Measurements of Cloud Liquid Water Over the SGP Site

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Introduction

The University of North Dakota Citation aircraft made in situ measurements of liquid water clouds on six flights in stratus clouds during the Spring 2000 Cloud Intensive Operational Period (IOP) at the Southern Great Plains (SGP) site. Four in situ instruments were used to measure cloud liquid water content (LWC): a particle measuring system (PMS) King liquid water sensor, a Counterflow Virtual Impactor (CVI), a PMS Forward Spectral Scattering Probe (FSSP) and a one-dimensional (1D) optical array probe (OAP). The latter two instruments provided droplet size spectra from which cloud LWC, effective radius, and spectral width could be determined. Sensor characteristics are given in Table 1. From the ground, several microwave radiometers were used to retrieve the cloud liquid water path (LWP).

Table 1. Sensor characteristics.

	FSSP	King	PMS 1D-C	CVI
Response (diameter)	3 μm to 62 μm (range)	7 μm to 200 μm (50% min and max size cut)	40 μm to 610 μm	Losses below 30 μm MVD
Sensing Technique	Forward Scattering	Hot Wire	Optical Array	Evaporation, Lyman-α
Corrections	Dye and Baumgardner (1984); Baumgardner et al. (1985); Baumgardner and Spowart (1990)		Baumgardner (1987)	

The in situ measurements of LWC show some disagreement, but these discrepancies can be attributed primarily to the operational characteristics and performance of the individual instruments. The King liquid water probe is expected to miss 20 percent of 10 μm droplets and its measurement efficiency decreases with median volume diameters > 20 μm, causing an underestimate of LWC in those conditions. The CVI used has a "cut size," or droplet size collected with 50 percent sampling efficiency,

of 9 μm for low-level sampling conditions. Sampling efficiency increases to 100 percent for clouds with median volume diameters (MVDs) of about 30 μm (Twohy et al. 2000). The FSSP has an upper size measuring limit of 62 μm (after corrections according to Baumgardner and Spowart (1990), and will give erroneously large values of LWC in mixed-phase conditions. The 1D OAP has an effective range of 40 μm to 610 μm (with corrections - Baumgardner 1987), with some statistical uncertainty in the smallest channels. Users of these Citation data should be careful in the interpretation and application of these values for validation of remote sensing retrieval algorithms.

A summary of the stratus flights is given in Table 2. Figures 1 through 6 show LWC values for each of these flights, as derived from the King, FSSP, and CVI. Note that heavy icing conditions were encountered during the second flight of March 18. The anti-icing capabilities of the sensors was not adequate to keep them ice-free, making the measurements during much of this flight suspect.

Table 2. Stratus mission summary.

	March 3	**March 17**	**March 18a**	**March 18b**	**March 19**	**March 21**
Cloud Thickness	400 m	360 m	2 km	1700 m	< 200 m	200/700 m
Character	Uniform	Not uniform	Layered	Layered	Scattered	2 layers (top/low)
LWC (g m^{-3})	0.2 - 0.4	0.1 - 0.6	Up to 0.8	0.4 - 0.8	0.1 - 0.2	0.1/1.0
FSSP MVD (μm) 1D-C conc. (L^{-1}) 2D-C images	12 – 14 < 10 Few nulls (blank images)	10 – 22 up to 50 Few nulls	30 500-1000 Drizzle	23 < 100 Some ice	10 < 1 None	10/20-30 < 10/80 Drizzle
Comments	More LWC near tops	Patchy LWC	Drizzle	Probes iced up	Very thin	Uniform low layer

When the cloud is composed of a mixture of cloud water and drizzle drops, no single in situ sensor can be used to measure the LWC. Figure 7 shows the particle size distribution from a portion of the first flight of March 18 where the drop distribution is quite broad. The corresponding distribution of liquid water is given in Figure 8.

For March 3 and March 21, we divided the Citation flight into a series of legs categorized as level flight, cloud ascents, or cloud descents. In the cloud ascents or descents, the Citation traversed most, if not all the way, through the cloud layer. We used the cloud ascents and descents to construct vertical profiles of cloud properties. Figure 9 shows a comparison of the microwave radiometer (MWR) retrieved LWP and that obtained from the FSSP and 1D-C probes during the ascents and descents on March 21. The LWP was derived from the MWR at the Central Facility. The figure shows that drizzle played a significant role during the early portion of the flight. Figure 10 shows one profile of the effective radius, based on FSSP data for March 3. This profile is typical of that day, showing particle sizes near 7 μm at cloud base and near 9 μm at cloud top.

