Subject: FSSP / DMT SPP-100 / CDP processing
Al Cooper
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Background

The variables related to the FSSP/SPP-100/CDP are: total concentration of droplets, the size distribution in individual size channels, liquid water content, surface area of droplets, mean diameter, effective radius, and liquid water content of cloud water. The dispersion is also calculated but is not always output.

The measuirements produced by the three probes are slightly different:

1. All produce: counts per channel for size distributions.

2. The FSSP records total strobes and the SPP records total counts and counts of droplets rejected for too-short transit time. The sum of these is equivalent to the total strobes of the FSSP. [1] Reject counts are those pulses with width less than the average. Width is measured as time above the minimum detection threshold, although in some versions of the FSSP there was a possibility of measuring the pulse width instead as the full-width-at-half maximum transit time by means of a delay line. If the electronics of the probe did not introduce any delay and the laser beam were perfectly uniform and circular in cross-section, one would expect

$$\bar{w} = 2R\int_0^1 \sqrt{1-x^2}dx = \frac{\pi D}{4}$$

   where $\bar{w}$ is the mean transit distance through the beam of diameter D and the integration variable is $x = 2h/D$ where h is the height above the beam centerline and so varies from $-D/2$ to $D/2$. This predicts that the height corresponding to the average transit distance is $0.619D/2$ so 61.9% of randomly spaced droplets would pass through the beam so as to produce a transit time as long or longer than the average.

3. The FSSP produces an "activity" related to the time the probe is processing information, while the SPP-100 provides "overflow counts" indicating how many pulses were missed and not sized or tested for transit time. Practical ways of estimating the dead time for the FSSP can be based on the activity or the measured strobes and 'fast resets' (where the droplet is outside the depth-of-field), but this is more straightforward in the SPP-100 because the droplets passing during overloaded conditions are counted and that count can be used to correct for the fraction that are missed. For the CDP, the claim is that the probe does not suffer losses from overloads.

[1] The variable REJAT has the long name "CDP Average Transit Rejected Particles." I think this is poorly named because no average is involved; the quantity provided by the probe is the total count of rejected particles.

4. The CDP and SPP-100 provide some additional housekeeping information, including:
   (a) average transit time (CDP only)
   (b) count of particles rejected for transit time
   (c) count of particles rejected as outside the depth-of-field
   (d) other probe characteristics (board temperature, baselines, etc.)

Present Processing Code

Processing common to all probes:

The probe serial number is used to look up some probe characteristics and processing conventions. These are included in the netcdf header, so key processing assumptions are available to users.

FIRST_BIN Droplet size distributions start at this bin. Bin numbers start at 0, but the first (0th) bin is not used and should be skipped in all cases.

LAST_BIN Droplet size distributions end one bin prior to this index. Because the index is zero-based, specifying (e.g.) 16 will cause the last bin to be the bin with index 15, but the index will start at zero unless FIRST_BIN specifies differently.

DepthOfField Distance along the laser-beam direction over which droplets will pass the DOF tests.

BeamDiameter Diameter of the laser beam used to illuminate droplets. This value is the full diameter without adjustment for the rejection circuitry based on transit time.

CellSizes Upper limit of each bin used to size the droplets. The first (zero-index) cell is unused, so the size specified for this bin is the lower limit for the next bin.

SPP-100:

The processing proceeds as follows:

1. Get available data:

symbol	**description**
m_i	counted droplets in the ith channel
TASX	true airspeed
rejAT	counted rejects for transit-time less than the average
oflow	counted rejected pulses arriving during probe overload conditions
frange	probe sizing range

2. Find sum of counts in all channels between first and last bins used: $M = \sum_{FIRST\_BIN}^{LAST\_BIN} m_i$.

3. Find the sample volume:

$$V = \frac{TAS * A}{R} \frac{M}{(M + rejAT)}$$

   where A is the sample area (given by the product of the beam diameter and the depth-of-field) and R is the sample rate (1 Hz or 10 Hz).

4. Use the sample volume so defined to calculate the concentration in bins between FIRST_BIN and LAST_BIN, setting other values to zero, and use the results to calculate the concentrations m_i in each bin as well as the summed contributions to the diameter weighted by concentration in each bin, and also the analogous sums of the square of the diameter and the cube of the diameter. For these sums, sizes are used that correspond to the midpoints of the bins, not the size limits that otherwise specify the upper limits of the bins.

   (a) The radar reflectivity factor is expressed in dBz and conversion factors are used to produce the appropriate units.

   (b) A quantity temporarily called the effective radius is set to the weighted sum of the square of the diameter (dbar2). A weighted sum of the cubes of the diameter (dbar3) is also calculated. The effective radius would then be dbar3/dbar2, but this isn't calculated. Instead, the sums are added to other sums from a probe covering larger sizes (like the 2DC) to obtain values for the effective radius that combine measurements over the full size range. It isn't clear that this is a useful measurement, though, because the combination lacks good resolution at sizes between the upper size limit of the SPP-100 and the lower size limit of the 2DC and so may fail to provide appropriate weighting to measurements in this range.

