Lab Measurements of Sample Areas - RAF Cloud Droplet Probes

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Summary

Measurements of CDP sample area were made in urgent but brief laboratory studies for RAF's two CDP probes (s/n #58 and #16). These two probes are nominally identical, but the features of these probes have changed over the past year, as follows: (a) electrical damage of #58 during the ICE-T project (July 2011) required rebuild by DMT; (b) December 2011 electronics and firmware upgrades were made by DMT on both probes. Subsequent to these upgrades, the probes have not flown. The GV will not have a second, comparative method of measuring cloud water in DC3. Results from these lab tests gave sample areas that are close to DMT's nominal 0.24 mm^2. We measured 0.23 and 0.35 mm^2.

Background

The motivation for this work was to look for an explanation of unexpectedly high concentrations of droplets in IDEAS-4 data. These concentrations led to high values of calculated LWC. Our routine data processing uses a constant 0.24 mm^2 as the sample area for the CDP. This area is provided by DMT and is based on optical geometry. It is not measured routinely.

In NOAA's ARCPAC project (NOAA P-3 aircraft), Sara Lance found inconsistencies in LWC between CDP, CAS and hot-wire LWC devices. To resolve the inconsistencies, she performed detailed lab studies of the NOAA CDP to characterize its performance at different locations within the probe's sample area. She found there are significant errors in concentration and sizing that result from coincidence and location of droplets in the sample area. She recommended inserting an optical pinhole mask to reduce the size of the signal acceptance aperture in order to reduce the coincidence error.

Her lab calibration experiments mapped the CDP response volume with monodisperse size water drops in a precisely controlled air jet. Details are in her AMT paper (Lance et al., 2010). In response to those studies, and in collaboration with Sara, DMT added an 800 µm optical mask to to reduce the likelihood that droplets outside the depth-of-field would be incorrectly accepted. The result was to reduce the coincidence error. Early in 2011, DMT also made additional changes to the electronics and firmware. The reader is referred to other information for the full history of these probes.

Uncertainty about the performance of RAF's newly-modified probes prompted us to explore measuring the sample areas using calibration equipment in Sara's lab at NOAA. There was a narrow window of opportunity to make these measurements because Sara was changing employers, and we needed her expert assistance and access to the equipment. The results provide a necessary check for data processing of data sets from TORERO, IDEAS-4 and DC3.

Measuring Sample Area

Equipment

The calibration system generates a narrow stream of droplets of identical size and directs them across the CDP laser beam (Figure 1). The operator adjusts precisely the location of this stream, reads the position verniers and writes their values in a log book. CDP data logging occurs at 10 records per second. The equipment is shown in Figure 2 and consists of the following components (full description in Lance et al., 2010):

- droplet system – MicroFab generator, water supply with pump & valves
- computer to control droplet system and record camera images
- air flow parts for droplet acceleration, targeting and drop size adjustment
- position control (±0.01 mm), X/Y micro-positioner stage, manual operation
- microscope cameras and optics for imaging drop generation and droplets in laser beam; USB
- CDP with ADS laptop to log data

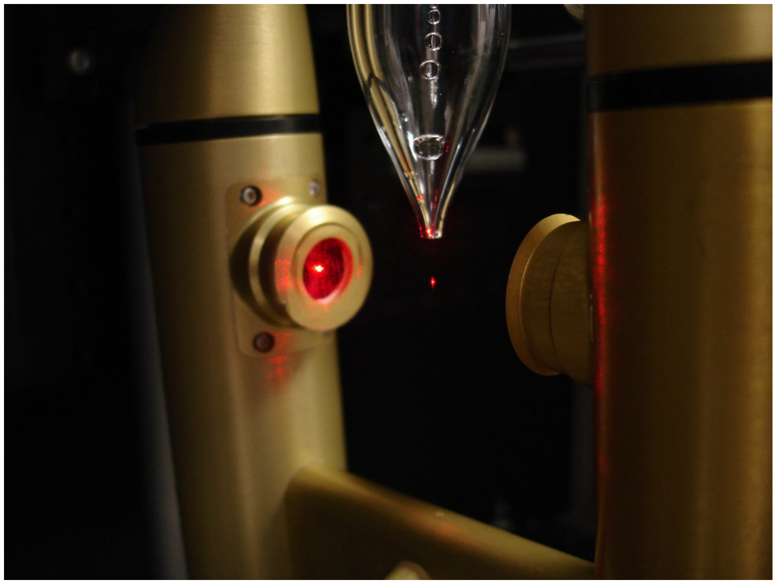

Figure 1. Photo shows droplet stream illuminated in CDP laser beam. Droplet is embedded in steady air stream accelerated and focused in glass nozzle.

