C–9–4 A FAST-RESPONSE OPTICAL SENSOR FOR MEASURING RAINFALL RATE AND RAINDROP SIZE DISTRIBUTION

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I. SUMMARY

We have developed a laser-beam system to measure rain rate and drop-size distribution averaged over a 200 m horizontal path.[1] The technique correlates the laser-beam scintillations produced by the raindrops at two optical detectors separated vertically by a few centimeters. We first obtain the path-averaged drop-velocity distribution by computing the covariance, as a function of time delay, between the scintillations recorded by the two detectors. Assuming a known monotonic relation between a raindrop's size and its terminal velocity,[2] we convert the velocity distribution to drop-size distribution. Our earlier optical measurements have verified that path-averaged drop-size distribution of a steady rain follows a Marshall-Palmer distribution.[3,4] Total path-averaged rain rate is obtained by integrating the drop-size distribution using a suitable weighting function. Optically measured path-averaged rain rate agrees well with simultaneous tipping-bucket rain-gauge measurements.[3]

II. THE INSTRUMENT

Our prototype system consists of a laser transmitter, two line detectors and an analog correlator whose output feeds a computer that calculates precipitation quantities. The transmitter is a 4 mW He-Ne laser and optical collimator that produces a uniform beam 20 cm in diameter. The two receivers are horizontal linear detectors 25 cm long and 0.15 cm high with a variable vertical separation that is typically a few centimeters. To minimize interference from other light sources, filters exclude all light except a 0.002 μm passband centered at 0.6328 μm, and a telescopic aperture restricts the field of view to 2°. Correlation between the scintillations from the two receivers is accomplished in analog delay devices that multiply and integrate to obtain time-lagged covariance functions. In our prototype system, the scintillations were recorded on analog tape and processed by computer later, but implementing a real-time readout of precipitation quantities would be straightforward.

III. SAMPLE MEASUREMENTS

We operated our system on June 23, 1976 at Boulder, Colorado, during a storm that produced a mixture of rain and hail. Detector separation was 4 cm and path length was 200 m. Figure 1 shows the time-lagged covariance functions for nine 5-min averaging intervals. The peaks at 4 ms delay correspond to a vertical velocity of 10 m s^{-1}, which is the terminal velocity of the hail component, whereas the 9 ms peaks are caused by raindrops whose terminal velocity was 4.5 m s^{-1}. Near the end of this storm (1220-1225), the hail disappeared, whereas rain was still falling.

We analyzed another storm on August 2, 1976 for a 2 1/2-hour period. Raindrop-size distributions for each 42-sec interval are shown in Figure 2. Total rain rate is also indicated for each interval by the height of the vertical line at the left end of each distribution. Both the rain rate and the drop-size distribution changed rapidly during this storm. The heaviest rainfall tends to be correlated with larger drop size, except in the beginning of the storm, where large drops occurred with rates of only 7 mm hr^{-1}.

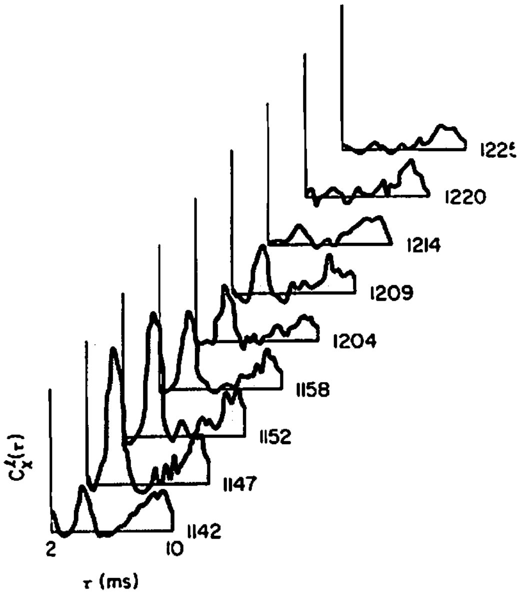

Fig. 1. The time-lagged covariance functions of the signals detected by two vertically separated line detectors with a separation of 4 cm on a 200-m path at Table Mountain during a mixture of rain and hail on June 23, 1976.