   (c) The liquid water content is calculated from the weighted sum of the cube of the diameters, as follows, with appropriate units and conversion factors so as to produce an answer with units of g/m^3:

$$\chi = \frac{\pi}{6} \rho_w \sum m_i d_i^3$$

   (d) The mean diameter is obtained from the weighted sum of the diameters divided by the total concentration in the allowed interval between FIRST_BIN and LAST_BIN.

   (e) A "dispersion" is calculated from the quotient of the standard deviation in diameter divided by the mean diameter.

5. Then a correction is applied for the overflow counts, as follows:

   (a) A test requires that the overflow count be less than 5000, otherwise no correction is applied. (I don't understand why this is the case; the overflow count could legitimately be over 5000, and no distinction is made between high-rate and low-rate processing.)

(b) Values for $m_i$and for the total concentration are then multiplied by a factor "ccc", which is given by

$$ccc = \frac{M + oflow}{M}$$

where M is as defined above and $oflow$ is the overflow count.

FSSP-100 (original version from PMS):

Many aspects of processing for the FSSP-100 are similar to that for the SPP-100, so this section will highlight the differences:

1. The specifications file for the FSSP-100 includes two additional parameters, specifying two time constants "TAU1" and "TAU2". The probe also provides variables called "activity" and "fbmfr" that are not present for the other probes discussed in this note. The two time constants relate to the time required to process normally sized droplets (TAU1) and droplets that pass outside the depth-of-field and are therefore processed faster (TAU2). These are not used in the standard processing but can be used to refine estimates of concentration to accound for the dead time of the probe. The variables activity and fbmfr are used, as described below. The activity is an estimate of the time the probe is overloaded and unable to process droplets, so it provides an alternate measure of the losses. "FACT" was calculated from the following equation in the case of the old interface cards to the FSSP:

$$FACT = FSTROB * TAU1 + FRESET * TAU$$

where "FACT" is the variable representing activity, FSTROB is the counted strobes (then representing accepted particles and particles rejected for too-short transit time), and FRESET is the counted fast resets (for particles out of the DOF). With the new interface card, the activity is provided directly as a housekeeping measurement. In either case, the correction applied for activity is the following factor that decreases the sample volume and so increases the concentration and other properties derived from the concentration:

$$C_a' = 1 - 0.71\,FACT$$

In a similar way, the value used for the beam fraction, *fbmfr,* is calculated from the ratio of the valid counted particles (M in the above section on the SPP-100) to the total strobes (which are analogous to the sum of all valid particles plus the velocity-reject particles). As for the SPP-100, M is calculated erroneously using only the droplets between FIRST_BIN and LAST_BIN, while FSTROB is a count of all particles accepted or rejected. (These should have corresponding limits.) FSTROB thus serves the role $(M + rejAT)$ does for the

SPP-100. The sample volume used to calculate concentrations is then

$$V = \frac{TASA}{R} \frac{M}{(FSTROB)} C_a$$

2. The derived quantities are then calculated as for the SPP-100.

3. No correction analogous to that for "oflow" is made because the activity measurement and the factor C_a account for this effect.\

CDP:

CDP processing is closely related to SPP-100 processing, except that neither the velocity-reject counts nor the overload counts are not used in processing. It is claimed that there are no dead-time losses in the CDP, so it is not clear to me how the overload counts should be used. The probe does provide housekeeping signals for the average transit time, and for counts of particles rejected for transit time or for being outside the depth-of-field. If the velocity-reject circuitry works properly and if the nominal sample area (0.24 mm^2) is appropriate with the velocity-reject circuitry operating (i.e., describes the sample area within which the averate transit time exceeds the average), no correction should be necessary for the velocity-reject counts.

It is useful to check the probe housekeeping values to see if the constant ratios needed to ignore the velocity-reject measurement are indeed present. That will be presented later in this note.

Reasons For Proposing Changes

1. An error was introduced for the PLOWS and ICE-T projects, such that a factor of 0.1 multiplied the velocity-reject counts for the SPP-100 probe. This had a substantial (30-60%) effect on measured concentrations and derived quantities from this probe.

2. Sums for determining the beam fraction for FSSP-100 and SPP-100 probes should cover the same ranges, but these projects and others in the past were processed using the lower and upper bin limits for the valid counts but using all velocity-reject counts. (This is probably a minor effect.)

3. The processing chain for the SPP-100 corrects the concentrations for overload losses *after* calculations are performed that lead to liquid water content, reflectivity, weighted powers of the diameters, etc. This in effect omits the effect of overloads from those derived quantities.

