distribution patterns and rainfall intensities over the open oceans. What data has been obtained is subject to much speculation and large inaccuracies. The reason for this problem is an instrumental one. Aside from the fact that meteorological surface observations are sparse over the open waters, inaccuracies arise from the types of rain gauges and the platforms on which they reside (Skaar, 1955; World Meteorological Organization, 1962). Error sources include the disturbing effects of a ship or buoy on the air flow near the sensor, the disturbing effect of the sensor itself on the air flow, the effect of the rocking motion of the ship or buoy, the effect of sea spray leading to overestimates in rainfall, and the effect of forward motion of a ship.

Some of this error could be reduced by improving the method of sensing rainfall. This report discusses the preliminary findings of comparison testing of an optical rain gauge and a self-siphoning rain gauge. Both of these gauges are relatively new in design and are substantially different from the conventional tipping bucket or weighing bucket rain gauges. These new gauges are developed for unattended use in remote areas including use at sea.

# 2 Instrumentation

Four rain gauges were obtained for intercomparison testing. Besides the optical and self-siphoning rain gauges, a simple plastic rain gauge and a tipping bucket rain gauge were included as standards. Photographs of the rain gauges can be seen in Figure 1. These sensors are described below.

## 2.1 Optical Rain Gauge

The design of the ORG-705 precipitation sensor is intended to overcome the limitations and inaccuracies of conventional precipitation sensors, especially at the extreme ranges of rainfall rate. This particular sensor is manufactured by Scientific Technology Inc. (S.T.I., see Appendix A for manufacturer's address and information). It is a single unit package with no moving parts developed for unattended use with minimal maintenance. The unit is relatively small, measuring under 1 m long, 0.5 m high, and 17 cm wide. Total weight is 4.3 kg.

The ORG-705 uses an infrared emitting diode (IRED) as a light source. As raindrops fall through the beam of light they induce optical scintillations in the detected light intensity. Measurement of the rainfall by scintillation technique has been well documented (e.g., Wang and Clifford, 1975; Wang *et al.*, 1977; Wang and Lawrence, 1977; Wang *et al.*, 1979). However, it has not been until recently that a small package such as the ORG-705 has been made commercially available. Early scintillation devices used path lengths of 100 m to measure rainfall. Clearly, such a device is not suited for operation at sea. The statistical average of the measured scintillation signals give a measurement of instantaneous rainfall rates. The optical gauge is intended to be insensitive to variation in the source intensity caused by extreme temperature variations, IRED ageing, or dirt on the lenses.

The measurement range of the ORG-705 spans from 0.1 to 1000 mm/hr. The time resolution is a 10 second exponential average, and the output is a 0 to 5 volt analog signal that is proportional to the log of the rainfall rate

$$RR = 10^{(\mathbf{Vout}\ -C)} \tag{1}$$

where $RR$ is the rainfall rate in mm/hr, Vout is the output signal measured by the rain gauge, and $C$ is a calibration constant, nominally equal to 0.65, which is determined by the manufacturer. Power requirements are standard 115 VAC (0.75

Amp). Quoted accuracies are 1% from 10 to 100 mm/hr, 4% from 1 to 500 mm/hr, and 10% from 0.1 to 1000 mm/hr.

## 2.2 Siphon Rain Gauge

Conventional tipping bucket rain gauges do not work well on moving platforms where the total acceleration vector is not constant. Many conventional rain gauges are also constructed from metals susceptible to corrosion in the marine environment. An effort was initiated at the National Data Buoy Center (NDBC) to develop a precipitation gauge for extended use on a buoy (Michelena, 1989). It was decided that a rain gauge on a moving platform should measure the volume of rainfall caught rather than its weight (Michelena, 1989). The result is a commercially available rain gauge manufactured by the R. M. Young Company which is based on the NDBC design. Early prototype designs are first described by Holmes *et al.* (1981) and Holmes and Michelena (1983).

A capacitance-type, water-level measuring transducer proved to be easiest to implement (Michelena, 1989). Precipitation is collected by a funnel which leads to a storage container. The water level in this rain accumulation container is sensed as a capacitance by an electronic transducer to obtain an analog signal proportional to the height of the fluid column. A stainless steel rod inside the collection tube is covered with a teflon sheath that serves as the dielectric. The water mass that surrounds the probe forms the outer "plate" of the coaxial-type capacitor, and the central metallic rod is the inner "plate." As more rain is accumulated, the water level in the rain accumulator tube rises, thereby increasing the total capacitance. Additional electronics are used to measure the value of the total capacitance and output an analog voltage that is directly proportional to the amount of precipitation collected by the rain gauge.

Dumping of the accumulated rain occurs when the rain storage tube is full by a self-initiating siphon that starts when the water level reaches the upper limit of the container. This empties the gauge for a new rain collection cycle. Any rainfall collected during the siphon dump is not recorded which may introduce an error in total rainfall measured. The early prototype gauge (Holmes *et al.*, 1981) dumped the contents of its storage tube in approximately 4 minutes. A sustained rainfall rate of 50 mm/hr would introduce an underestimate of total rainfall by approximately 3 mm. Since then, improvements have been made on siphon dump time and our study has shown that the dump time of the Young siphon rain gauge to be on the order of 20 seconds. The mean time series of height versus time from dumps is shown in Figure 2. The profile can be approximated by a straight line. An error of less than 0.1 mm would be introduced for a sustained rainfall rate of 50 mm/hr. This can be seen in Figure 3. Even in extreme rainfall rates, the associated error is still minimal.

The NDBC prototype rain gauge has been found to operate reliably on the NDBC ocean test platform for a period of 18 months (Holmes and Michelena, 1983). This test platform is a 10 m discus buoy located in the Gulf of Mexico. The capacitance probe used has a stable calibration and is not affected by the environmental temperatures at the test platform. The siphon dumping technique has been quite successful and errors introduced by siphoning are minimal.

The Young rain gauge is fairly light weight (4 kg) and compact, measuring 14 cm across at its widest (collection funnel) and is 65 cm long. The quoted resolution of the rain gauge is 1 mm of rainfall with an accuracy of $\pm 2$ mm. The output signal ranges from 0 to 5 volts corresponding linearly to 0 to 50 mm of rain. Circuit power requires 8–30 volts at less than 3 mA (unregulated). The operating temperature is 0 to 50 $C$, or $-20$ to 50 $C$ with an optional 28 volt heater.

## 2.3 Plastic Rain Gauge

An inexpensive rain gauge constructed of clear butyrate plastic was also used to measure rainfall. This simple gauge has a 280 mm capacity with a 0.2 mm resolution. The catch area of the gauge is approximately 81 $cm^2$. Although this gauge is not intended for use at sea, these data were manually recorded after rainfall events for comparison against the total rainfall recorded by the optical and siphon gauges.

## 2.4 Tipping Bucket Rain Gauge

An 8" tipping bucket rain gauge from Climatronics Corporation was used as a standard with which to compare the optical and siphon rain gauges. It is one of the standard measuring devices for rainfall used by National Weather Service observing stations.

Operation of a tipping bucket rain gauge is quite simple. Precipitation is channeled into a hinged dual bucket which tips back and forth every 0.254 mm (0.01 inch) of water collected. When the bucket tips, it activates a sealed reed switch which sends a digital signal to the data acquisition system. Upon tipping the accumulated water is drained from one side of the bucket and the opposing bucket is then filled and tips back upon receipt of the next 0.254 mm of rainfall.

Rainfall rate is computed by dividing 0.254 mm of water by the difference in time between successive tips. The total rainfall is simply the number of tips multiplied by 0.254. An Alter-Type wind screen was placed around the tipping bucket rain gauge to help minimize the loss in precipitation catch due to streamlining effects of strong winds around the gauge orifice. The quoted accuracies of this device are $\pm 1\%$ for rainfall rates up to 75 mm/hr and $\pm 5\%$ for rates up to 250 mm/hr.

It was found that the tipping bucket rain gauge grossly overestimates rainfall. These errors were due to the force of the rain funneling into the bucket which causes premature tipping and to adhesion of water droplets (with dirt) to the sides of the bucket causing an imbalance in weight of the bucket. No useful data was recorded from this sensor for this data set.

# 3 Tests

Rainfall data of the optical and siphon rain gauges are recorded on a NEC APC-IV computer using a 12-bit Metrabyte analog-to-digital (A/D) board. Data are sampled at once per second and averaged over 7.5 minute blocks. The sensors are located on a roof top in Woods Hole near the W.H.O.I. docks. Each sensor is approximately 5 m from each other and 1 to 2 m up from the surface of the roof. Although these sensors have an open exposure to the sky, taller buildings are found on either side. This may lead to anomalous rainfall in high wind conditions in the wake of these taller superstructures.

Rainfall caught by the plastic rain gauge was manually recorded usually after each rainfall event.

# 4 Data Analysis

After several weeks of data collection which yielded poor agreement between the optical rain gauge and the others, the ORG-705 was returned to the factory for recalibration. At the factory a breach in the sensor itself was found that caused the sensor to underestimate rainfall. The sensor housing is sealed from the environment, and that seal must be maintained in order for the sensor to work properly. Even the slightest of humidity increases inside the sensor will cause erroneous values.

Following the return of the ORG-705, a total of 12 rain events were recorded. They ranged from very light rains and drizzles to moderately heavy but short showers. Total accumulations ranged from a few millimeters up to several tens of centimeters.

Figures 4a–15a depict the rainfall rates as determined by the optical rain gauge. Figures 4b–15b depict the cumulative rainfalls of both the optical and siphon gauges. In most instances, the siphon rain gauge measured slightly more rainfall than the optical rainfall. The cumulative rainfall profiles generally had the same slopes. Offsets existed during high rainfall episodes where the cumulative rainfall of the siphon gauge jumped more than the optical gauge. Whether or not this can be attributed to averaging of the signal remains to be seen. However, allowing for the sudden offsets, the slopes of both sensors match well. A relatively short but strong rainfall episode can be seen in Figure 14a which lasted about 6 hours. Figure 14b shows excellent agreement of all three gauges.

A comparison of rainfall totals of the optical rain gauge against the siphon rain gauge can be seen in Figure 16. There is a slight bias towards higher totals from the siphon gauge. The same may also be said of the optical gauge when compared against the plastic rain gauge (Figure 17). However, the slope of the linear least-squares fitted line is closer to unity. As found in earlier studies, the siphon and plastic gauge totals show a nearly one-to-one correspondence but with a slight offset (Figure 18).

It should be noted that the measurements of rainfall from the plastic gauge are also subject to errors. Such errors may be due to evaporation (Hamilton and Andrews, 1953), splashing of excess water into the gauge (Ashmore, 1934), and wind effects around the gauge (Alter, 1937).

# 5 Discussion

The test area was not the best suited for rainfall measurement. Nearby buildings may lead to spatial variations in rainfall. Even so, the results are encouraging and both the optical and siphon rain gauge sensors show much promise.

