Intercomparison of Cloud Base Height at the ARM Southern Great Plains Site

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Abstract

Instruments that measure cloud base height at the Atmospheric Radiation Measurement (ARM) Program site in Lamont and Blackwell Oklahoma are examined. These instruments include, the Micropulse Lidar, Belfort Laser Ceilometer, Vaisala Ceilometer, and Millimeter-Wavelength Cloud Radar. Instruments at the ARM sites record information regarding cloud radiative forcing and feedback effects, variables that represent a great amount of uncertainty in climate prediction. However, flawed observations and dissimilarities in instrument performance when reporting cloud types hinder our ability to fully understand these processes. Also, users of ARM data assume these instruments are interchangeable, but this may not be the case. The purpose of this paper is to address the observed differences between these instruments under different atmospheric conditions and cloud types both qualitatively and statistically, and to test a method that may be useful to identify outliers.

Qualitative analysis revealed that the Micropulse Lidar is superior in reporting high cloud bases and jagged cloud bases, but inferior to both ceilometers when reporting low clouds. However, statistical results were inconclusive, due to large standard deviations encountered in all cloud episodes. Histograms used to identify outliers gave reasonable results when cloud bases were visibly similar, but resulted in skewed or bimodal distributions for other cases. These results are discussed for observations taken during the Spring 2000 Cloud Intensive Observing Period.

1. Introduction

The Atmospheric Radiation Measurement (ARM) Program is an interagency program created in 1989 with funding from the United States Department of Energy. The primary objectives of the ARM Program are to develop, test, and improve the accuracy of parameterizations that describe atmospheric radiative transfer, water vapor, and the formation, dissipation, and radiative effects of clouds (Stokes and Schwartz, 1994). These processes play a major role in our earth's climate and climate change; however, cloud radiative forcing and feedback are not well understood. All climate models contain code, which accounts for how cloud droplets absorb, scatter, and reradiate solar radiation, but recent observations have indicated clouds absorb roughly 40% more sunlight than model calculations suggest (Kerr 2003). Therefore, a main goal of ARM is to improve our understanding of these processes so that model parameterizations can be improved while still maintaining computational simplicity, which will then allow better confidence to be placed on the models used to study and predict climate change (Stokes and Schwartz 1994).

In order to study these atmospheric processes, ARM established three cloud and radiation testbed (CART) sites in climatologically significant locations. The Tropical Western Pacific site, which sits in the region with the warmest sea surface temperatures on the planet (the "warm pool"), has three observational facilities located on Manus Island, Nauru Island, and in Darwin Australia (ARM website 2003f). The North Slope of Alaska sites are located in Barrow and Atqasuk, Alaska, and record data on Arctic clouds and radiation (ARM website 2003d). Also, the Southern Great Plains Site covers 55,000 square miles in Oklahoma and Kansas, with a central facility in Lamont, Oklahoma and observes a wide variety of temperatures and cloud types. Instruments at these sites measure cloud base height, radiation, surface meteorological data, and more (ARM website 2003e).

This project focuses on cloud data (in particular, measurements of cloud base height), and the discrepancies present between the ARM instruments that measure it. There are four instruments used in this project that ARM currently operates to record cloud base height. The Micropulse Lidar (MPL) is a ground based remote sensing system that transmits an upward pulse of energy and measures reflected energy that returns to the instrument. Cloud base heights are determined from the time delay between the pulse and reflected energy (ARM website 2003b). The Vaisala Ceilometer (VCEIL) measures cloud base height as a function of distance using a laser (ARM website 2003g). The Belfort Laser Ceilometer (BLC) detects clouds by transmitting a pulse of infrared light and recording the backscattered light (ARM website 2003a). The Millimeter-Wavelength Cloud Radar (MMCR) reports the extent and composition of clouds at the CART site using reflectivity values (ARM website 2003c). For this reason, the MMCR was used as ground truth for this project.

These instruments detect the same clouds, yet they seldom produce the same cloud base heights. Many users of ARM data likely assume that these instruments are interchangeable, but this is not the case. In order to improve cloud representations in General Circulation Models, it is necessary to understand the strengths and limitations of each instrument. Indeed, recent observations have suggested that flawed observations may contribute to erroneous outcomes of these models (Kerr 2003). The purpose of this project, therefore, is to investigate the differences of reported cloud base height for specific cloud types and weather conditions, and to determine some of the causes of these differences.

2. Data and Methodology

Cloud base height data were obtained from the Southern Great Plains Central Facility from the MPL, the BLC, and the MMCR. Also, data from the VCEIL and a second MPL were obtained from Blackwell Tonkawa Airport, which was a temporary facility established during 5 – 21 March 2000, for the Spring 2000 Cloud Intensive Observing Period (IOP). Two motivations for using this time period are the increased care placed on the operation and maintenance of each instrument during an IOP, and the additional data collected, such as human visual observations of cloud types and fractional cloud coverage. During March, there is a reasonable chance of encountering liquid phase clouds in the troposphere, and the air is not warm enough to support substantial insect life that can contaminate readings. In addition, the seasonal time period of the most active deep convection is avoided (Mace et al, 2003).