Procedures

Droplets are produced by voltage pulses from the MicroFab drop generator, one droplet per pulse. Size, spacing and stability of drop production is set by the voltage amplitude, waveform and duty cycle, typically 500 Hz for these tests. The droplet generator jet is in the center of airflow that points downward and accelerates through a narrowing glass funnel. This arrangement produces a focussed stream of identical size droplets. Velocity across the CDP laser beam can be adjusted using the air flow; typical values ~40 m s^{-1}.

The droplet stream was initially placed in the approximate center of the CDP sample area. Then Bill monitored the droplet concentration while Dave made small adjustments on the X and Y stages, moving the droplet stream parallel or perpendicular to the laser beam (see Figure 2). When the concentration decreased to ~50 /sec (10% of the beam's central value), we called that location the edge of the sample volume and wrote down the time and values for X and Y. At the edges, very small adjustments (~10 µm) resulted in large changes of CDP concentrations. This procedure is illustrated in Figures 3 and 4.

Note that the CDP firmware is continuously averaging pulse widths in order to determine the acceptance. Our slow movements at the edges may have caused an unwanted averaging bias.

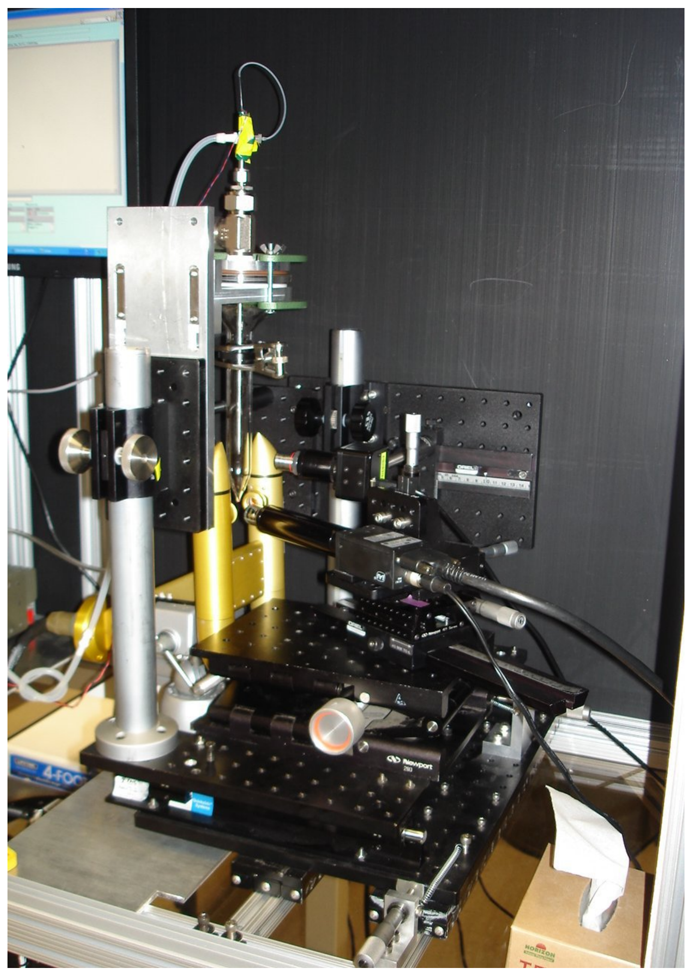

Figure 2. Test apparatus holds CDP (gold) fixed in place. Droplet stream and air flow downward through CDP laser beam. X/Y/Z micro-positioner stages support the droplet generator and two cameras. Movement is along and perpendicular to the laser beam.

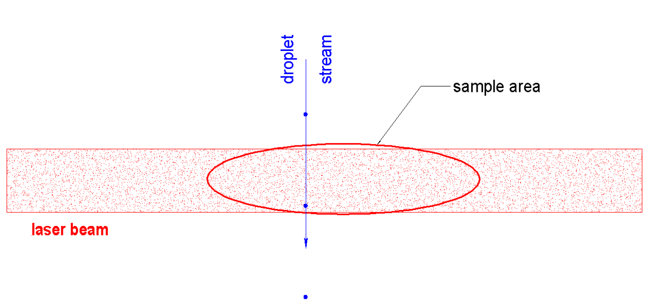

Figure 3: Side view of laser beam showing the paths of single droplets. Approximate sample area outlined. Beam diameter ~0.2 mm.