The optical and siphon rain gauges have both advantages and disadvantages. The optical rain gauge has the inherent advantage to measure rainfall rate instantaneously throughout a wide range. The rainfall rate can easily be integrated to obtain cumulative and total rainfalls. However, the major power restrictions limit the operation of this gauge to ships only. S.T.I. is currently designing a newer optical rain gauge which is about 1/3 the size of the ORG-705 and can operate on the power budget available on a buoy. The other main disadvantage is the limited accuracy. As observed in this study, many of the rainfall rates were less than 1 mm/hr which places the accuracy of measurement at 10%. The optical rain gauge seems best suited for moderate rainfall rates even though it can measure extremely light rainfalls. Another problem with the optical rain gauge is that it measures the vertical component of the falling rain. Should any sea spray cross the light beam moving vertically, that signal would be recorded as a rainfall. Any vertical motion, either upwards and downwards, is observed as a rainfall. This problem should not be a major factor if the optical rain gauge is sufficient distance from the sea surface during rough weather.

The siphon rain gauge which was developed for use on a buoy is better suited to measuring rainfall volume rather than rate. A tube can be fitted to the siphon spout and led to a reservoir which can be used as a check against the rain measured by the gauge. The capacitance sensor can pick up electrical noise. A capacitor has just been put on this gauge to solve this problem. Another problem lies with the sampling scheme of the gauge. Should the sampling rate be sufficiently long and the rainfall rate be high, it is possible to run through a complete siphoning cycle. However, with an adequate sampling interval, in this case 7 and 1/2 minutes, there is sufficient time resolution to discern individual rainfall episodes.

The siphon rain gauge is relatively immune to salt water and moderate tilting (R. Young, personal communication). Manufacturing tests show that moderate tilts as observed on a buoy have minimal effect on the output signal of the sensor. Also salt water solutions have minimal effect on the signal. The effect of funnel catch area on collection efficiency (Huff, 1955) will also be addressed by work being done at the R. M. Young Company.

Further testing will continue with these rain gauges. Future plans include more dock side testing of the siphon and optical rain gauges, acquisition of the new S.T.I. low power optical rain gauge, and testing of the siphon rain gauge on a buoy.

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World Meteorological Organization, 1962. Precipitation measurements at sea. *W.M.O. Technical Note No. 47*, Geneva, Switzerland, 18 pp.

# Appendix A

**Manufacturers:**

Climatronics Corporation
Airport International Plaza
140 Wilbur Place
P.O. Box 480
Bohemia, New York 11716
(516) 567-7300
100097 8" Tipping Bucket Rain Gauge $550.00

Science Associates
P.O. Box 230
Princeton, New Jersey 08542
(609) 924-4470
6331 Plastic Rain Gauge $ 40.00

Scientific Technology Inc.
2 Research Place
Rockville, Maryland 20850
(301) 948-6070
ORG-705 Precipitation Intensity Sensor $4500.00

R. M. Young Company
2801 Aero-Park Drive
Traverse City, Michigan 49684
(616) 946-3980
50505 Precipitation Gauge $548.00
Heater (optional) $206.00

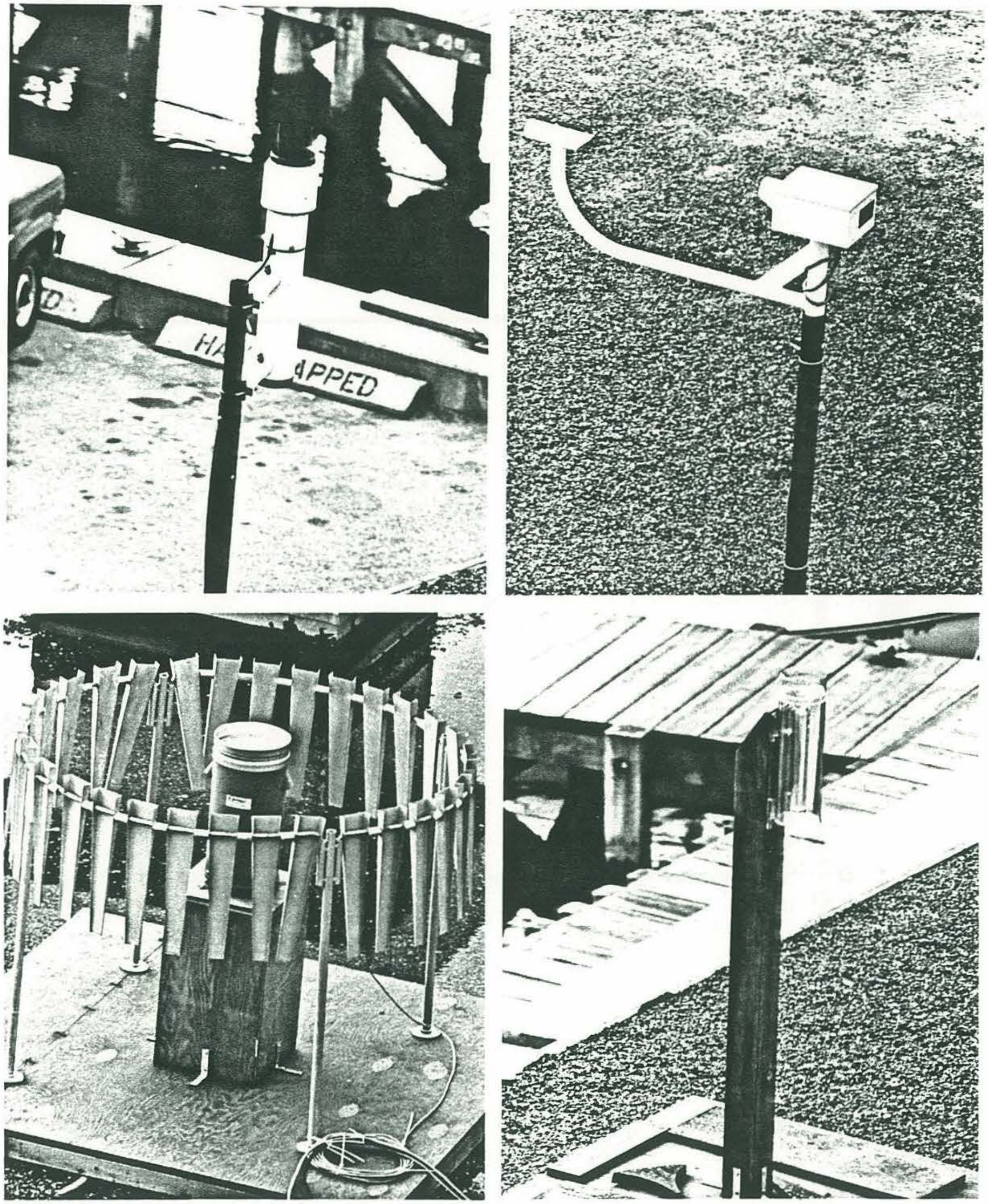


Figure 1: Photos of (from top left corner, clockwise) R. M. Young self-siphoning rain gauge, Scientific Technology Inc. ORG-705 optical rain gauge, Science Associates plastic rain gauge, and Climatronics Corporation 8" tipping bucket rain gauge.

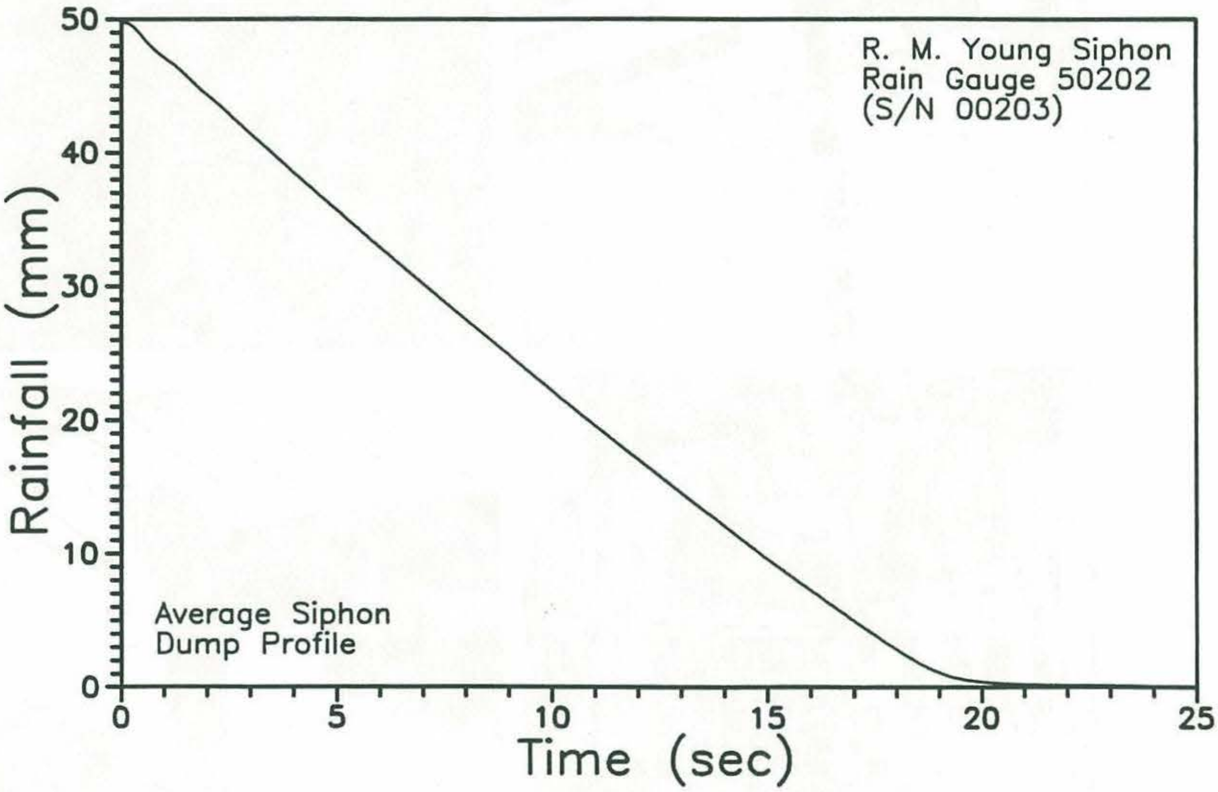



Figure 2: Average siphoning time of R. M. Young siphon rain gauge.

