8.6 A New Groundbased Precipitation Spectrometer: The Meteorological Particle Sensor (MPS)

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1. INTRODUCTION

A number of instruments are currently available for measuring raindrop size distributions at the surface. None of these instruments measure sizes less than 100 µm and only a few measure drop fall velocity. The most accurate type of sensors for size distribution measurements are optical array probes (OAPs) that measures the images of individual particles (*Knollenberg,* 1970). These instruments do not measure fall velocity, and undersize or miss droplets under windy conditions (*Illingsworth and Stevens*, 1987). A new spectrometer, the Meteorological Particle Sensor (MPS) has been developed that uses the same optical technology but minimizes problems caused by windy conditions and adds the ability to measure droplet fall velocity with a resolution of better than 0.01 mm s^{-1}. In addition, the minimum size resolution of 50 µm provides information on drizzle droplets not previously available.

2. DESCRIPTION OF THE MPS

The MPS projects a collimated beam of light from a diode laser between to vertical arms spaced 20 cm apart. The light beam illuminates a linear array of 64 photodiodes that is monitored by the signal processing electronics to look for changes in light level of each of the diodes. When a precipitation particle enters the beam, the state of each diode is recorded during the passage of the particle through beam. The shadow image that forms on the array is stored only if at least one of the diodes is shadowed by more than 50%. This insures that particles are close enough to the center of focus that their image is within 10% of the particle size and clearly defines the instrument sample volume. The size of the particle is determined from the maximum width across the array and the particle velocity is determined by dividing the size of the particle by the amount of time it takes to cross the array. This is illustrated in the diagram in Fig. 1.

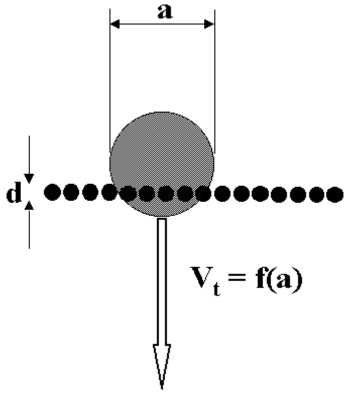

Figure 1
The particle size is determined from the maximum width of the shadow measured during the particle's transit, a. and its fall velocity, V_T, is determined by dividing this size by the measured transit time.

The transit time is measured with a 2 MHz clock, which gives a time resolution of 0.2 µs, or a precision of better than 0.01 mm s^{-1} for particles falling at 10 ms^{-1}.

The MPS is mounted on a turntable with a wind vane to keep the sensor array oriented perpendicular to the average wind vector. This mechanism maintains the trajectories of particles across the diode array at the correct angle for measuring both size and velocity with no distortion or losses. Figure 2 shows a photograph of the MPS in its field-deployed configuration.

The MPS calculates a second-by-second size distribution from those particles that meet the 50% occultation criterion and also that fall totally within the diode array, i.e. that don't shadow either of the end diodes. This size distribution is sent to the data system as a serial stream in RS232 format. In addition, each particle image is stored in a buffer

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that is sent asynchronously to the data system as it is filled. Each particle in the image buffer is accompanied by its arrival time to the nearest millisecond and by its transit time across the array. The former provides the means to evaluate if arriving particles are distributed uniformly random in space, the latter is used to calculate the fall velocity.