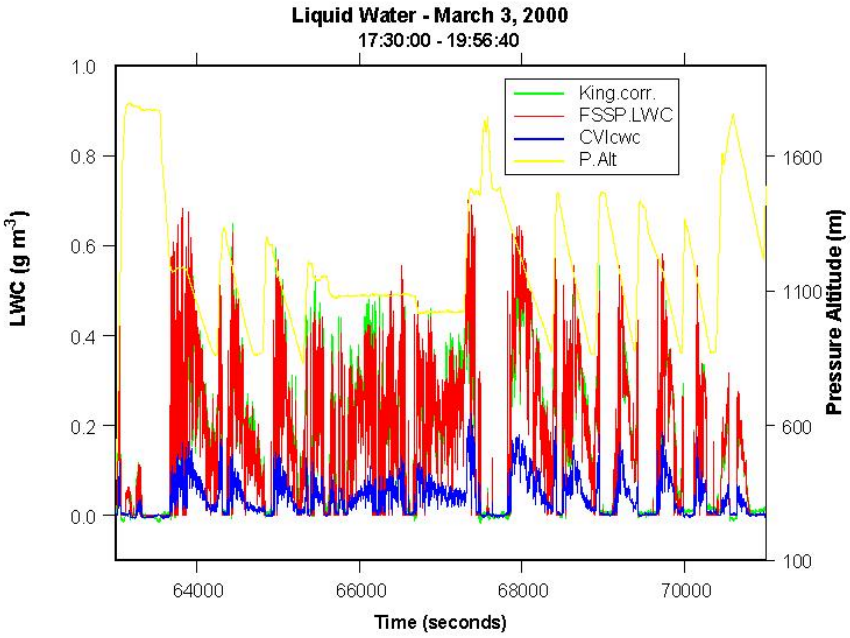

Figure 1. LWC values from the King, FSSP, and CVI.

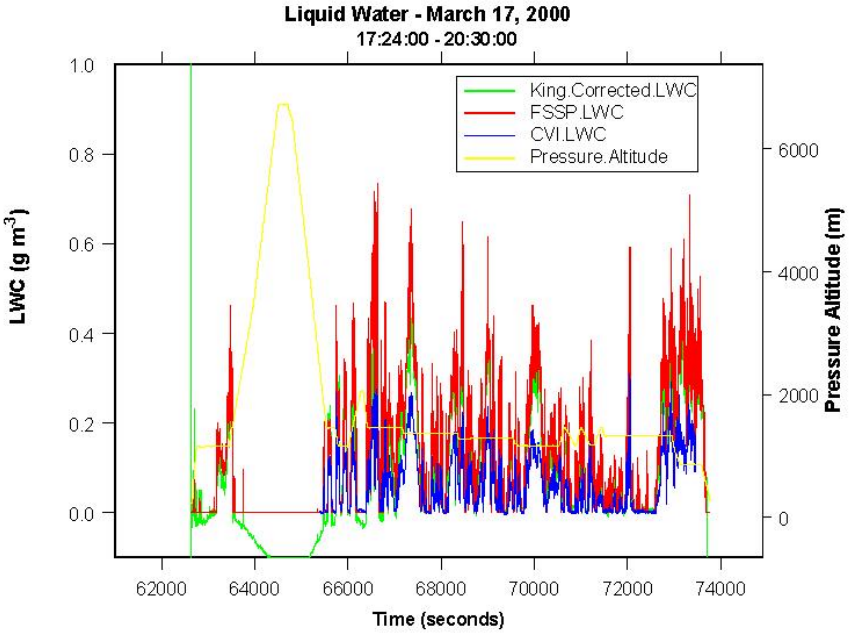

Figure 2. LWC values from the King, FSSP, and CVI.