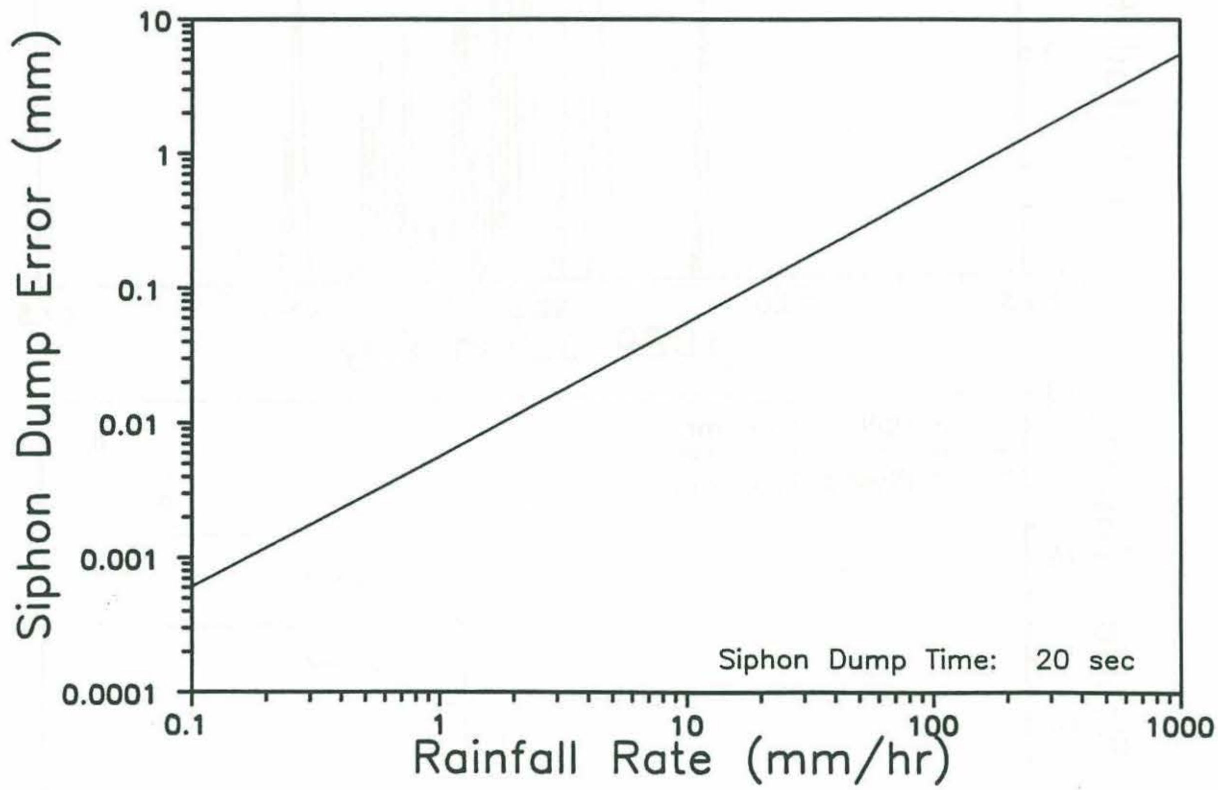
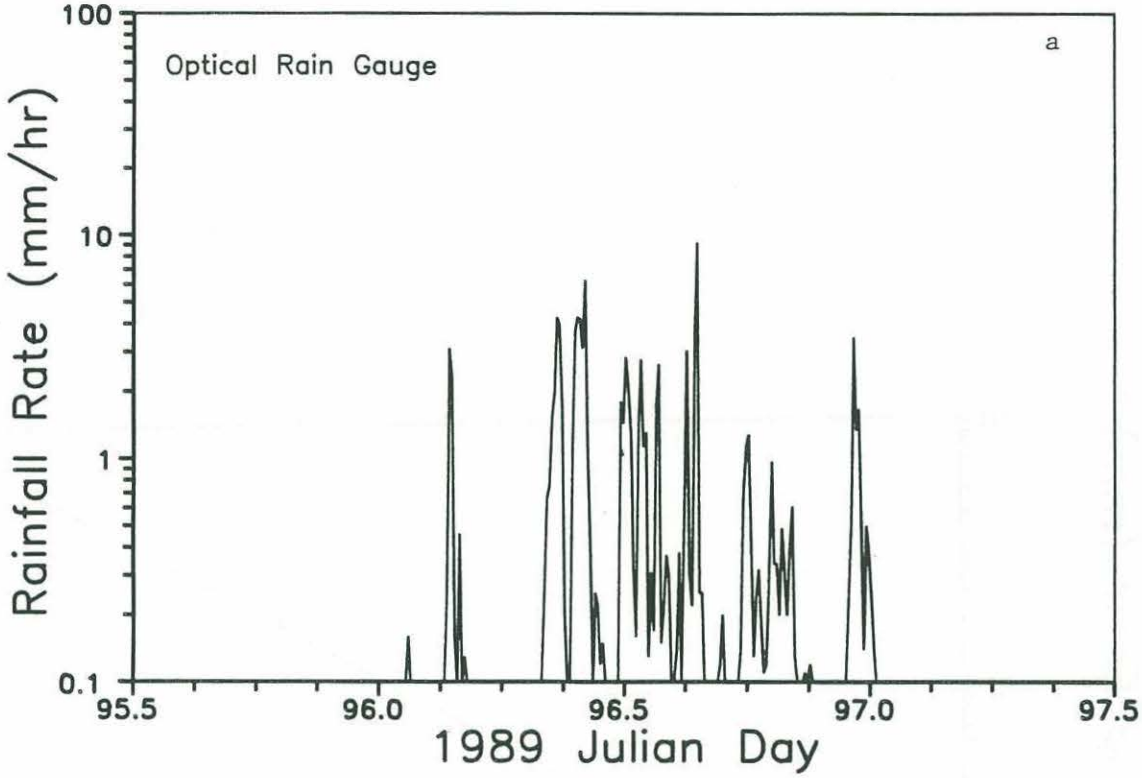



Figure 3: Siphon dumping error of the R. M. Young siphon rain gauge as a function of rainfall rate. This dumping error is the amount of rainfall that enters the gauge and is lost during the siphon dump. This curve is for a siphon dump time of 20 seconds.



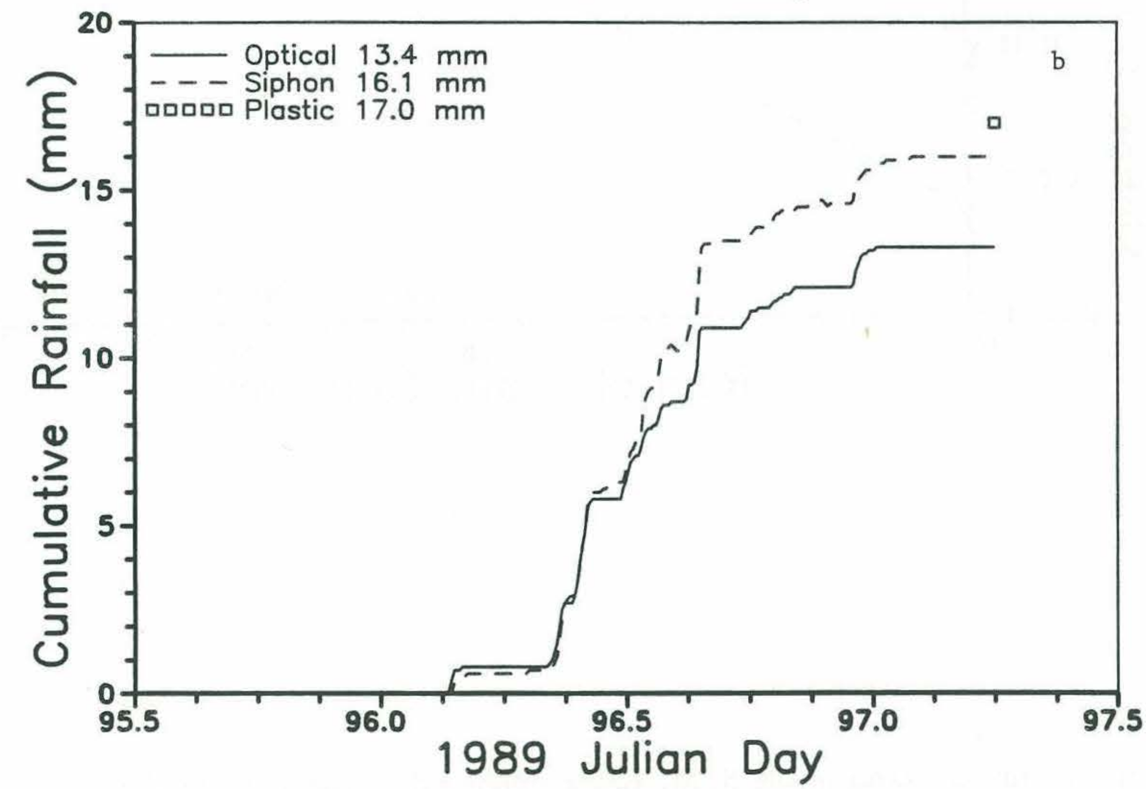




Figure 4: Time series plot of (a) rainfall rate of optical rain gauge and (b) cumulative rainfalls of optical, siphon and plastic rain gauges.