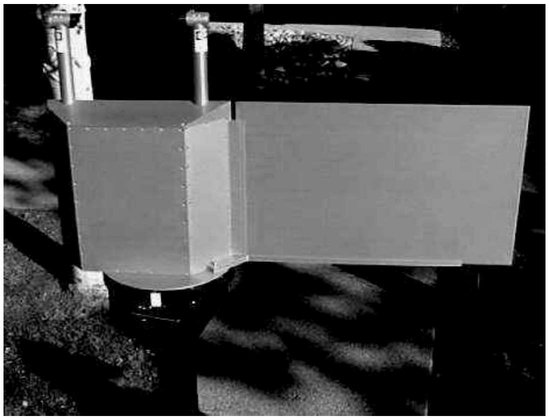

Figure 2
The MPS deployed in the field

4. MEASUREMENT EXAMPLES

Figure 3 illustrates the evolution of size distributions over a forty minute period during a rain shower, where each spectrum represents a 10 minute average. The 50 µm size resolution reveals the multimodal nature of the underlying distribution and the distinctive gap in the size distribution between 50 µm and 300 µm. The distribution of droplets greater than 300 µm has the form of the well-known Marshall-Palmer distribution (*Marshall and Palmer,* 1948), but the shape deviates significantly from this form below 300 µm.

Figure 4 shows the distribution of fall velocity as a function of size. The dashed line shows the predicted values from the laboratory studies of Gunn and Kinzer (1949). The agreement between field and laboratory measurements is quite good above 200 µm, but below this size there is an anomalous increase in fall velocity. Further analysis is currently in progress but these higher velocities could represent satellite droplets from the breakup of larger drops.

As mentioned above, the image, fall velocity and time of detection of each particle detected is stored. With this information the fine detail of precipitation events can be examined as shown in Fig. 5, where the size of each particle is plotted as a function of time. From this graph we can see numerous interesting patterns in the precipitation that can be analyzed to evaluate how the distribution of particle size changes throughout an event.

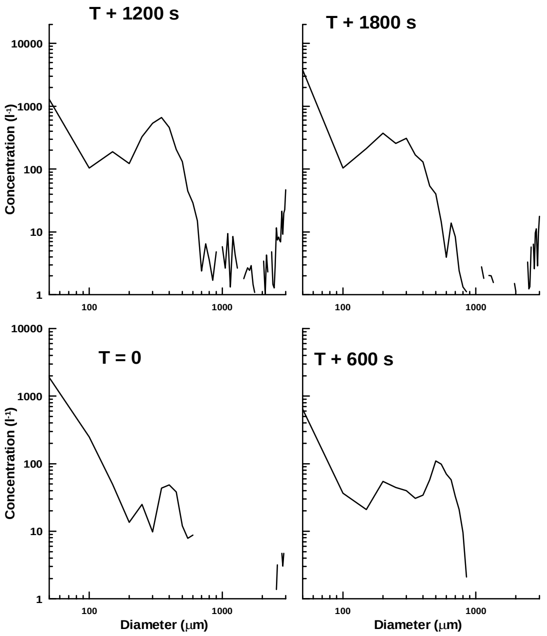

Figure 3
These size spectra are ten minute averages.

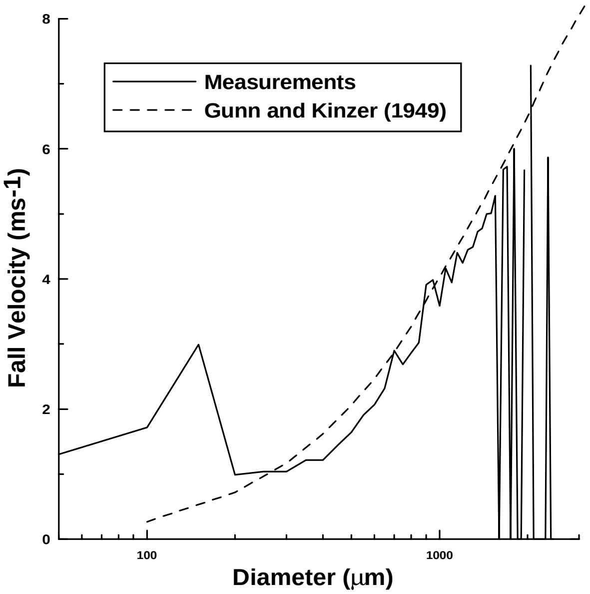

Figure 4
Comparison of fall velocity measurements from the MPS and those derived from laboratory studies.