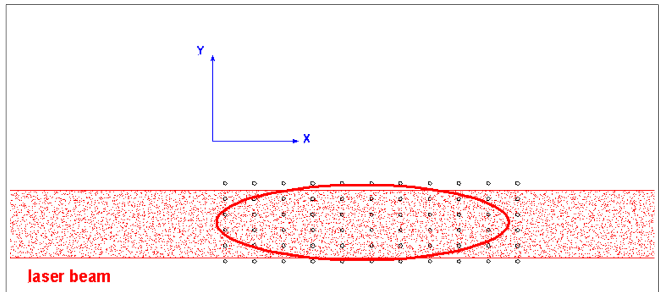

Figure 4: Looking down through laser beam. Dots show where X/Y position was adjusted to place the droplet stream at different locations in laser beam. Approximate sample area outlined.

With this system, it is possible to make precise measurements of the sample area and to perform a size calibration. Due to time limitations, our study did not measure routinely the drop size at different positions in the beam. That was an important part of Sara's paper, and details are available there. However, on the second day, for CDP #16, we performed a few size calibration measurements with the droplet stream in the center of the sample volume. Drop size was measured by microscope images of droplet streaks. Size was changed by moving the generator closer to the glass funnel tip, or further from it. By changing the position, the residence time also changed for the droplets to be carried in the dry air to the funnel tip, and this provided time for the droplets to change size by evaporation. The measured size range was 25 to 42 µm diameter. ADS files were recorded as 30-minute segments which were merged, and *nimbus* was used to make netcdf files for analysis (*cdp_0417.nc, cdp_0418.nc*).

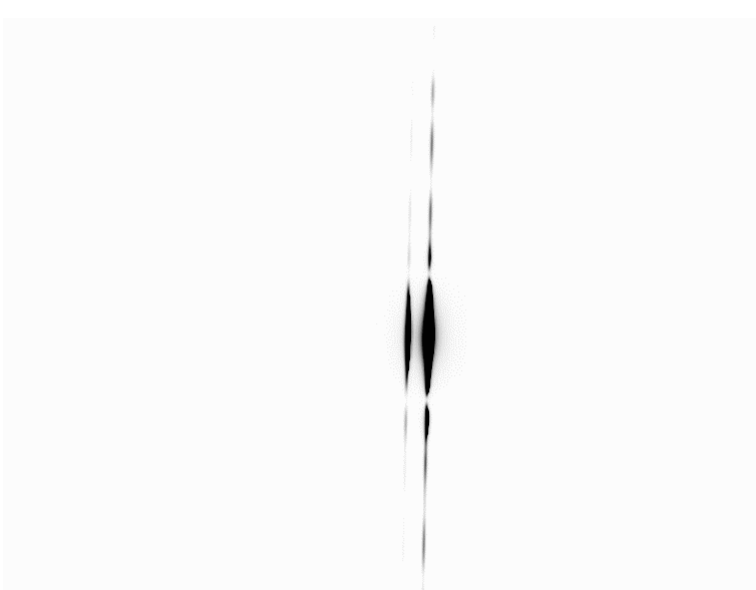

Figure 5: Microphoto image of edge glare or streaks as a 37 µm droplet crosses the laser beam vertically. The dashed pattern indicates non-uniform illumination.

We did not measure analog voltage pulses from the droplet detectors. That measurement can be used to evaluate the *qualifier* and *amplitude* signals, as described in Sara's paper. It is the basis for her *Monte Carlo* numerical simulation study.

Results

Sample Area

The sample area was estimated from the average X and Y distances between droplet detection edges. The sample area is calculated by assuming a rectangle, and is close to DMT's specification, 0.24 mm^2. No estimate of uncertainty is made here.

	X-distance, mm	Y-distance, mm	area, mm^2
CDP #58	1.37	0.17	0.23
CDP #16	1.38	0.25	0.35

Near the edges of detection, the response in sizing and drop detection (counts) is very sensitive. Small changes in position ~10 µm, produced very large changes in the measured size and droplet count. This sensitivity is documented in Lance et al. (2010, Figure 6), from a large number of sample area measurements. The results in our brief lab study are consistent with Lance. For example, Figure 6 here shows 4-minutes of measurements as a constant droplet stream was moved across the sample region. Note the size distribution shows a very narrow and well-defined peak near the center of the sample area. Near the edges, the sensitivity decreases substantially, the apparent distribution is wider, and the droplet count falls off toward zero.