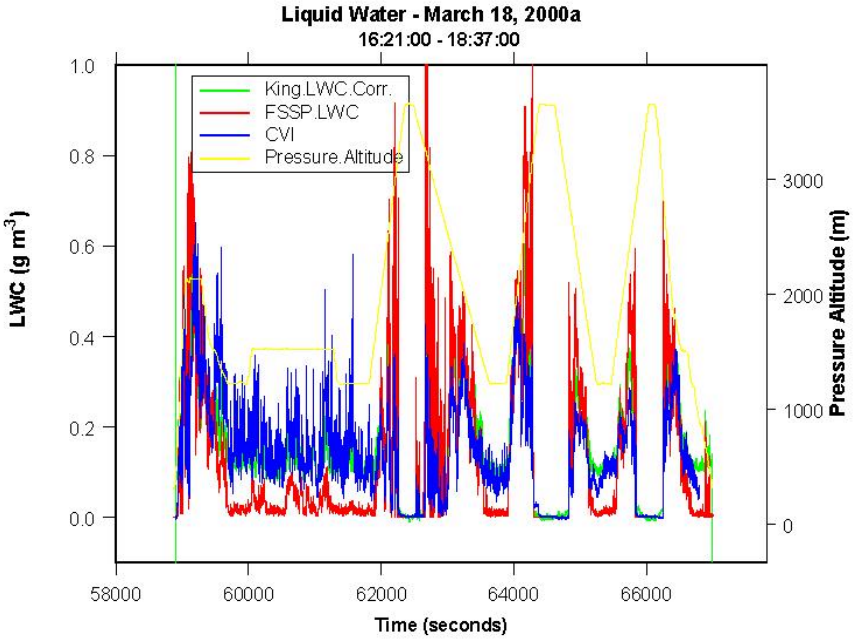

Figure 3. LWC values from the King, FSSP, and CVI.

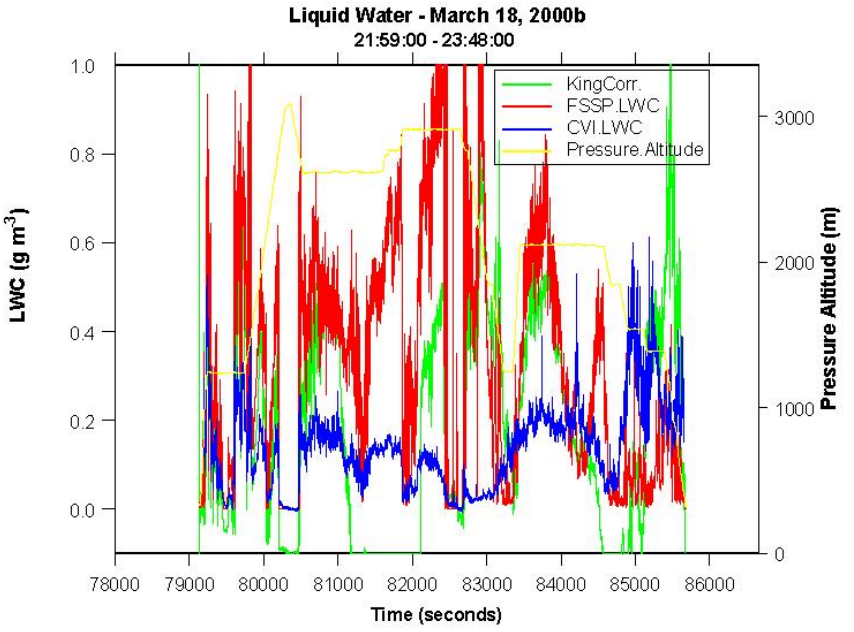

Figure 4. LWC values from the King, FSSP, and CVI.