4. The overload correction should be to introduce a factor of $(M + revAT)/(M + rejAT + oload)$ but instead $M/(M + oload)$ is being used.

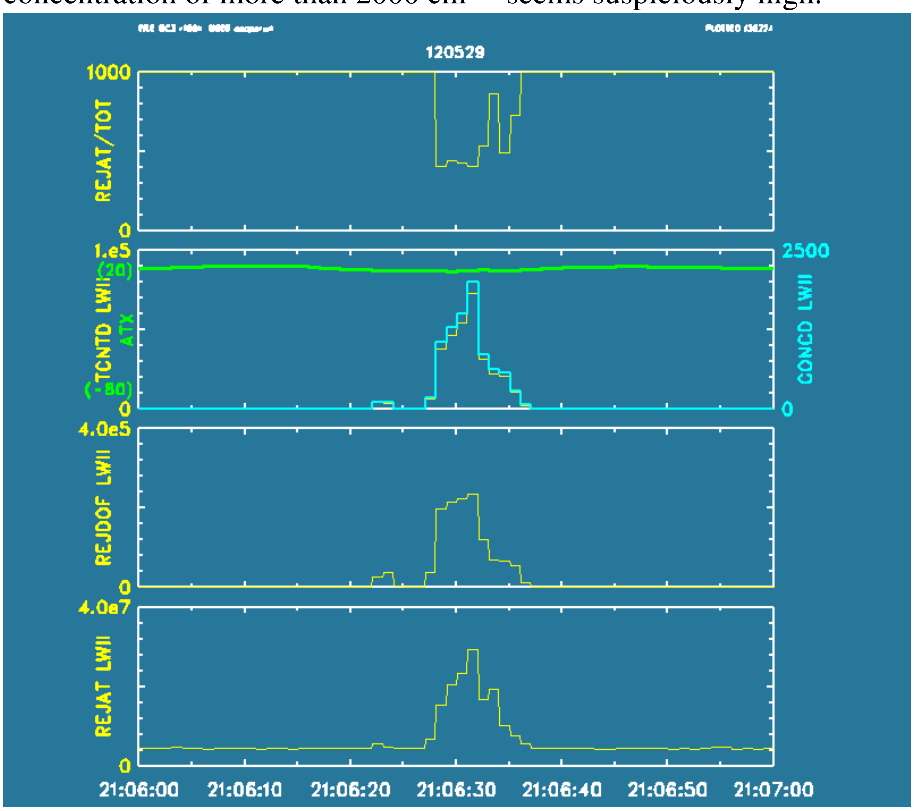
5. Some simplification and clarification of the processing chain is possible.

Analysis

Problems

1. The recorded cdp reject counts for projects IDEAS4, HIPPO-4, HIPPO-5, and PLOWS were all zero, so no correction for the reduction in beam fraction caused by the transit-time test could be (or was) made. This is not a problem as long as the beam diameter that was used was appropriately adjusted for the expected transit-time definition. The CDP manual gives the sample area as nominally 0.24 mm^2. The absence of a count for the pulses rejected for too-short transit time makes it impossible to check if this is reasonable.

2. For DC3, there are non-zero values for REJAT and REJDOF for the CDP. However, the values for REJAT are not reasonable numbers. The counts were everywhere at least $(0.5-1)\times 10^7/s$ or more throughout the flights, including periods in clear air, and in real water cloud they increased by typically an additional $2\times 10^7/s$. The total counts from the CDP for the same period were about 0.7×10^4, so the ratio of rejected to accepted pulses was about 300 while this was expected to be about 0.62. The velocity-reject counts are obviously not working and producing far too much noise and values much too high. (For the CDP in DC3, the ratio between total counts and concentration is 36.4 at a TAS of 150 m/s. This is the expected sample volume at this airspeed if the sample area is 0.24.) However, the concentration of more than 2000 cm^{-3} seems suspiciously high.