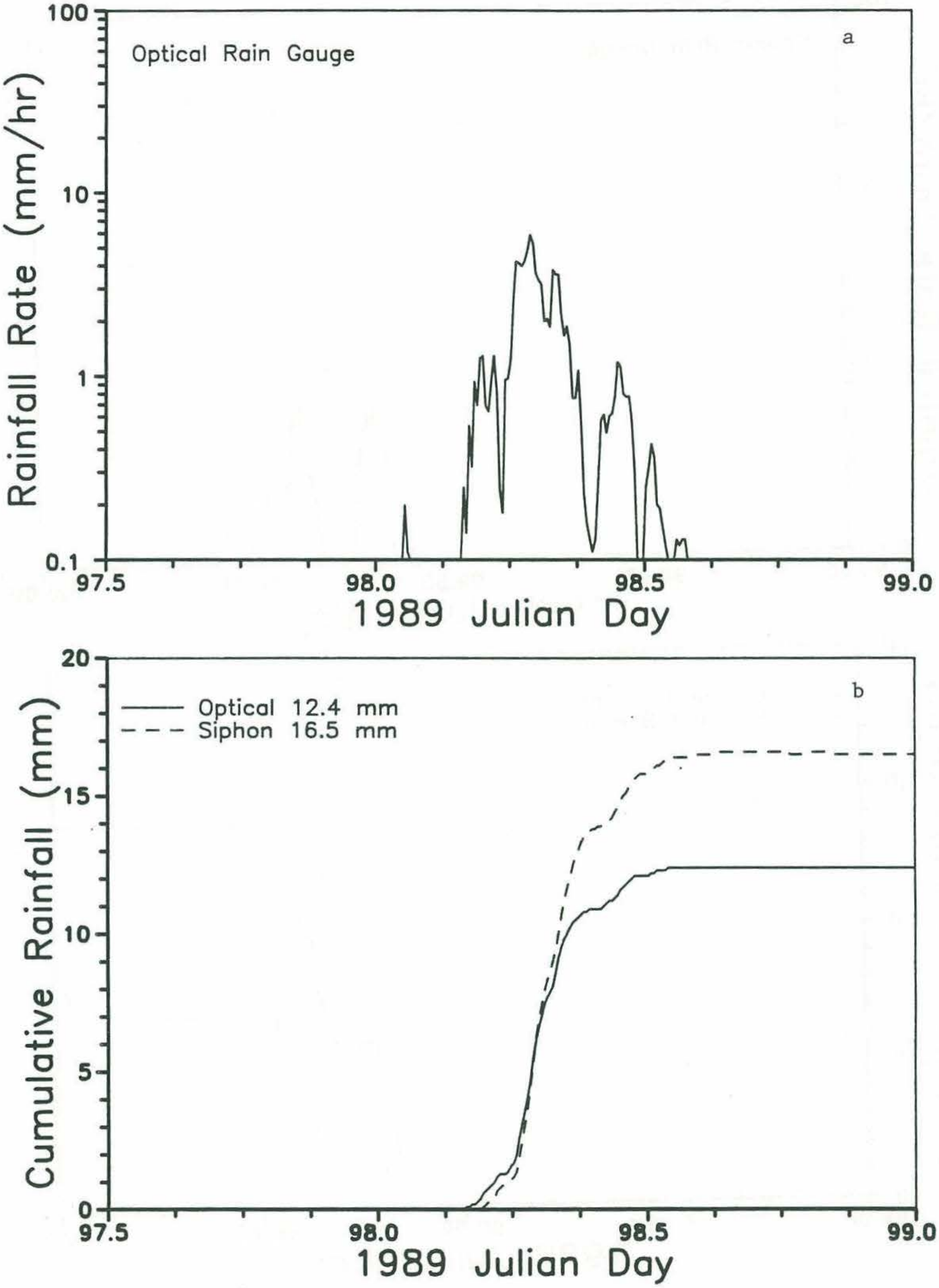



Figure 5: Time series plot of (a) rainfall rate of optical rain gauge and (b) cumulative rainfalls of optical and siphon rain gauges.

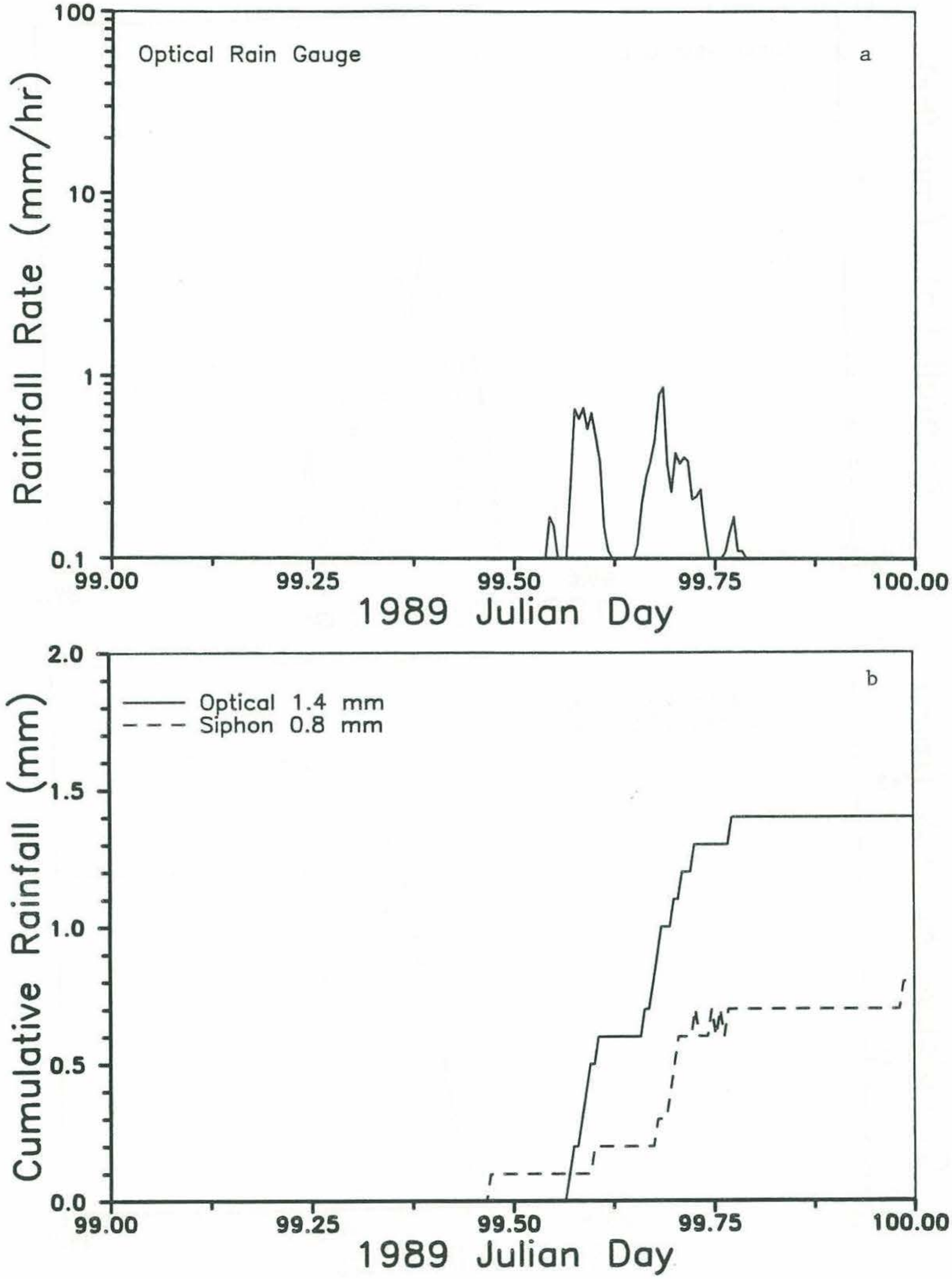



Figure 6: Time series plot of (a) rainfall rate of optical rain gauge and (b) cumulative rainfalls of optical and siphon rain gauges.

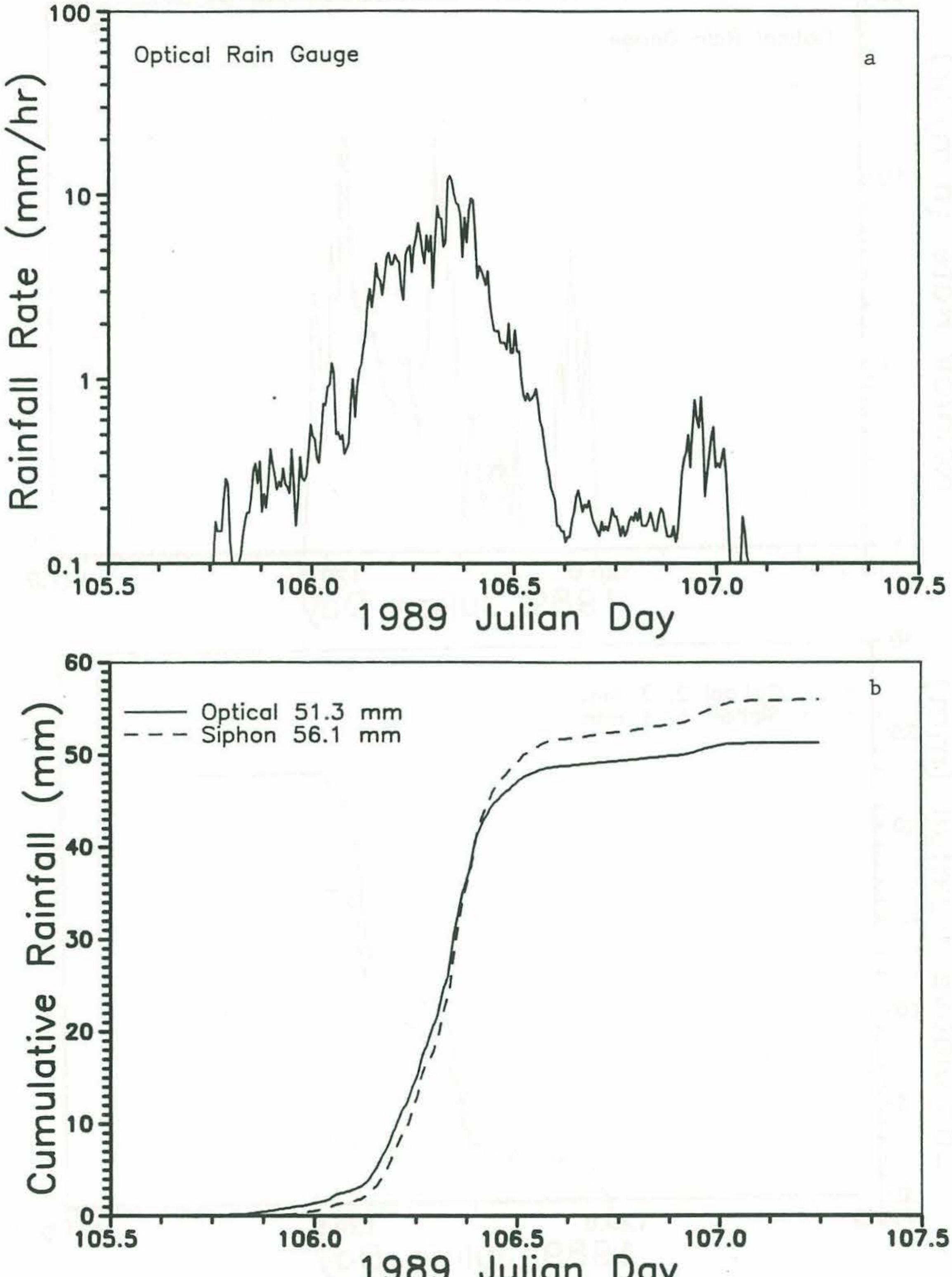



Figure 7: Time series plot of (a) rainfall rate of optical rain gauge and (b) cumulative rainfalls of optical and siphon rain gauges.