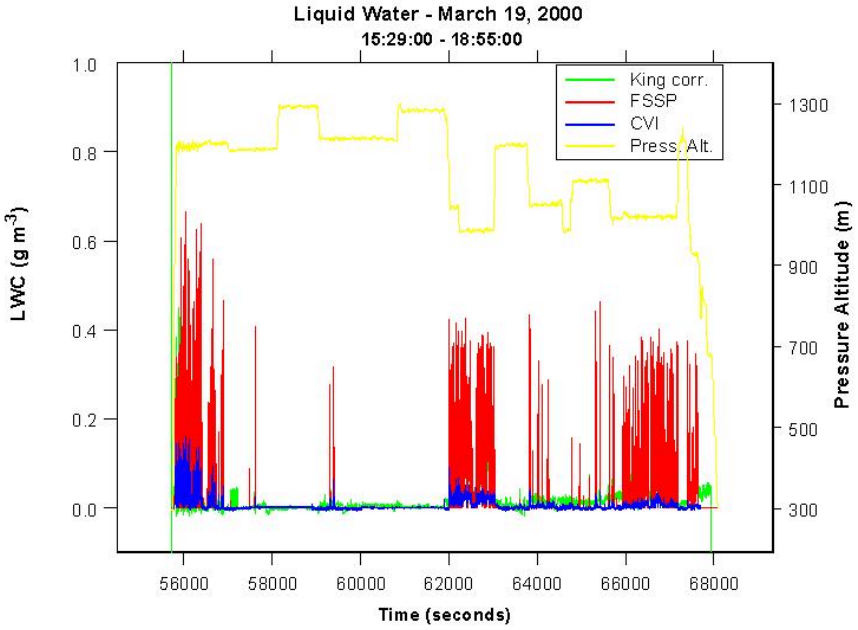

Figure 5. LWC values from the King, FSSP, and CVI.

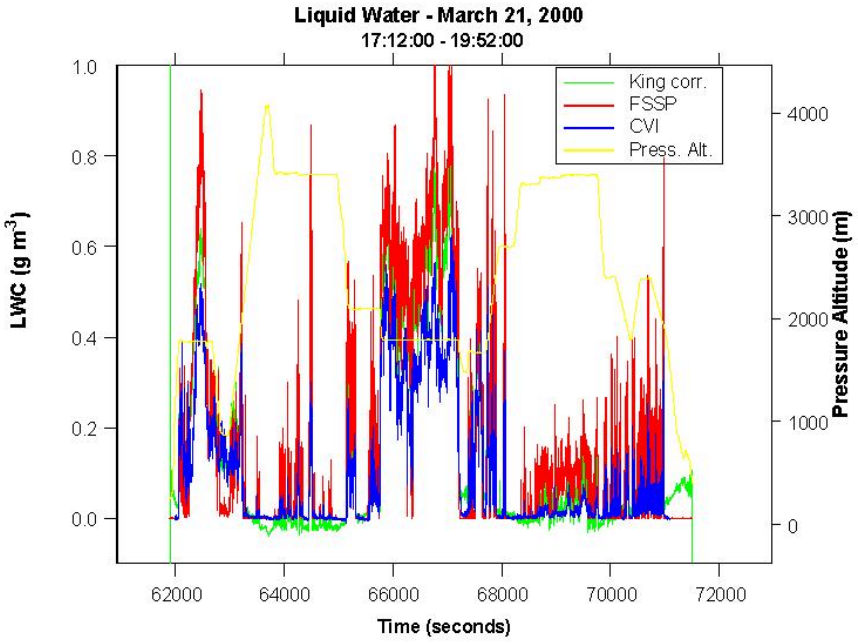

Figure 6. LWC values from the King, FSSP, and CVI.