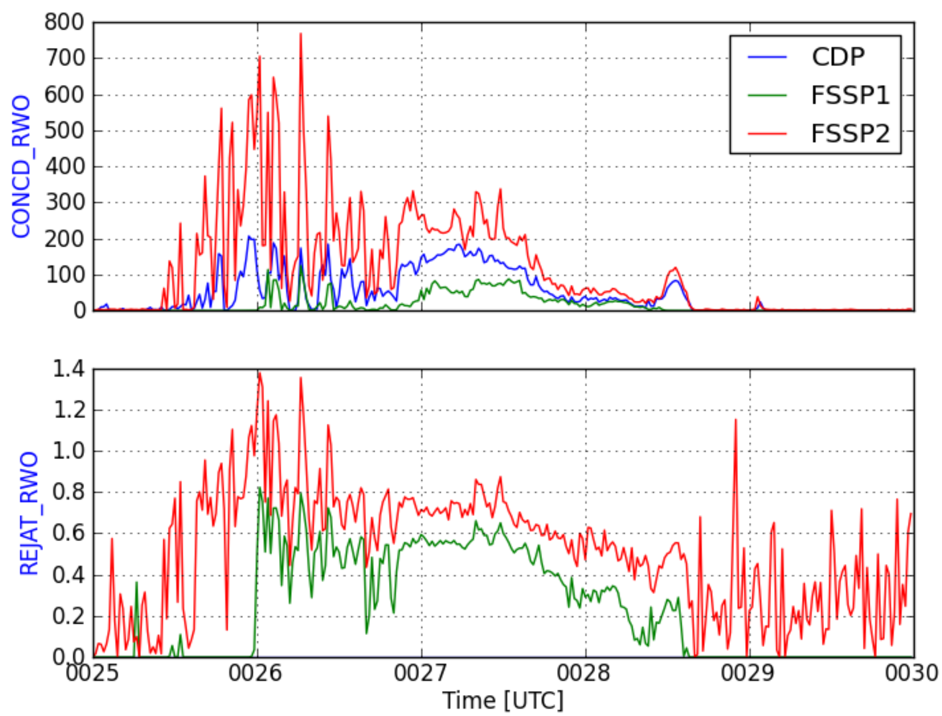
3. At the peak, the cloud pass from DC3 discussed in point 2 above had REJDOF about 3.2 times higher than the total counts.

The Velocity-Reject and DOF Fractions:

The theoretical value for the ratio of particles rejected for having too-short transit times to those accepted by the velocity-reject circuitry, for a uniform beam and electronics having response times fast compared to particle transit times through the beam, should be:

$$F_1 = \frac{1. - 0.619}{0.619} \simeq 0.62$$

The ratio of particles out of the depth-of-field to those inside, F_2, should also be reasonably consistent. Because the value in ice could be substantially different, it is useful to test this in all-water clouds. The figure below shows an example of a cloud pass from PLOWS (RF04) where the temperature was above 0°C.



The following are some troublesome aspects of this plot:

1. The concentrations vary over a wide range. At about 002652, the respective concentrations from the CDP, FSSP1, and FSSP2 are 109, 15, and 238 cm^{-3}. The shapes of the plots

of concentration vs time are quite different, e.g., showing structure for the FSSP2 at about 002720 that does not appear in the other two curves. Just before 0026, there is a segment where the FSSP1 concentration is zero while that from the other probes suggests a normal cloud pass.

2. As noted before, the REJAT counts from the CDP are zero throughout this project.

3. The reject fractions for the FSSPs are quite variable but in the core region of the cloud they are reasonably close to the expected value of 0.62. The fractions are higher early in the pass and lower later, although the mean diameter (not shown) is fairly steady. At about 0028, the reject fraction drops to about 0.3 for FSSP1, and it is hard to understand why this should occur when the mean size is steady (at around 10 μm).

4. The variation in the lower plot, and the absence of information from the CDP regarding transit-time rejected droplets, seems to call into question the validity of assuming that the reject fraction is constand in the CDP and can be ignored in processing, although with a different laser it might have different reject characteristics. It will be important to examine this further, though.

5. The respective reject fractions for the CDP, FSSP1, and FSSP2 (not shown) are about 60-100, 1-2, and 3-4. The CDP has been changed since this time, so it will be useful to examine this again in the pending C-130 tests.

Recommendations

1. For SPP-100/FSSP-100 probes, sums for determining the beam fraction should cover the entire range, not the range between cells considered valid for output, because no corresponding test can be applied to the rejected pulses. (This is probably a minor effect.)

2. For the CDP, the processing can continue to ignore the correction for velocity rejection, at least until how this functions in the probe can be determined and fixed. No changes are suggested now.

3. Correct the concentrations for 'oflow' before calculating derived quantities in pms1d_cv. The following defines the correction factor to be applied to the sample volume (for the SPP-100):

$$C' = \frac{M}{(M+rejAT)}\frac{(M+rejAT)}{(M+rejAT+oflow)} = \frac{M}{M+rejAT+oflow}$$

4. Change the name of the variable rejAT from "xxx Average Transit Rejected Particles" to "xxx Total Transit-Time-Rejected Particles"

5. Suggesed implementation:

SPP-100 and FSSP-100, where 'TACT' is calculated:

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sum all channels (don't limit to FIRST_BIN-LAST_BIN)
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SPP-100 only, in the line where 'vol' is calculated:

```
vol[probeNum] *= (float)(tact[probeNum])
     / (float)(tact[probeNum] + rejAT + oflow);
(Then omit this correction where it occurs now, below where pms1d_cv is included.)
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—- END —-