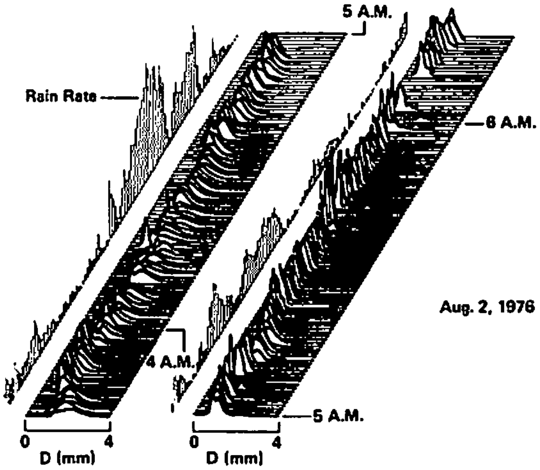

Fig. 2. The raindrop size distribution for every 42 seconds. The vertical axis is the relative fraction of rain rate contributed by drop-size intervals. The horizontal axis denotes the raindrop diameter. Total rain rate is also indicated for each interval by the height of the vertical line at the left end of each distribution.

Figure 3 compares the optically deduced rain rate during this storm with the rate measured by a single tipping-bucket rain gauge near the optical receiver. The agreement is good but might have been better if readings of several rain gauges along the path were averaged.

Figure 4 shows the mean raindrop size vs rain rate during this storm. The solid line shows the relation predicted by the Marshall-Palmer distribution.[4] The scatter of experimental points is substantial for rain rate less than 10 mm hr^{-1}, whereas a linear relationship falling somewhat below the Marshall-Palmer line is evident for the higher rates.

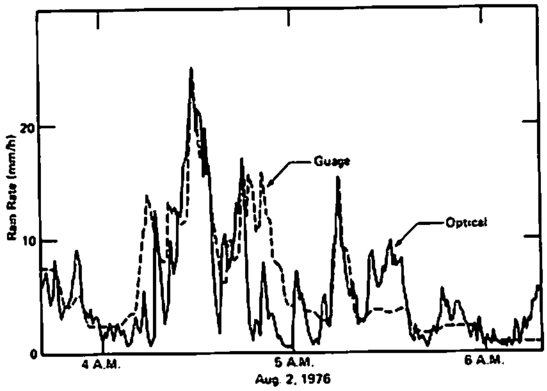

Fig. 3. A comparison between optically detected rain rates (solid-line) and rain rates measured by a tipping-bucket rain gauge near the receiving end of the path (dash-line).

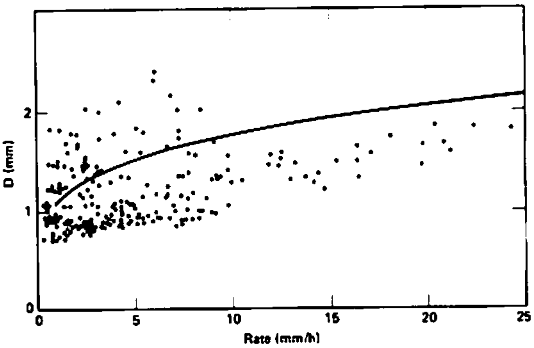

Fig. 4. The mean raindrop size as a function of rain rate. The solid-line indicates the mean drop-size if raindrops follow the Marshall-Palmer distribution.

IV. CONCLUSIONS

We have demonstrated an optical device that measures path-averaged rainfall rate and drop-size distribution. The technique offers the following advantages: 1) The measured quantities are path-averages and do not depend on variations whose spatial scale is smaller than the optical path length. 2) Prior knowledge of the drop-size distribution is not required to obtain total rainfall rate. 3) The actual path-averaged drop-size distribution can be measured. 4) Because spatial integration (path averaging) is used, shorter time integration is required and time resolution as short as 20 sec is possible.

V. REFERENCES

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[3] T-i Wang, G. Lerfald, R. S. Lawrence, and S. F. Clifford, Appl. Opt. 16, 2236 (1977).

[4] T. S. Marshall and W. McK. Palmer, J. Meteorol. 4, 186 (1948).