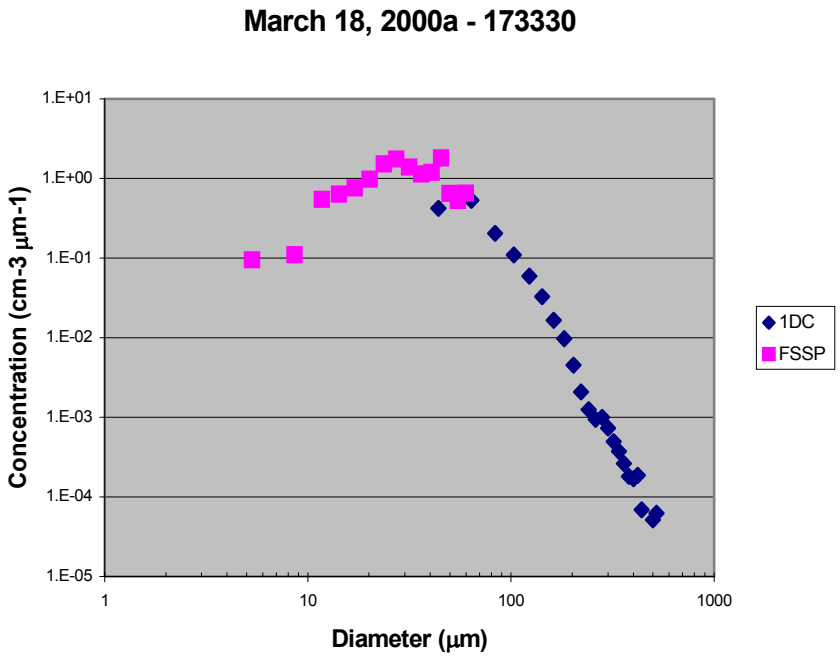

Figure 7. Particle size distribution from part of the March 18 flight.

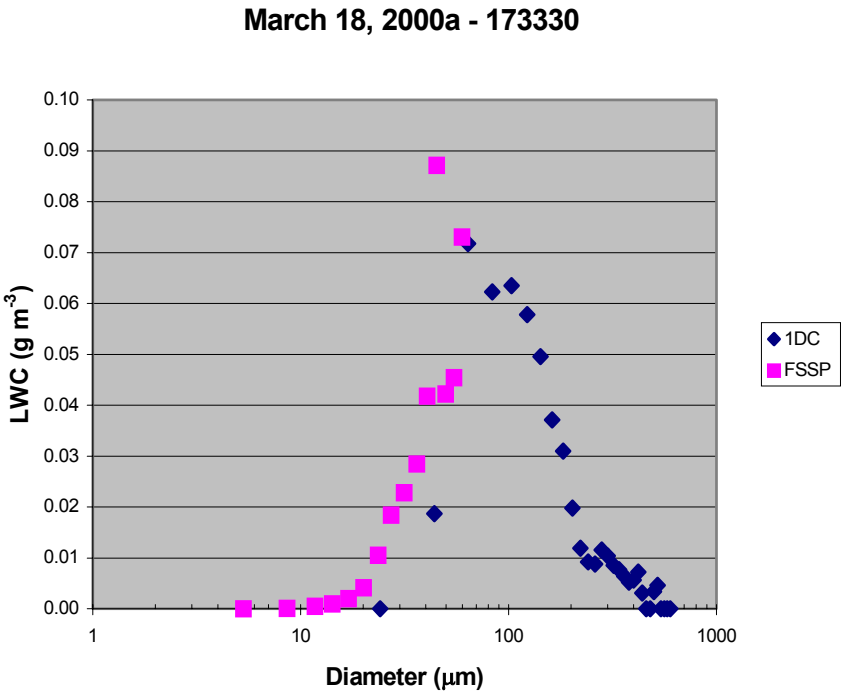

Figure 8. LWC from part of the March 18 flight.

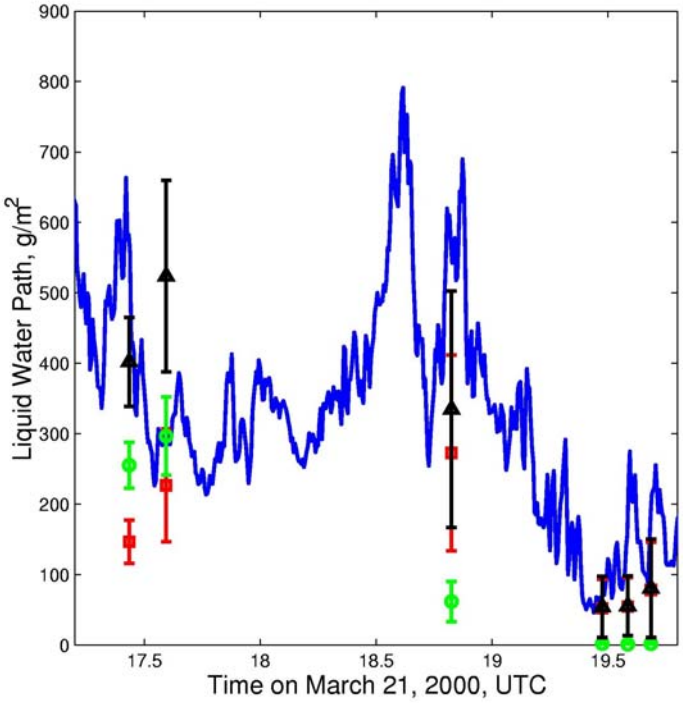

Figure 9. LWP for microwave radiometer (blue), FSSP (red), 1D-C above FSSP range (green), and FSSP+1D-C (black).