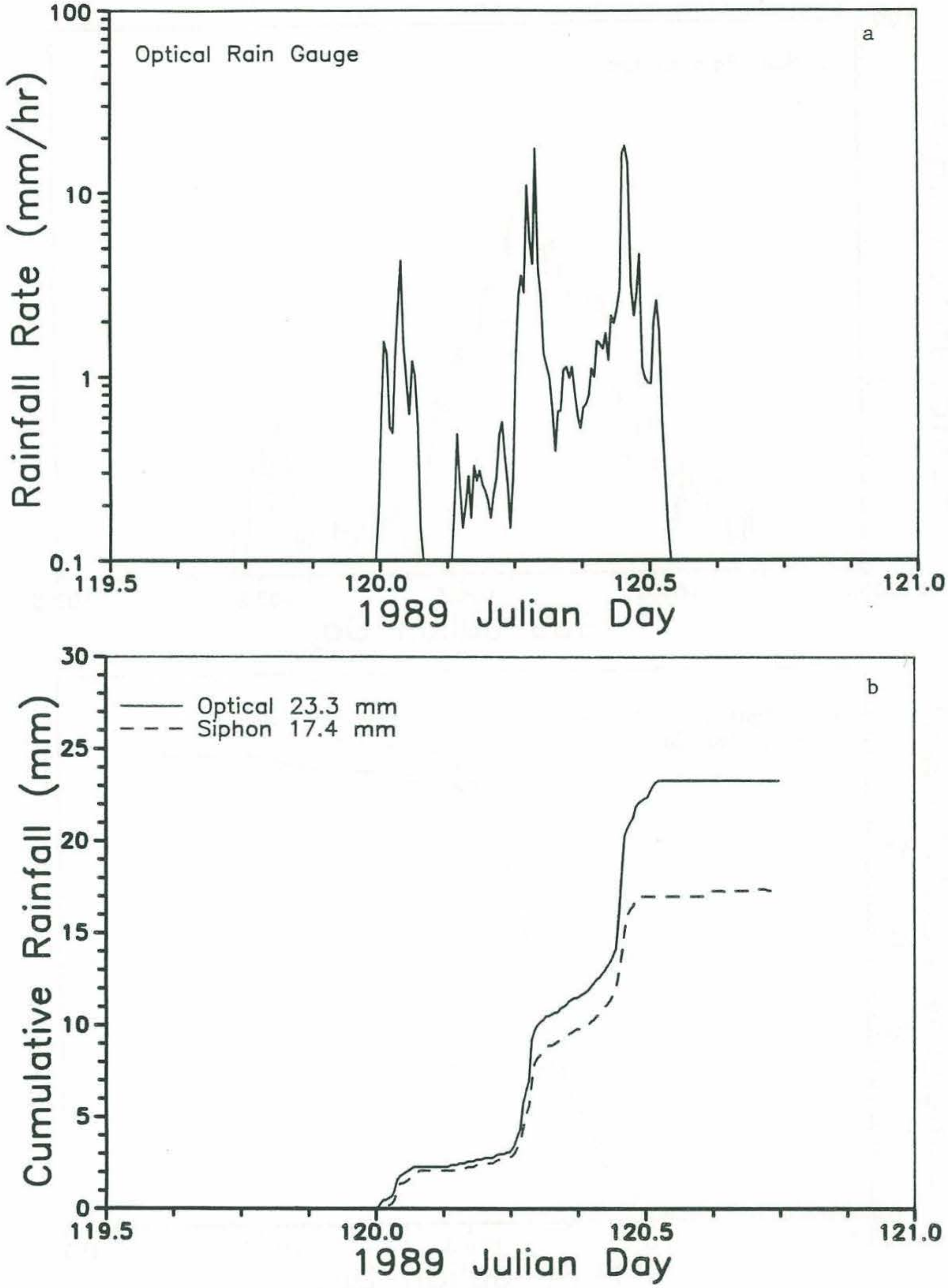



Figure 8: Time series plot of (a) rainfall rate of optical rain gauge and (b) cumulative rainfalls of optical and siphon rain gauges.

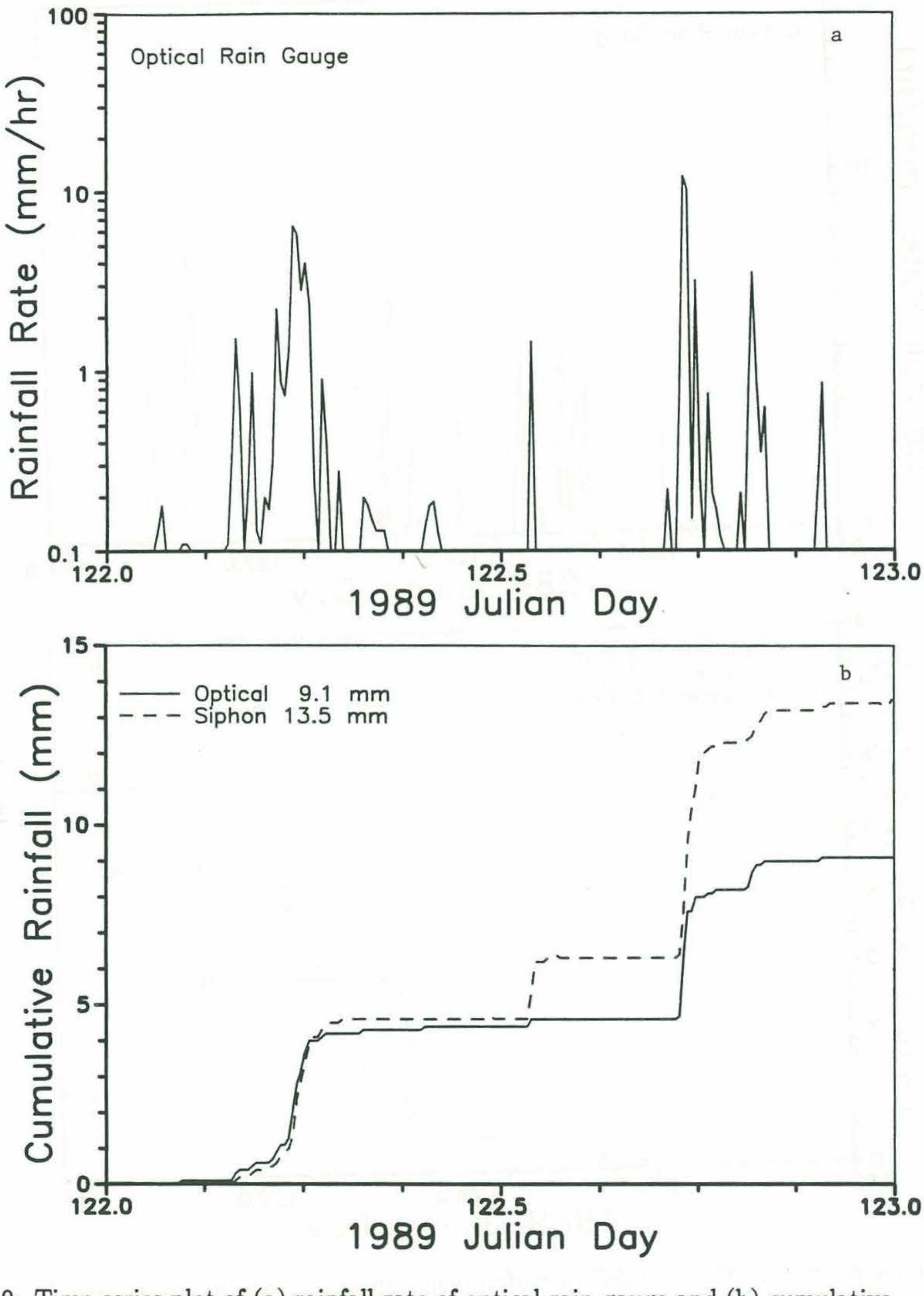



Figure 9: Time series plot of (a) rainfall rate of optical rain gauge and (b) cumulative rainfalls of optical and siphon rain gauges.

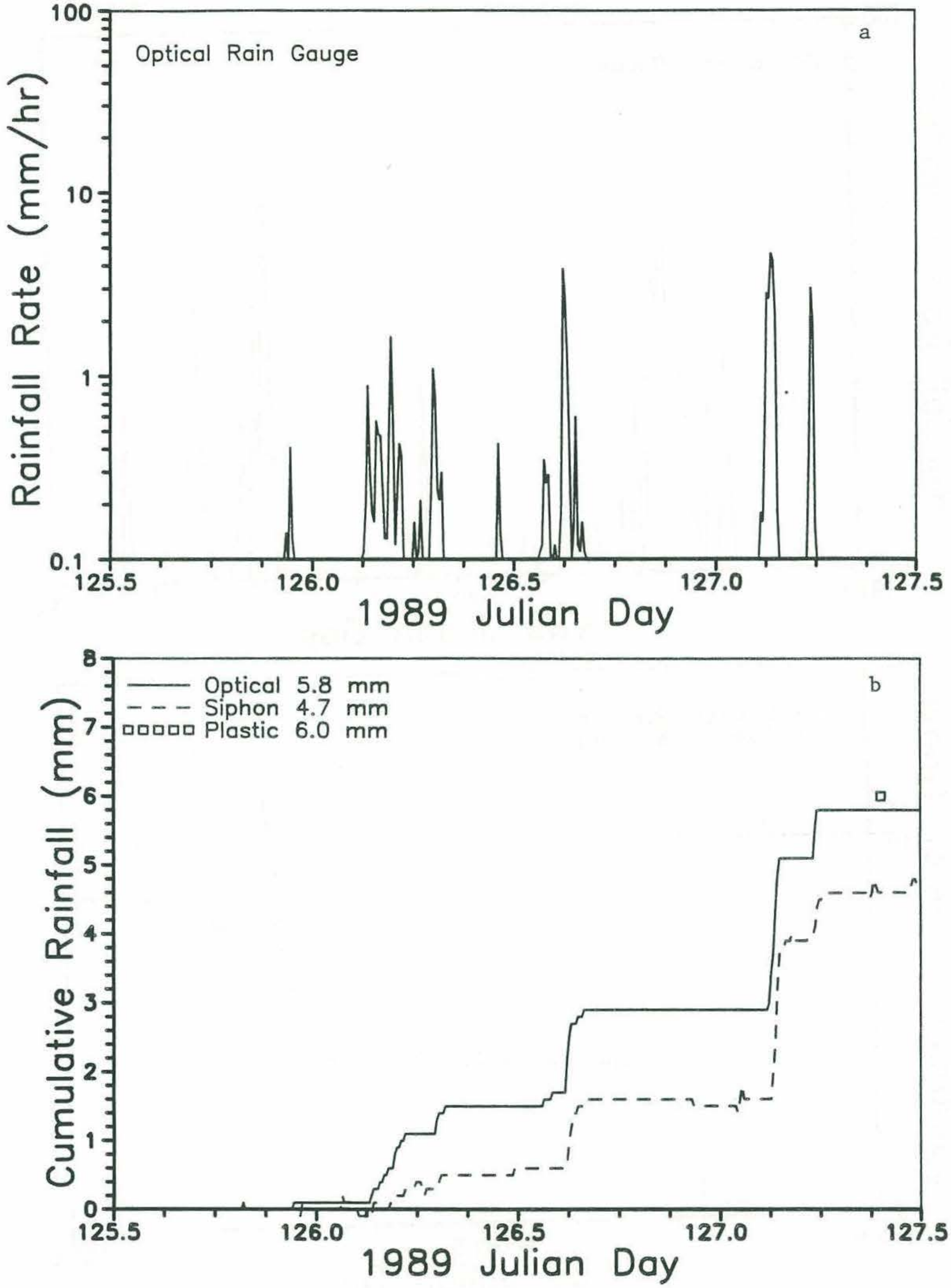



Figure 10: Time series plot of (a) rainfall rate of optical rain gauge and (b) cumulative rainfalls of optical, siphon and plastic rain gauges.

