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# The Spurious Effects of Splashing Precipitation on Droplet Measurements and the Lack of Natural Cloud Droplets in a RICO Rain Shaft

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## 1. Introduction

During the Rain In Clouds over the Ocean experiment (RICO, Rauber et al. 2004), the NCAR C-130 aircraft targeted precipitation shafts below cloud bases on several missions. This situation provides opportunity to study the effects of precipitation splashing on the instrumentation. The effects on the Forward Scattering Spectrometer Probe (FSSP, Dye and Baumgardner 1984) and the Two Dimensional Stereo imaging probe 2D-S (Lawson et al. 2006) are the focus herein.

First, it is necessary, and interesting in its own right, to demonstrate the lack of cloud droplet sized particles in the rain shaft. This is accomplished using data from the new 2D-S probe that images both cloud droplets and precipitation. Until the advent of the 2D-S, cloud droplets and precipitation have always been measured with different probes and, therefore, there were no means to distinguish between real measurements and spurious results caused by splashing precipitation.

Our analysis will show that the natural concentrations of cloud droplets in a rain shaft are insignificant and, thus, the measurement of cloud droplets therein may be interpreted as spurious effects of precipitation splashing. A preliminary quantifying of those effects is also reported. The FSSP probe measures significant numbers of droplets with realistic size distributions due to splashing of precipitation. The effects, however, are not overwhelming and reasonably well predicted from PMS 2D-C and 2D-P (two-dimensional optical array probes, Knollenberg 1981) measurements of the precipitation.

## 2. The lack of natural droplets in a rain shaft

Campos (1999) reviews the current knowledge on breakup of rain into smaller particles. The main experimental-observational data on the subject is from Low and List (1982). However, there no information was reported on the numbers of cloud droplet sized particles produced by raindrop breakup.

The 2D-S is unique in its ability to image both cloud droplets and precipitation drops. Splashing events are a regular occurrence and easily identified by visual inspection of the 2D-S images (**Figure 1**). The groups of very many small images close together are the splashing events. Visual inspection also suggests that there are no natural cloud droplet sized particles. That is, all the small particles are associated with the clearly identifiable splashing events. However, visual inspection is restricted to a very small amount of data. Larger data segments may be analyzed automatically using the distance between the particles to distinguish natural versus splashing particles.

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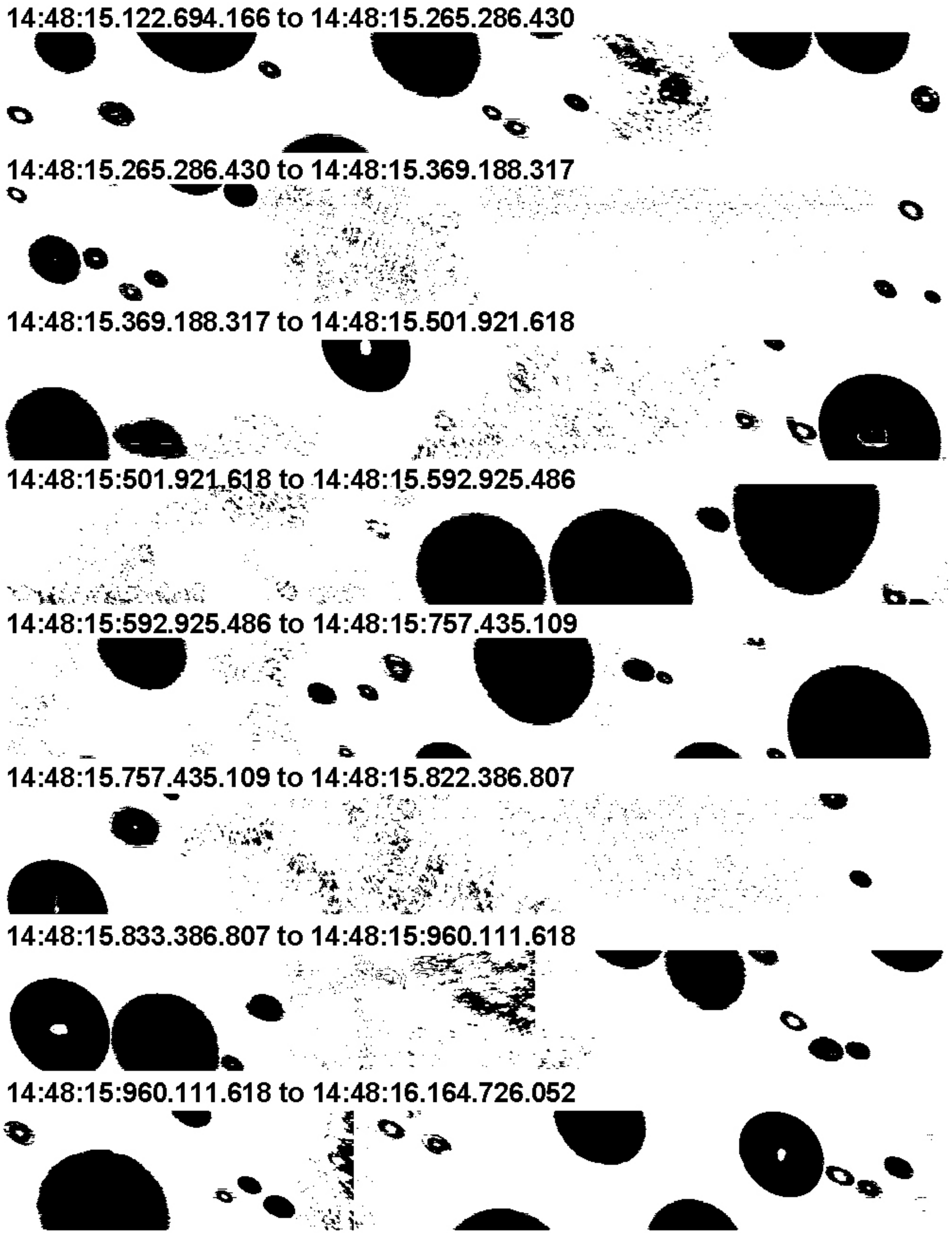