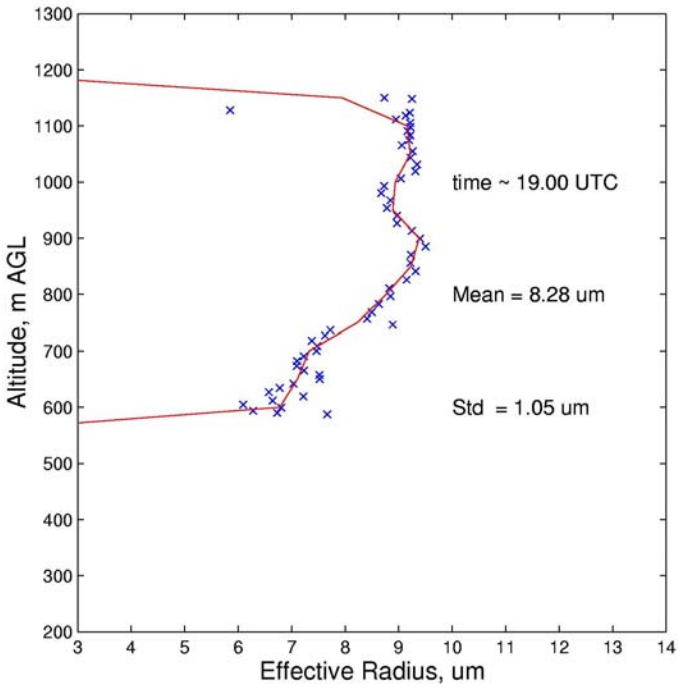

Figure 10. Profile of effective radius from March 3 FSSP data. Red curve is best fit for 50-m layers.

We have used some of these profiles in radiative transfer calculations in combination with MWR data. These calculations suggest that the measured effective radii are reasonable (within the expected accuracy of the measurement) (Figure 11). Note that the inclusion of drizzle (black curve) improves the agreement with shortwave flux measurements early in the flight period, but worsens it thereafter, when Citation measurements indicated that the liquid water was contained mostly in smaller droplets.

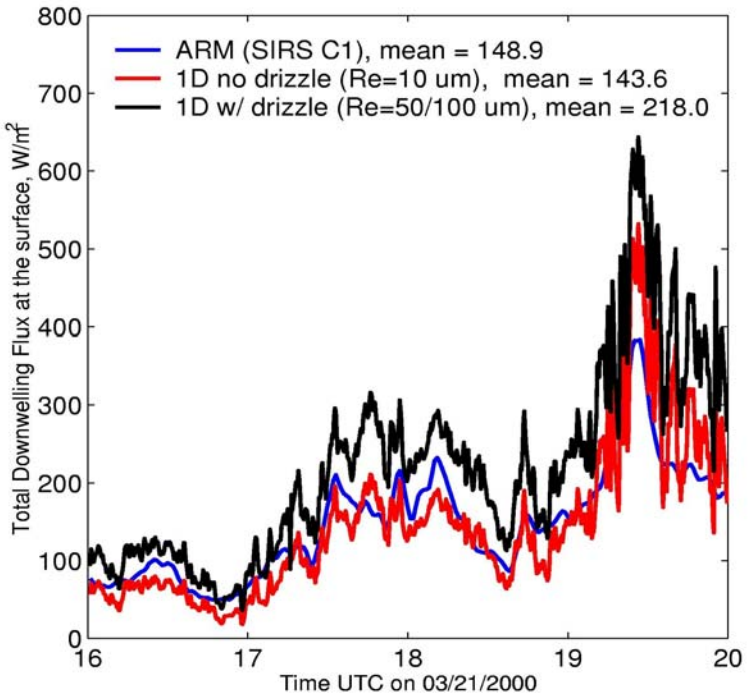

Figure 11. Results of radiative transfer calculation based on MWR LWP and in situ measurements. (SIRS C1 is the surface broadband shortwave flux at the CART site.)

References

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