Aircraft Measurements of Cloud Liquid Water Content using the Forward Scattering Spectrometer Probe

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Why Measure Liquid Water Content?

- Basic Cloud Parameter (MPACE)
- Icing Studies (WISP04, Sikorsky)
- Comparison with Remote Sensing Measurements (THORpex, IOP1)

Liquid Water Content Calculation

The amount of liquid water for a given volume of air may be determined through mass integration of the cloud droplet distribution.

$$LWC = \rho_w \sum_{i=1}^m N_i d_i^3$$

- $\rho_{\rm w}$ Density of Water
- N_i Concentration of droplets in size channel i
- d_i Droplet diameter in size channel i
- m Total number of channels

Forward Scattering Spectrometer Probe (FSSP) On the Right Wing of the Citation Research Aircraft



Optical Path of the FSSP



The beam splitter divides the scattered light onto two photodetectors. One photodector is optically masked to not receive scattered light from near the laser beam's center of focus. Droplets are rejected as being out of the depth of field when the signal from the masked detector exceeds that from the unmasked detector.

FSSP schematic is taken from Dye and Baumgarnder, [1984]

FSSP Effective Sample Volume

- Sample Volume = TAS*DOF*BD*(Tc/Ts)
- TAS Aircraft True Air Speed (~100 m/s)
- DOF FSSP Depth of Field (~2.9 mm)
- BD Laser Beam Diameter (~0.2 mm)
- Tc Number of Droplets Sized (Total Counts)
- Ts Number of Droplets within the DOF (Total Strobes)





The effective laser beam diameter is the fraction of the total diameter where droplets are within the laser beam long enough so they can be sized. A running average of the droplet transit time through the beam is maintained. If the droplet time within the laser beam is less than the average, it is rejected from sizing but included in the running average.

UND FSSP Velocity Acceptance Ratio



The velocity acceptance ratio is based on the ratio of total FSSP counts to total FSSP strobes. Dye and Baumgarnder [1984] state that the theoretical velocity acceptance ratio is 62%.

Coincidence and Deadtime Corrections

$$cf = \frac{1}{1 - 0.73 * F_a}$$

cf-Correction factor

F_a – Activity Fraction

The 0.73 constant is an empirical factor found from computer simulations which takes into account particles which are still in the beam at the end of a reset delay period. This factor is described by Baumgardner [1983] and Baumgardner et al [1985].

UND FSSP Particle Loss Correction

July 2, 2004 Flight



Percentage of particle losses based on the measured FSSP activity.

Theoretical Loss Correction



Plot of the expected loss of the NCAR Research Aviation Facility's FSSP probe flying at 100 m/s. Figure taken from the NCAR Research Aviation Facility Bulleting No. 24.

FSSP Calibration Procedure



The FSSP is calibrated before and after each field project to determine the instruments depth of field, laser beam diameter, and channel size boundaries. The channel counts obtained from measurements on beads of known size are used to determine the FSSP channel boundaries.

FSSP Mie Function



FSSP Mie Function is taken from Dye. and Baumgarnder, [1984]

FSSP Bead Calibration Check



checked by sampling beads of known size.

March 10, 2004 Citation Flight



4 Hz averaged FSSP and King Probe cloud liquid water content data.

September 24, 2004 Citation Flight



4 Hz averaged FSSP and King Probe cloud liquid water content data.

How well do they Compare? March 10, 2004



How well do they Compare?

September 24, 2004



Ice Contamination





The FSSP LWC calculations assume spherical water droplets.

Rapid Visualization of Data



One Last Plot



Conclusions

- Beam fraction, coincidence, and deadtime corrections need to be applied to the FSSP data to obtain accurate LWC measurements; however, apparently no airspeed correction has to be applied to the FSSP data.
- The FSSP liquid water content agrees with the King Probe LWC in ice free conditions. Cases from two different field programs found FSSP to King ratios of 0.96 and 1.20.
- Well written software can automatically post process the FSSP data to provide accurate plots of the FSSP LWC measurements during field projects.

Future Work

- Do more comparisons between the FSSP and King Probe LWC measurements.
- Compare the FSSP and Rosemount Icing Probe LWC measurements.
- Investigate the possibility of using an airspeed correction to the FSSP data.
- Use the 2-DC probe measurements to develop a criteria where by the FSSP LWC value is replaced with it's missing value code when there is ice contamination.