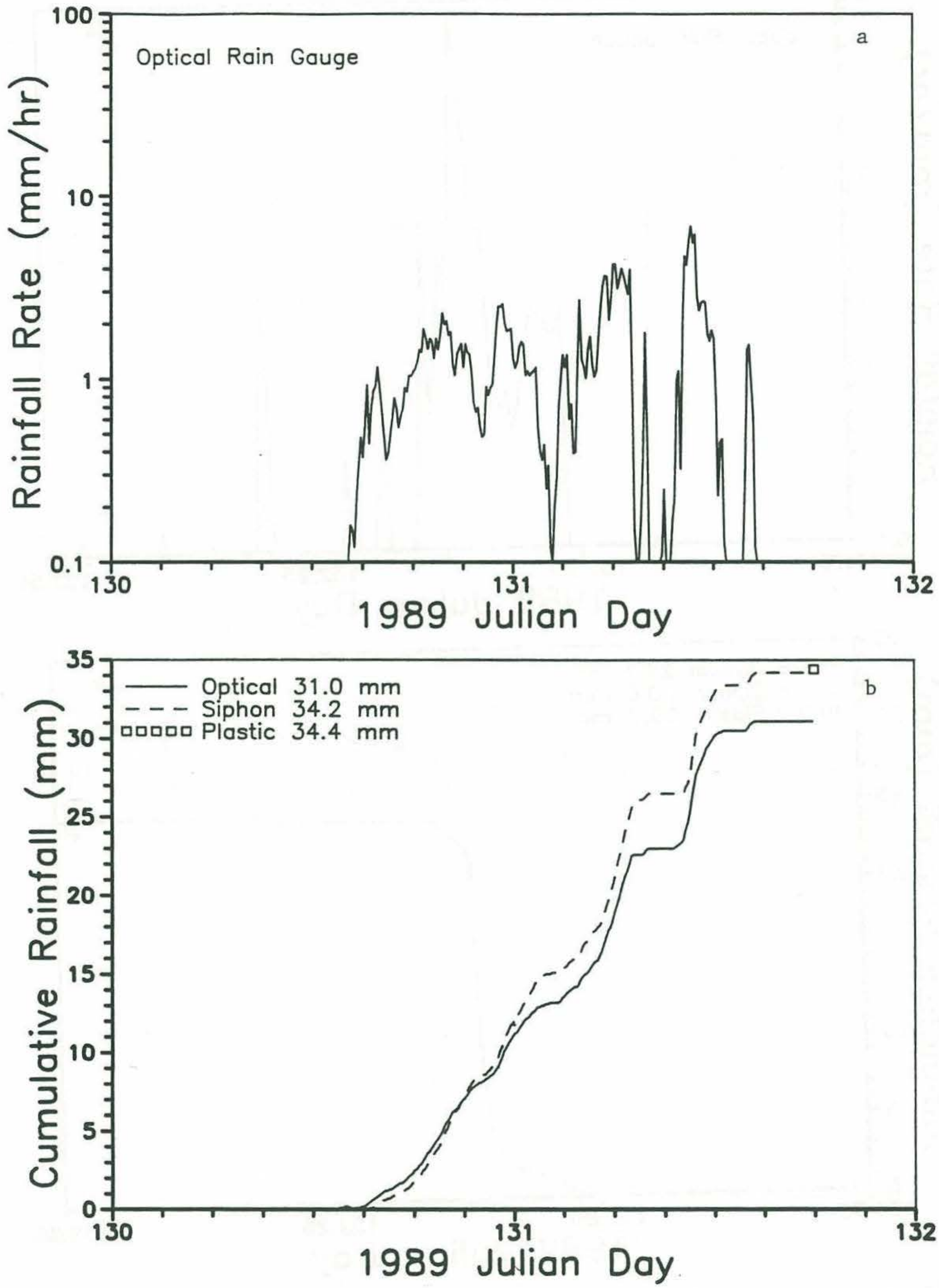



Figure 11: Time series plot of (a) rainfall rate of optical rain gauge and (b) cumulative rainfalls of optical, siphon and plastic rain gauges.

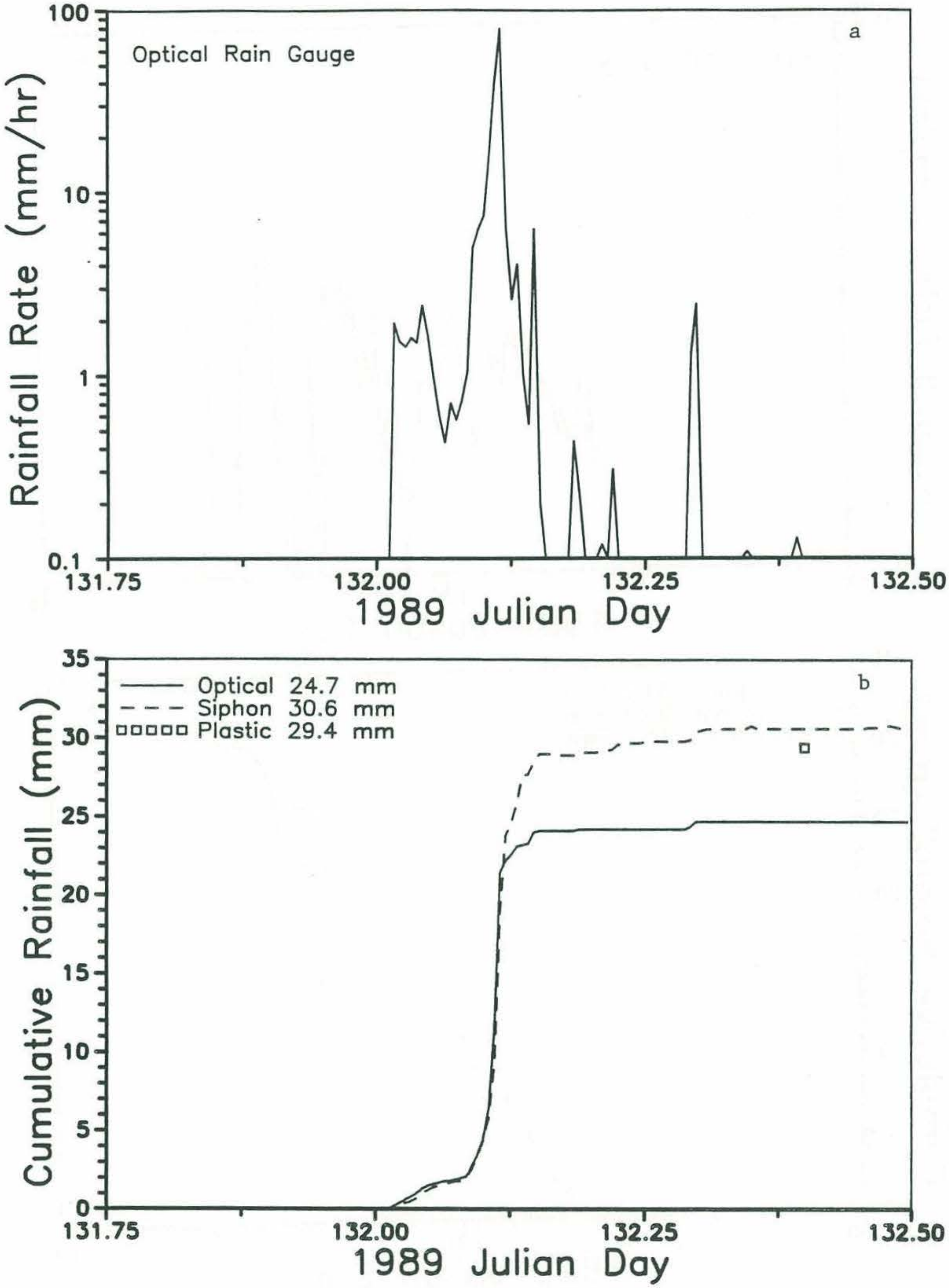



Figure 12: Time series plot of (a) rainfall rate of optical rain gauge and (b) cumulative rainfalls of optical, siphon and plastic rain gauges.

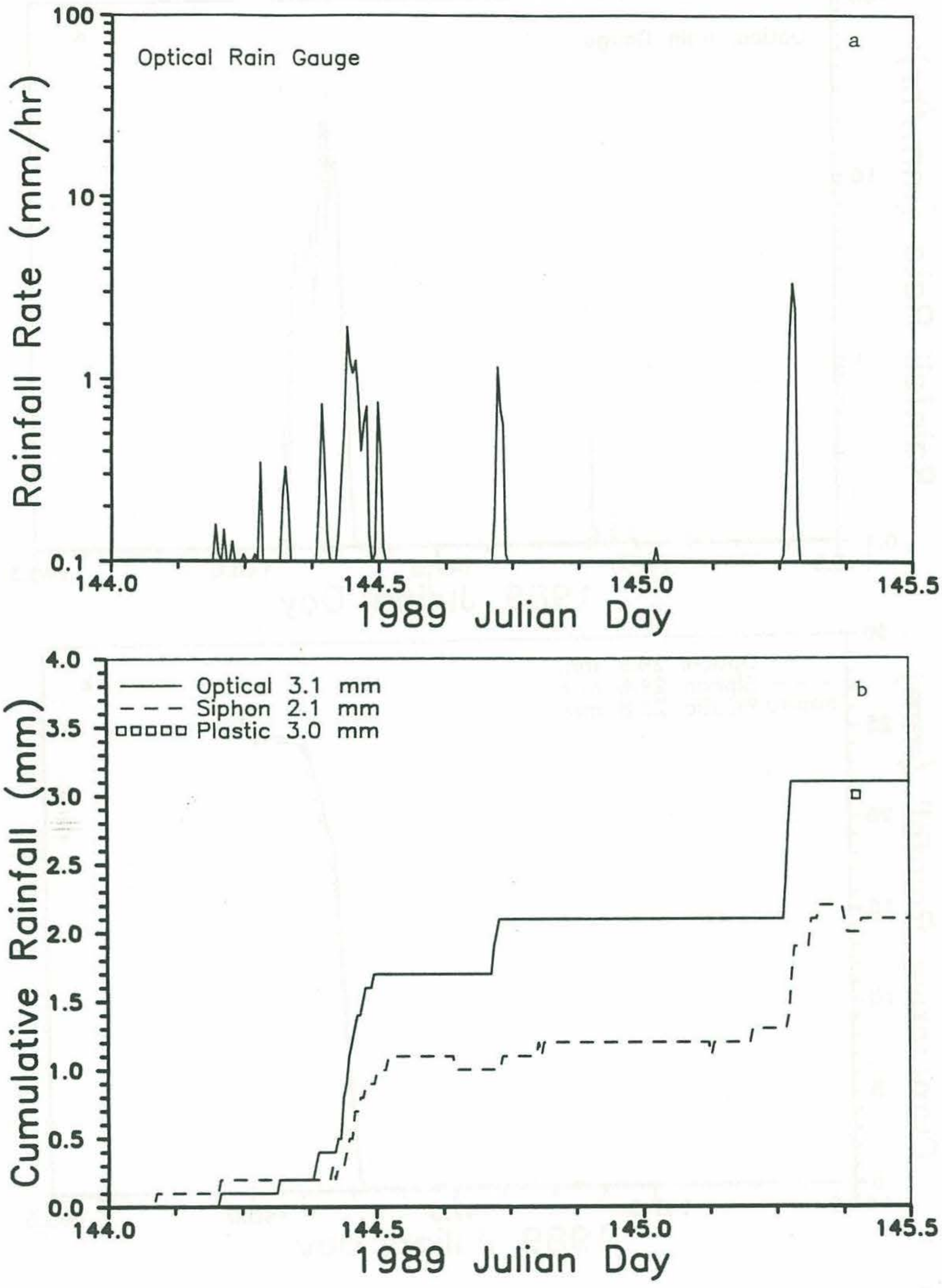



Figure 13: Time series plot of (a) rainfall rate of optical rain gauge and (b) cumulative rainfalls of optical, siphon and plastic rain gauges.