Figure 1: Typical images of natural precipitation drops and spurious images from splashing of drops on the probe. The white space representing distances between images has been eliminated.

The distances between spurious particles due to splashing are, on average, very much smaller than the distances between natural particles and thus may be used to distinguish between spurious and real images. However, the individual distances between particles are exponentially distributed (the so called waiting time distribution) for both types of events. Therefore, there is no unique cutoff distance that perfectly segregates the data into spurious and natural particles. To choose a reasonable cutoff value, the Particle Size Distribution (PSD) was calculated for particles satisfying the condition that the distances to the next nearest particles, the one before and the one after, are greater than a given cutoff value. The same is done for particles satisfying the condition that the distances to the next nearest particles are less than the given cutoff value. The former will be referred to as the natural particles PSD and the latter as the spurious particles PSD, keeping in mind that they are approximations. Since the particles should be round, artifacts are removed from both PSDs by requiring that the ratio of the array dimension size to the direction of travel dimension size be between 0.5 and 2. The means of these PSDs are calculated and plotted versus the cutoff value (**Figure 2**). The mean of the natural particles PSD initially rises quickly with the cutoff value as spurious particles are eliminated. The PSD then settles down and changes very little with further increases in the cutoff value. The mean of the spurious particles PSD grows rapidly then slowly with increasing cutoff as well. By a cutoff of 20 mm, it seems that the natural PSD is dominated by natural particles. The spurious PSD is likely influenced by including some natural particles. Our aim is an accurate estimate of the natural PSD so choosing a high cutoff value makes sense.

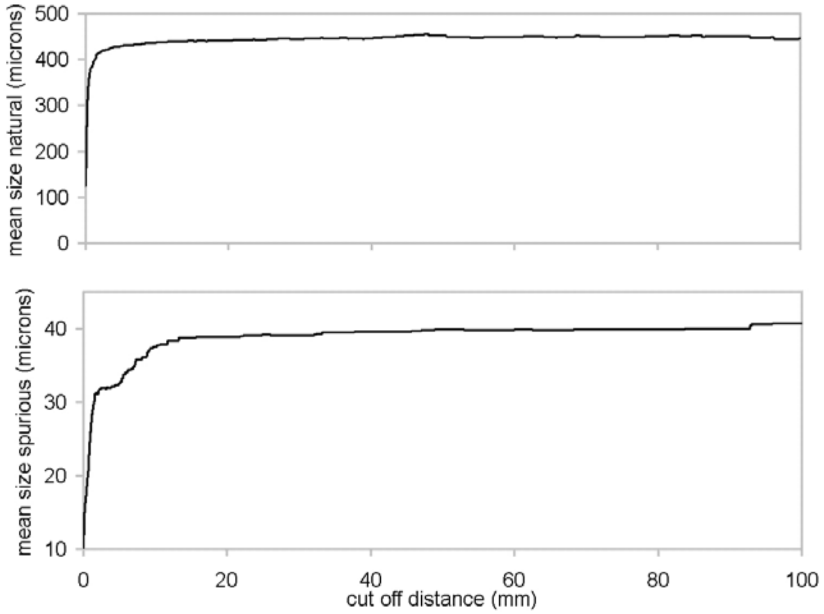

Figure 2: The means of the natural and spurious PSDs, as defined in the text, versus the cutoff distance used to discriminate between the two categories.