The particle-by-particle arrival time information provides another means of examining the uniformity of precipitation events. Numerous papers have been written on the homogeneity and steadiness of rain (e.g., *Jameson and Kostinski*, 2000, 2001, 2002). One method for looking at variations from Poisson processes, i.e. homogeneity, is to construct frequency distributions arrival time between particles, as seen in Fig. 6. If drops are distributed uniformly random in space, on a log-log plot the distributions will appear as a straight line whose slope is proportional to the drop concentration (*Baumgardner et al.*, 1993). Figure 6 illustrates this technique with frequency distributions constructed from particles in different size ranges.

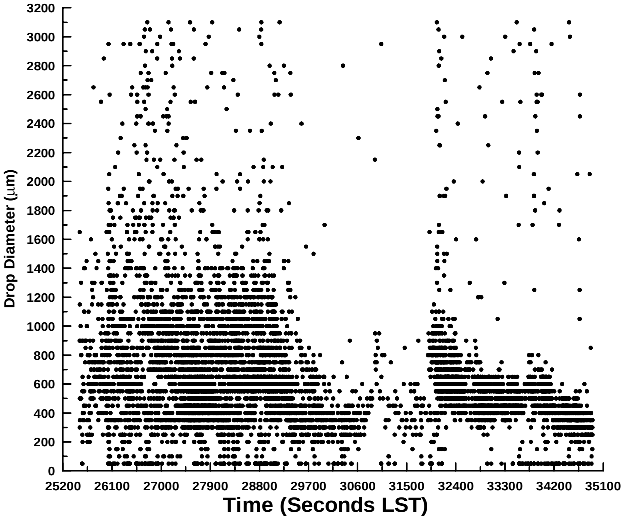

Figure 5
The sizes of individual particles are shown as a function of time for a short segment of a precipitation event.

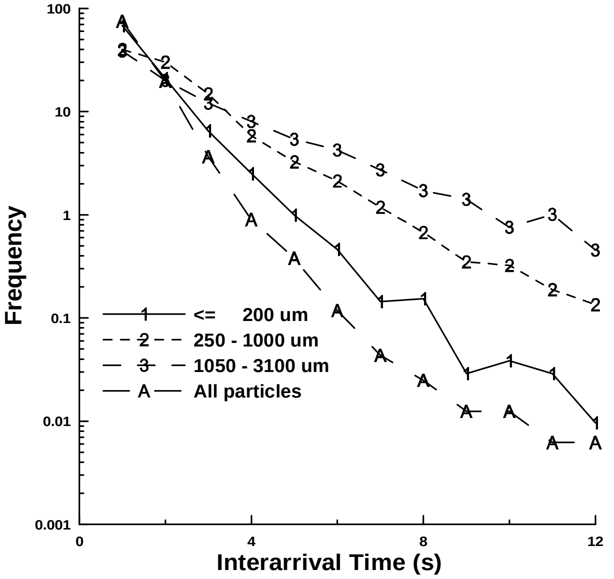

Figure 6
This is a frequency distribution of time between particle arrival times

The National Weather Service is currently testing the MPS to assess its capabilities for measuring drizzle, as well as comparing its results with a conventional, automatic recording rain guage. After five months of operation, the comparison shows that there is generally good agreement between the two instruments but that the MPS underestimates precipitation accumulation in heavy rain, and overestimates in drizzle (*Lewis et al.*, 2002). These differences are still being analyzed but the initial hypothesis is that heavy rain may contain drops larger than the MPS size range, whereas in drizzle the automatic rainguage may not adequately collect the smaller droplets or the MPS may be oversizing multiple drops in the beam

5. SUMMARY

The MPS is a valuable tool for research studies focused on understanding precipitation processes. The capability of retaining every essential piece of information about each particle will allow investigators to better understand the underlying mechanisms that govern these processes. The preliminary analysis of only a few precipitation events provide a glimpse at a number of previously unrecognized features of the rain drop distribution that await further analysis.

6. ACKNOWLEDGEMENTS

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