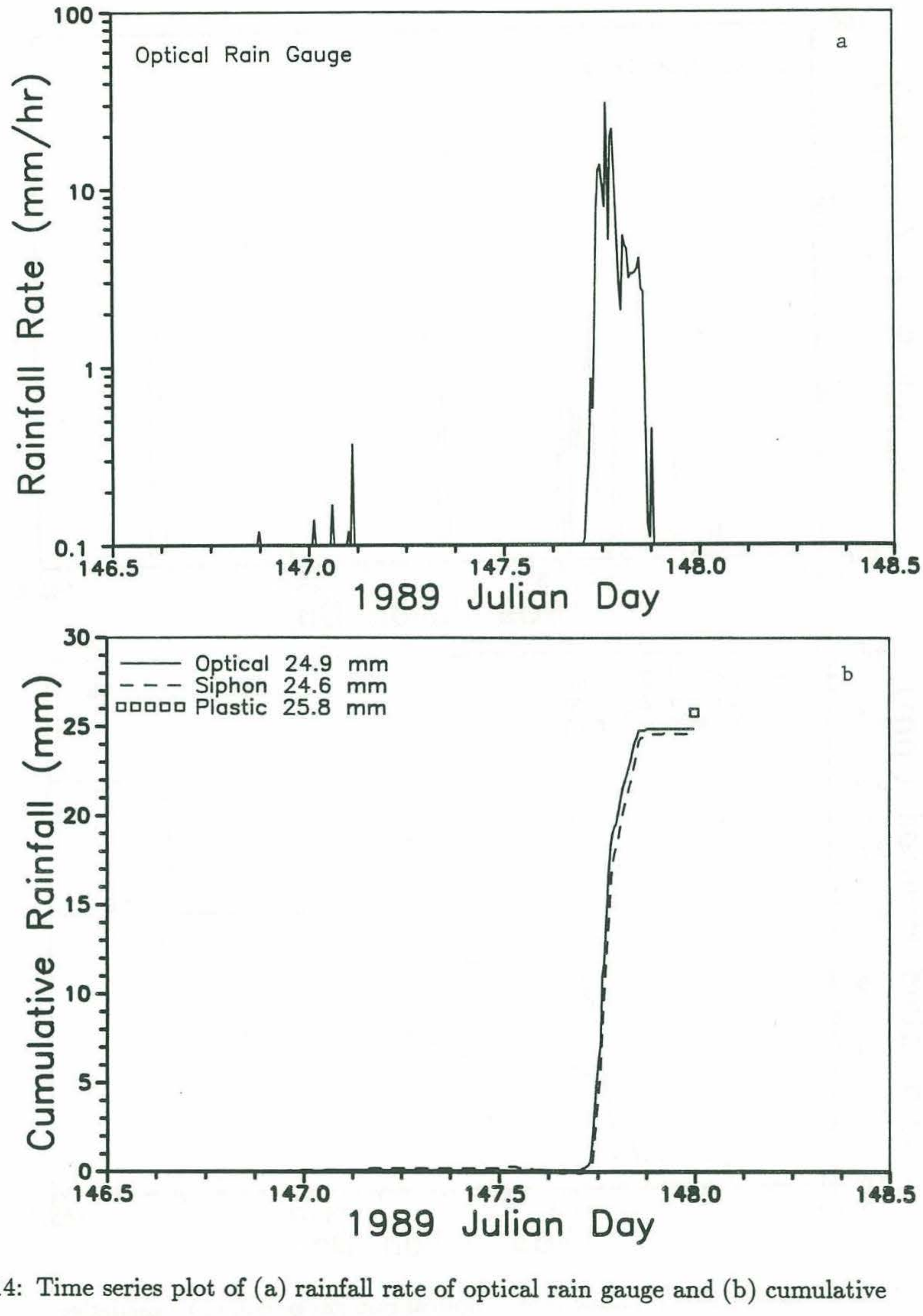



Figure 14: Time series plot of (a) rainfall rate of optical rain gauge and (b) cumulative rainfalls of optical, siphon and plastic rain gauges.

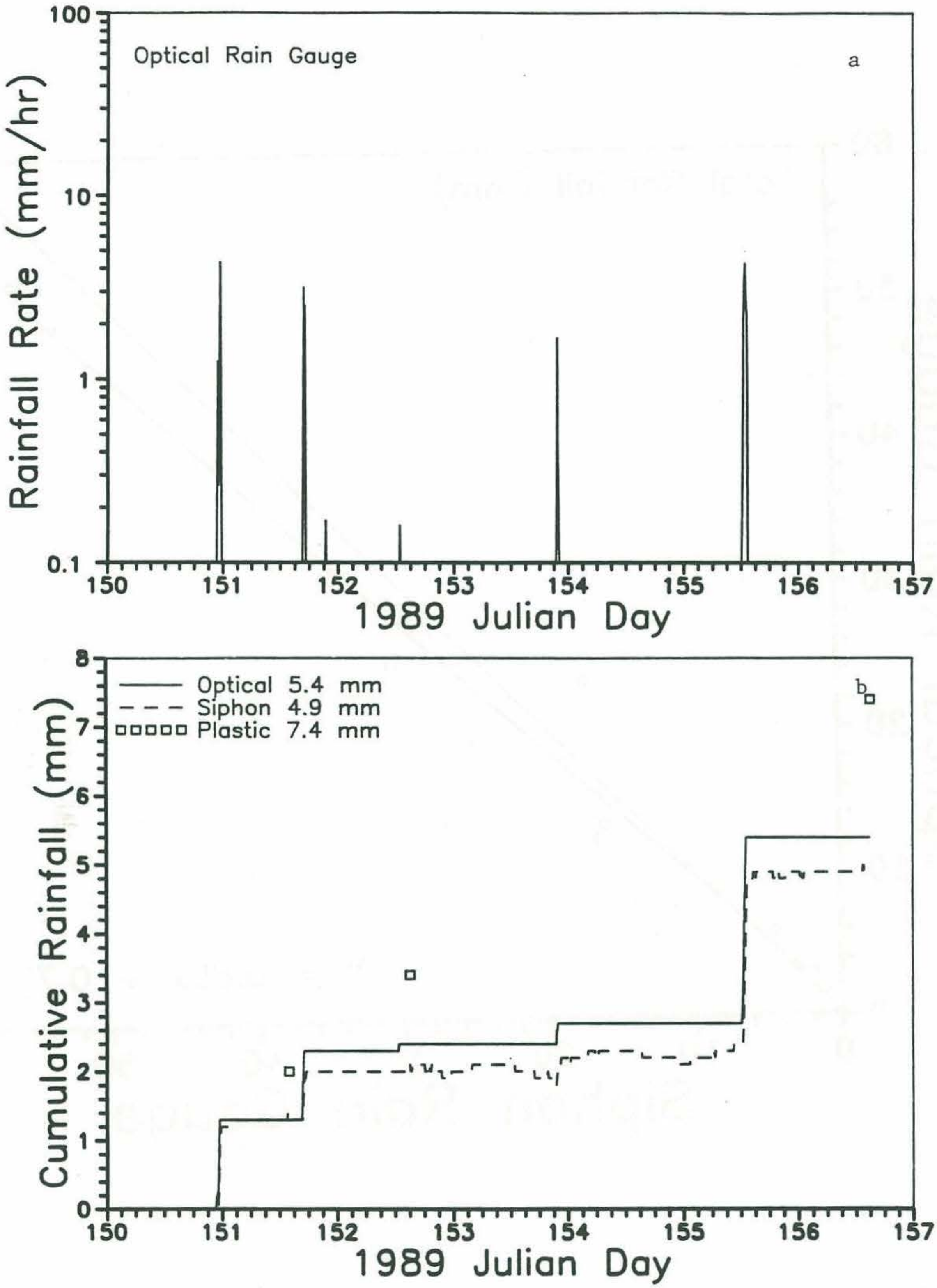



Figure 15: Time series plot of (a) rainfall rate of optical rain gauge and (b) cumulative rainfalls of optical, siphon and plastic rain gauges.