**Figure 3** shows the natural and spurious PSDs for a cutoff value of 20 mm. These size distributions present the number of counts per bin divided by the bin width in microns. No adjustment was made for the changing sample volume with particle size or for diffraction effects on particle sizes. Thus, these PSDs are not representative of the true PSDs in the rain shaft. These were shown to illustrate that there are no natural cloud-droplet-sized particles in the rain shaft. The natural PSD does have 12 counts in the first size bin (nominally 10 μm) and 1 count in the second size bin (nominally 20 μm). The source of these counts has not been determined but we do not interpret them as natural particles. Such small droplets could not be produced by natural drop breakup without producing particles in the size range from 30 to 100 μm. Furthermore, even if they were real, their numbers are insignificant compared to the number of spurious counts in those size bins.

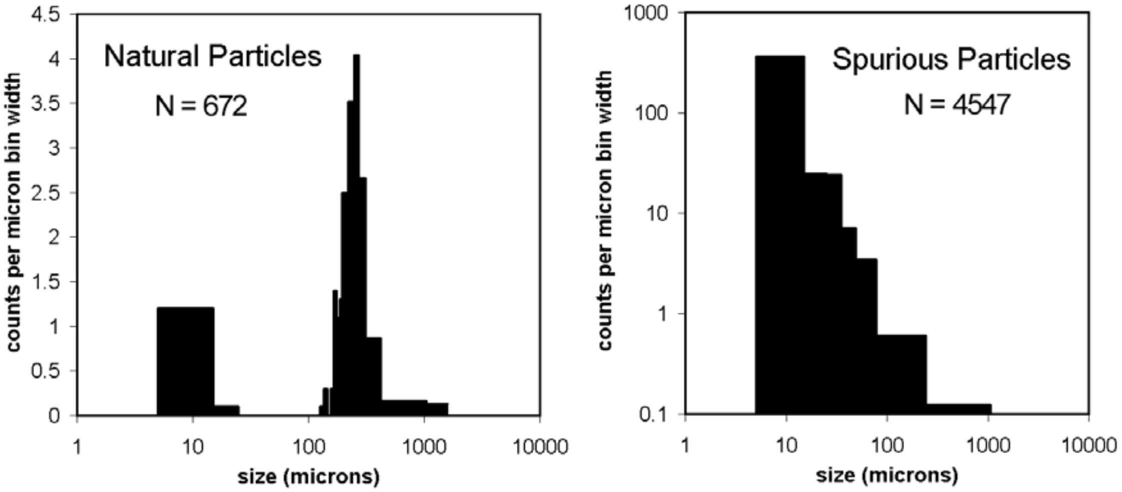

Figure 3: 2D-S Particle Size Distributions (PSDs) of natural and spurious particles, as defined in the text, in a rain shaft.

The lack of natural cloud droplets in the rain shaft does not necessarily imply that none are produced by drop breakup. Some may be produced but evaporate in the rain shaft downdraft.

### 3. Spurious FSSP droplets

**Figure 4** shows a nearly linear relationship (FSSP_LWC = 0.01 x 2D-C&P_LWC) between the spurious liquid water content (LWC) measured by the FSSP and the composite LWC measurement from the NCAR standard 2D-C and 2D-P probes (2D-C&P). The later were combined using 2D-C below 1.1 mm and 2D-P above 1.1 mm. On 19 January 2005 precipitation shafts were a primary target for the C130 mission. Each of the data points in figure 4 is an average over a segment that was determined by the following criteria. The segment must be at least 5 seconds long during which the FSSP concentration remains within 0.6 and 1.2 times the mean FSSP concentration for the same period and the 2D-C&P LWC remains within 0.3 and 2.0 of its mean for the same period. This allows the automation of the processing, removes biases, and insures some degree of uniformity over the averaging regions. 86 rain shaft segments, at 600 feet altitude on 19 January 2005, met the criteria. The square of the correlation coefficient for these 86 data points is 0.87. The high correlation suggests that the spurious effects of precipitation on the FSSP may be reasonably well predicted.

**Figure 5** shows the correlations between the spurious FSSP concentration and two 2D-C&P probe concentrations, the total and only those drops larger than a millimeter. The correlation with the largest drops is better, as expected since those are the splashers.