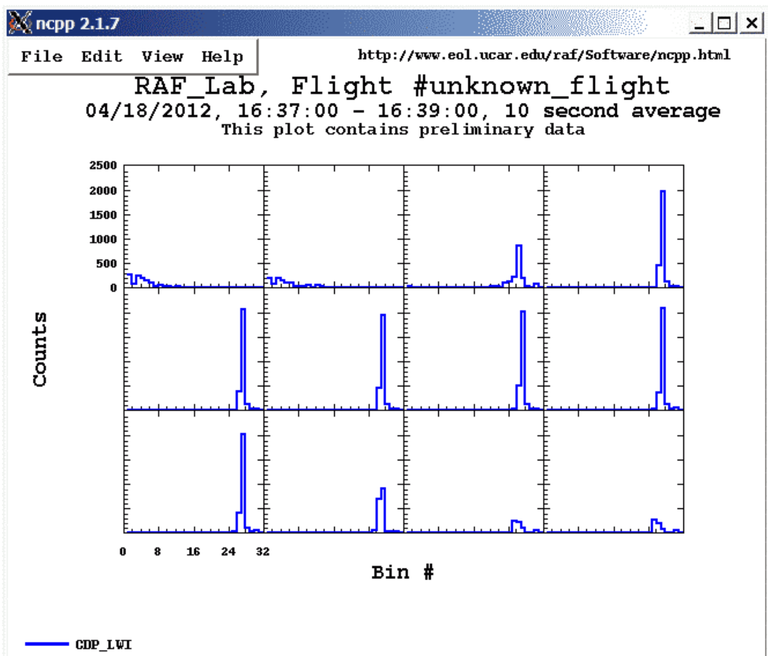

Figure 6: Apparent changes in measurement as droplet stream was moved ~0.3 mm, crossing the laser beam.

Size Calibration

The size calibration was checked only for CDP #16. The results compare well with the DMT factory calibration, which is based on glass beads, corrected to the index of refraction for water.

microscope dia (µm)	CDP bin#	CDP dia (µm)
25.9	18	25.5
30.0	20	29.25
33.5	22	33
37.2	24	36.75
40.9	25	38.63

Recommendations

Glass beads are typically used for calibrating the CDP, and a correction is made to the apparent size to account for the difference between index of refraction of crown glass *($n = 1.51$)* versus water ($n = 1.33$). More information is in references. Glass calibration beads typically exhibit surface roughness and irregularities. The population of beads does not have a monodisperse size distribution, and the atomization process can generate single beads mixed with multiple beads per particle (2, 3, 4, ..). Another challenge for glass bead calibration is to generate a uniformly spaced stream of beads and to control precisely its position. The water micro-drop calibration system is more difficult to use but it has none of these limitations.

Based on these results, the nominal sample area of 0.24 mm^2 appears to be correct. A more detailed assessment could be made when equipment funds and staff time are available. RAF could build a calibration system, for use within RAF or as a community shared facility. The following table identifies the equipment needed to build a calibration system similar to the one we used in Sara's lab.

Table 1: Equipment list. Costs are approximate

item	*vendor*	*cost*
JetDrive III drop generator & assorted orifices (RAF already owns)	MicroFab Technologies, Inc. Plano, TX *http://www.microfab.com/*	0
diagnostic microscope, USB camera EM-310C	BigCatch *http://www.bigcatchusa.com/product/em-310c/*	200
metrology microscope, model CV-A10 CL	JAI	1,200
objective lenses, extension tubes	Edmund Optics	200
glass funnel flow tube	Allen Scientific Glass, Boulder, CO	200
X/Y micropositioner stage computer controlled NT68-640; plus Z-axis manual travel	Edmund Optics *http://www.edmundoptics.com/mechanics/positioning-stages-slides/*	4,000
small water pump	McMaster-Carr	20
image acquisition computer card	National Instruments, PCIe-1427 Epiphan Systems VGA2USB *http://www.epiphan.com/products/frame-grabbers/vga2usb/*	300
DC power supply, 0-24v, 1A	(RAF already owns)	0
oscilloscope, 2-channel, computer interface, such as DS1052e	Rigolna *http://www.rigolna.com/ds1052e/*	330
Plexiglas enclosure, metal frame	RAF build	200
	TOTAL	**6,650**

References

Lance, S., Brock, C. A., Rogers, D., and Gordon, J. A.: Water droplet calibration of the Cloud Droplet Probe (CDP) and in-flight performance in liquid, ice and mixed-phase clouds during ARCPAC, *Atmos. Meas. Tech*., 3, 1683-1706, doi:10.5194/amt-3-1683-2010, 2010. *http://www.atmos-meas-tech.net/3/1683/2010/amt-3-1683-2010.html*

Nagel, D., U. Maixner, W. Strapp, M. Wasey, 2007: Advancements in techniques for calibration and characterization of in situ optical particle measuring probes, and applications to the FSSP-100 probe. *J. Atmos. Oceanic Technol.,* 24, 745–760. doi: http://dx.doi.org/10.1175/JTECH2006.1