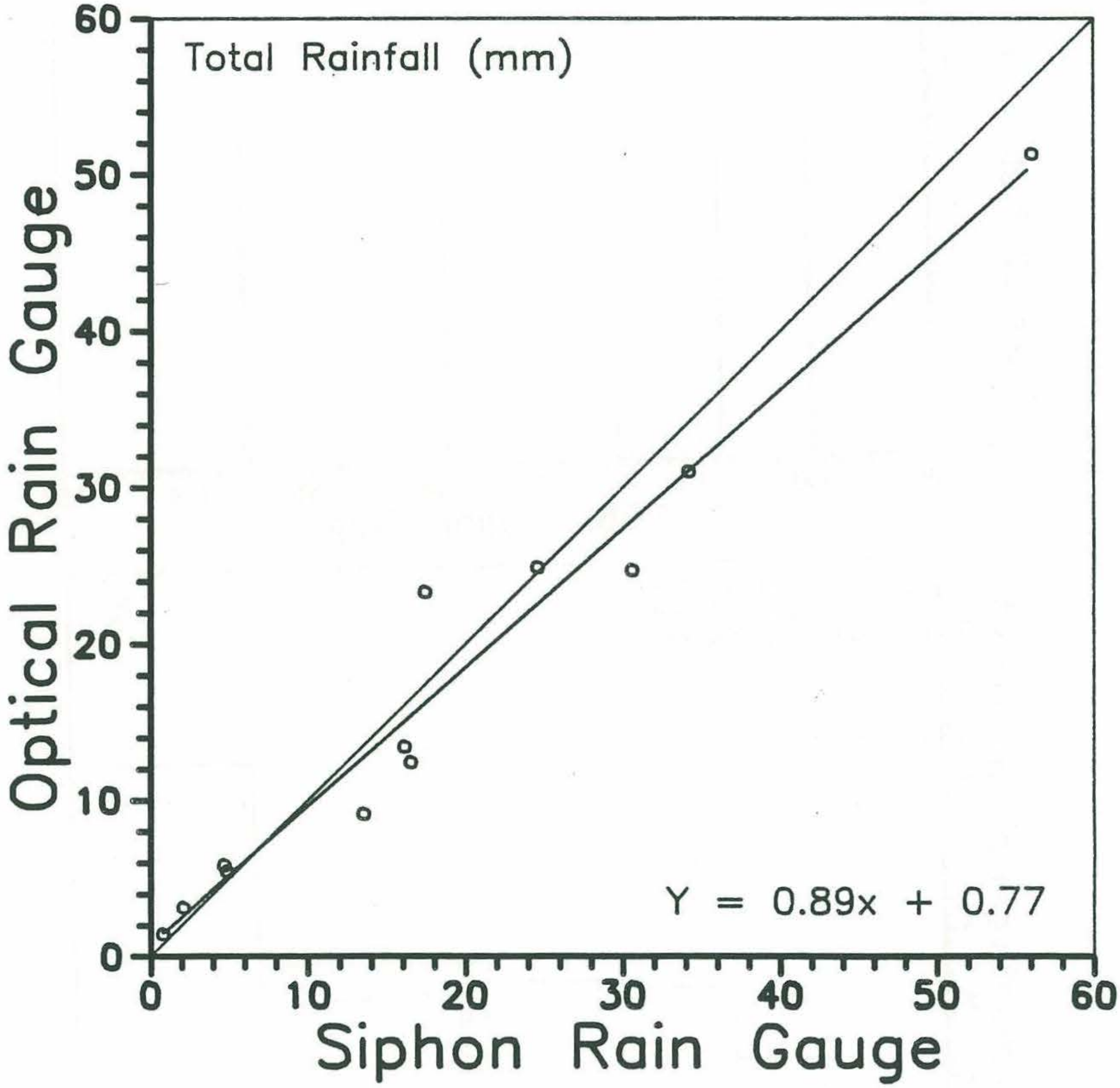



Figure 16: Scatter plot of total rainfall of optical rain gauge versus siphon rain gauge with linear least squares best fit.

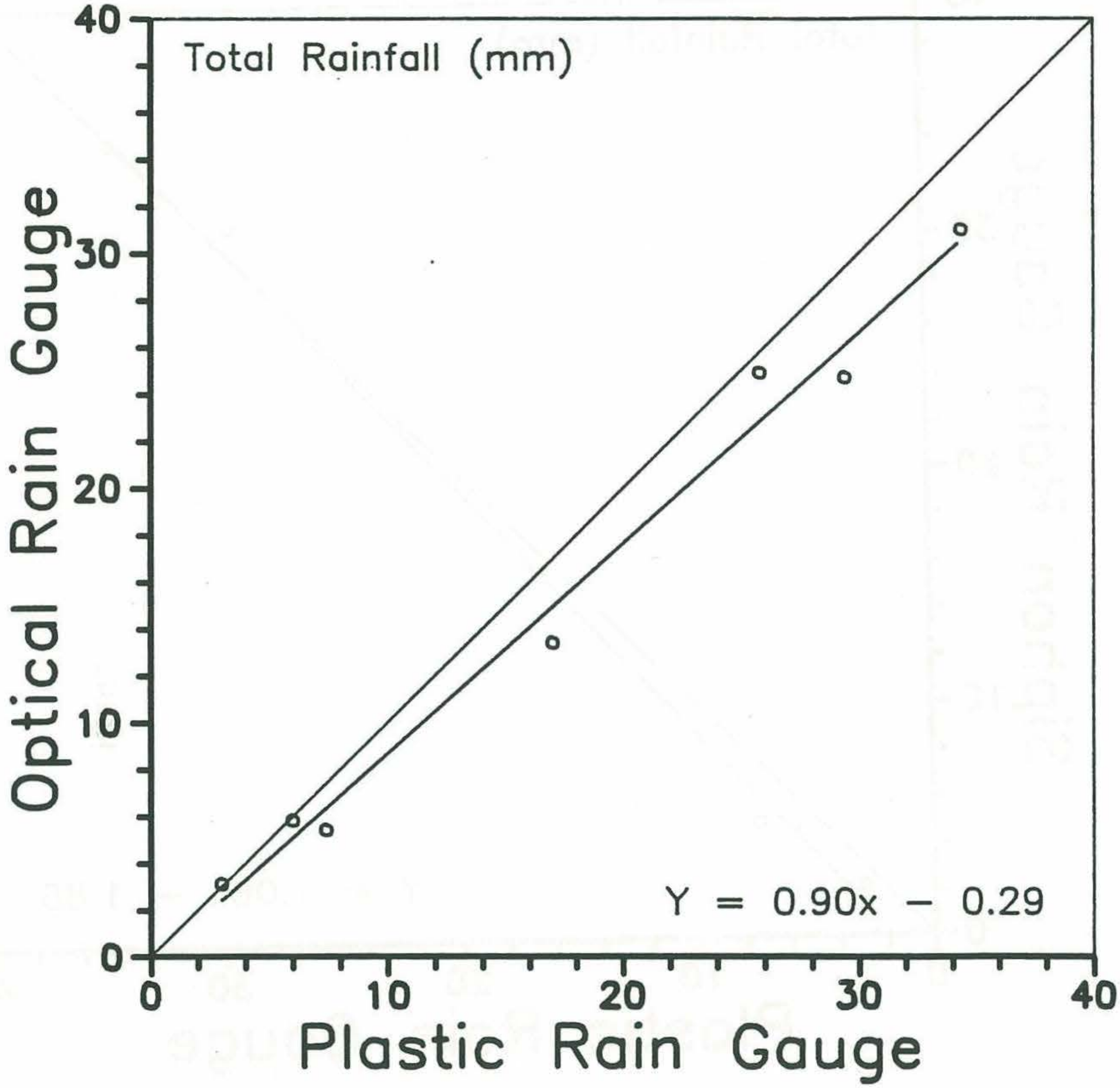



Figure 17: Scatter plot of total rainfall of optical rain gauge versus plastic rain gauge with linear least squares best fit.

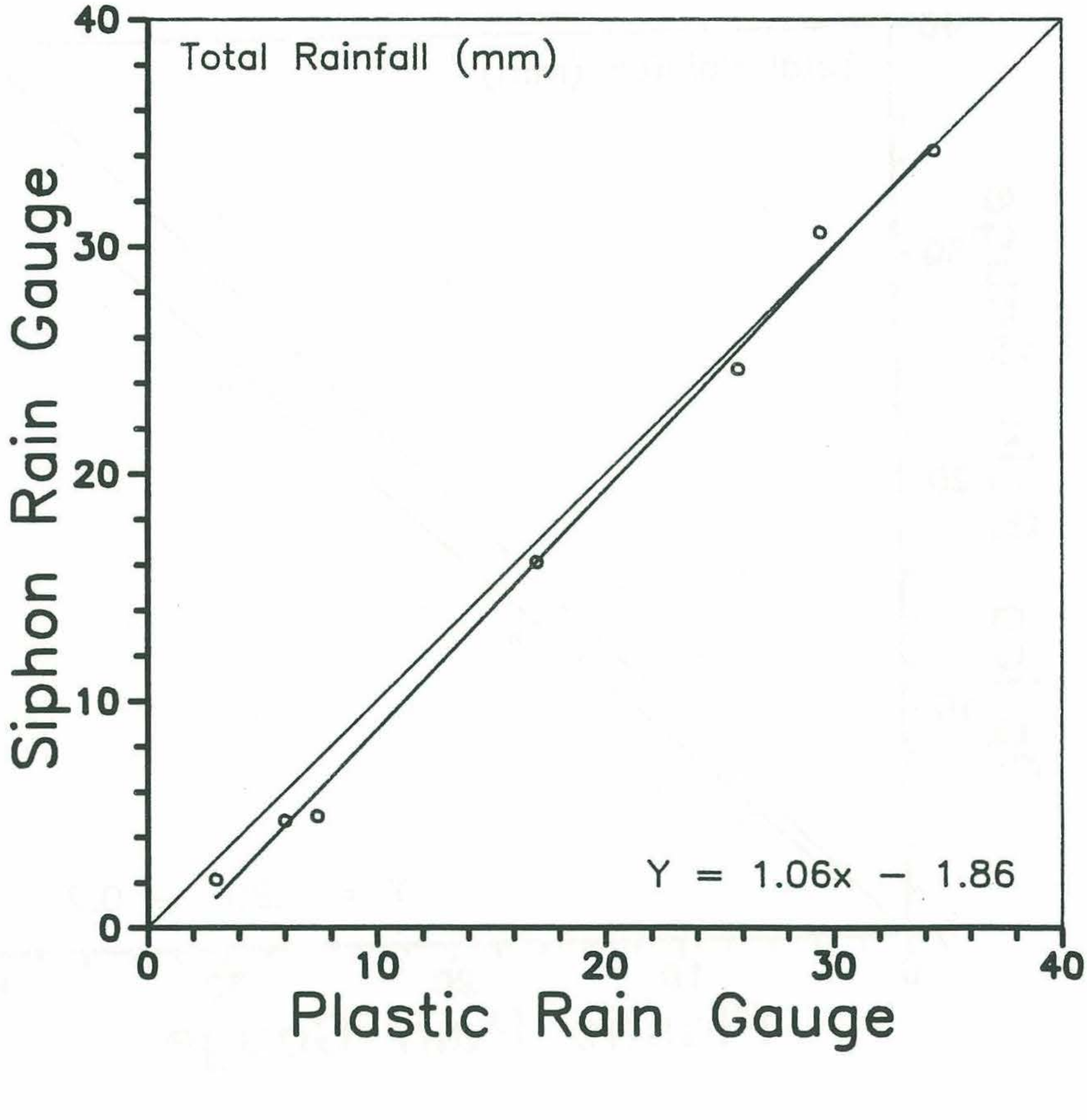



Figure 18: Scatter plot of total rainfall of siphon rain gauge versus plastic rain gauge with linear least squares best fit.

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16. Abstract (Limit: 200 words)

Rainfall data obtained from an optical rain gauge and a capacitive siphon rain gauge are analyzed and discussed. These sensors were developed for unattended use and are being considered for use at sea on ships and buoys.

17. Document Analysis a. Descriptors

1. precipitation sensors
2. marine meteorological measurements
3. ship and buoy instrumentation

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

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