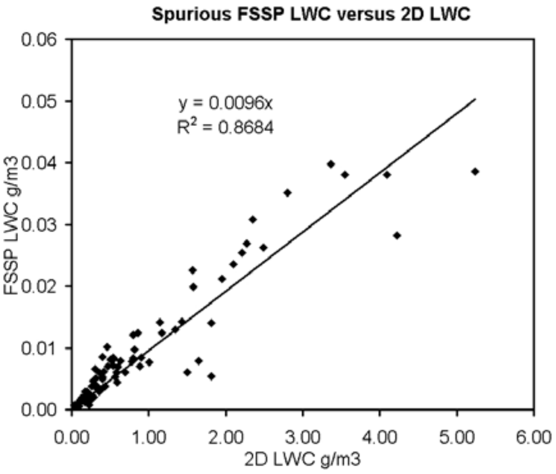

Figure 4: FSSP LWC versus 2D-C&P LWC for 86 rain shaft penetrations made at 600 feet altitude on 1-19-2005. The equation of the linear least squares best-fit equation and the square of the correlation coefficient are shown.

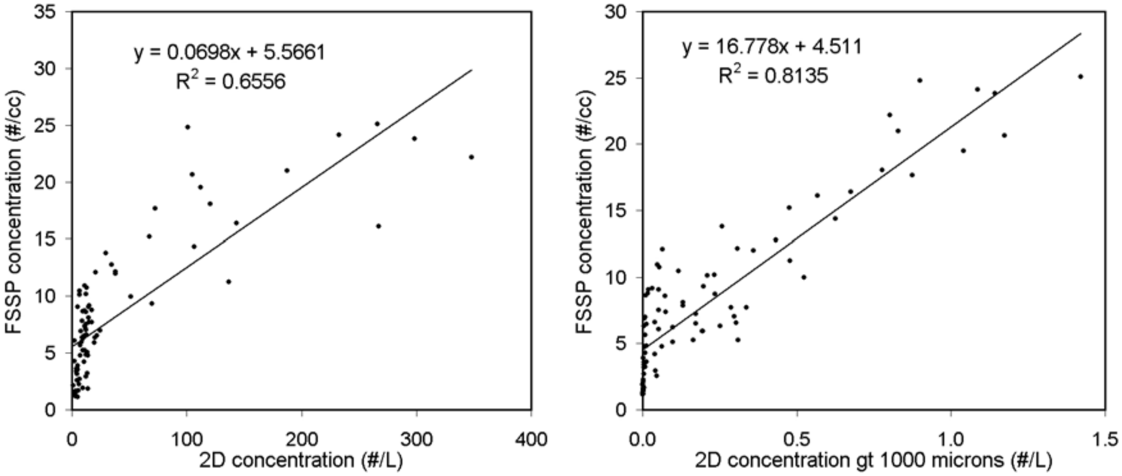

Figure 5: FSSP concentration versus 2D-C&P concentration and 2D-C&P concentration of particles larger than 1 mm for 86 rain shaft segments made at 600 feet altitude on 1-19-2005. The equations of the linear least squares best-fit equations and the square of the correlation coefficients are shown.

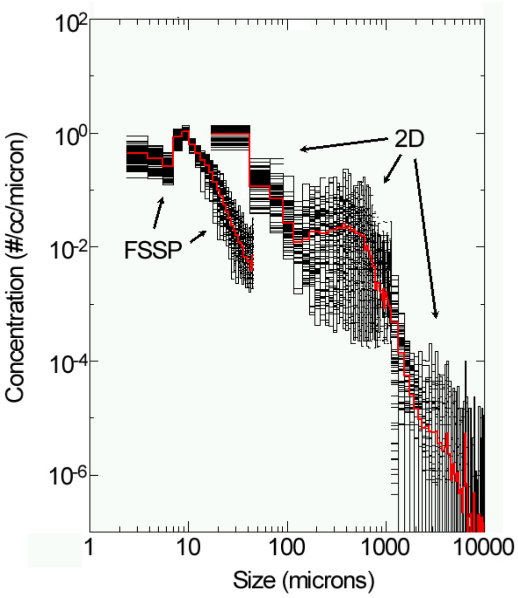

Figure 6: 86 rain shaft PDSs from the FSSP and 2D-C&P probes. The means are shown in red.

**Figure 6** shows the spurious FSSP size distributions, which look quite normal, and the 2D-C&P probes' precipitation size distributions. The later shows that a full rain distribution exists, with drops larger than 1 cm.

## 4. Conclusions

The ability of the 2D-S to image both cloud droplets and precipitation particles has allowed the discrimination between real and spurious images produced by splashing precipitation. For the rain shaft investigated, there are no natural cloud-droplet-sized particles. This facilitates quantification of the spurious effects on both the 2D-S (Fig. 3) and the FSSP (Figs. 4 –6) probes.

## 5. References

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