Plots of cloud base height versus time from all four instruments were analyzed, an example of which is shown in Figure 1, for the VCEIL. Cloud base height from the MPL and the BLC, were displayed on the same plot for the Central Facility in order to perform a qualitative analysis of instrument performance. The first step of this analysis was to identify times when instruments were not operational or maintenance affected data quality. Upwelling and downwelling radiation, temperature, and precipitation data were combined with MMCR data to determine the atmospheric conditions for each time period studied. Plots of the VCEIL and the MPL cloud base height were created and compared in the same way for the Blackwell Facility.

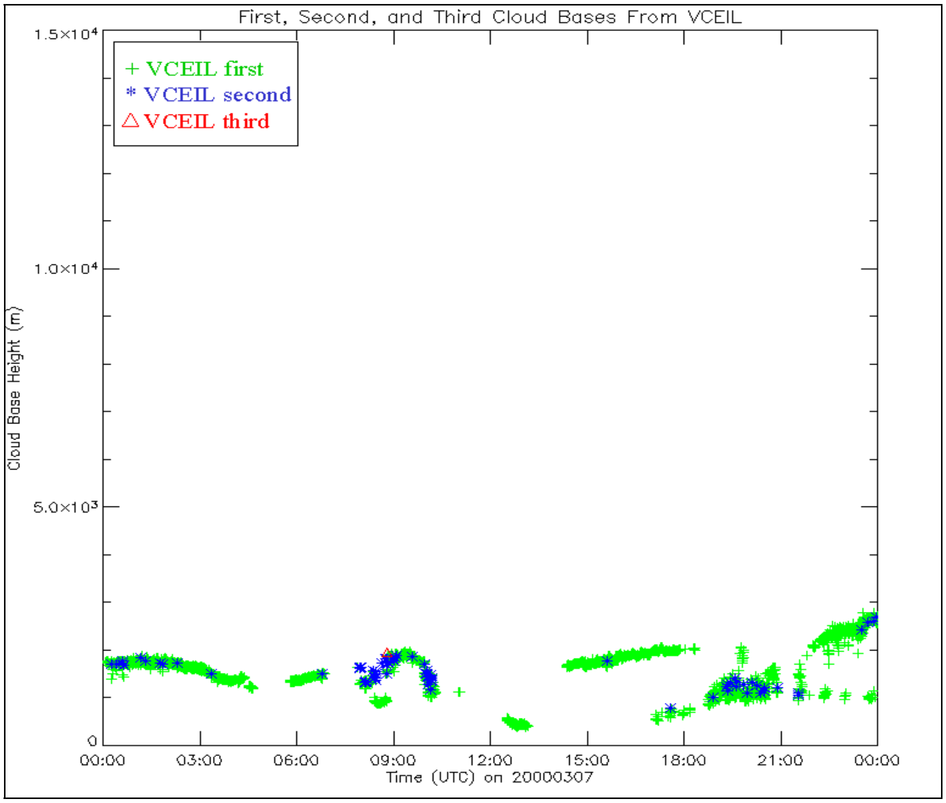

Figure 1. A plot of cloud base height versus time from the Vaisala Ceilometer on 7 March 2000.

After completion of the qualitative analysis, a statistical comparison of measured cloud base height between the instruments was performed; means, standard deviations, and linear correlations were calculated. Matched pairs of two variables are required to calculate a correlation, therefore, this was calculated only when both instruments reported clouds. In addition, hypothesis tests were performed on the difference between mean cloud base heights (D)

$$D = \text{Ceilometer cloud base height} - \text{MPL cloud base height} \quad (1)$$

for both the Central and Blackwell Facilities at the 95% and 99% confidence levels. A hypothesis test result of true implies that the difference between mean cloud base heights is statistically zero, using $A_1 \leq D \leq A_2$, where A_1 and A_2 are given by the following formulas.

$$A_1 = -z\, S(D) \quad (2)$$

$$A_2 = z\, S(D) \quad (3)$$

The variable z is 1.96 at the 95% confidence level, and 2.575 at 99%. S(D) is the standard deviation of the difference statistic D calculated using the following equation.

$$S(D) = ((\text{Ceilometer standard deviation})^2 + (\text{MPL standard deviation})^2)^{1/2} \tag{4}$$

A false result implies that the difference between mean cloud base heights is not zero.

In addition, a quality control check was performed on the dataset by calculating the normalized differences between cloud base heights for both facilities (Battone and Moore 2003). The results are displayed in a histogram to highlight outliers, as shown in Figure 2. Outliers were defined as normalized values falling more than three standard deviations away from the mean. These outliers were also displayed on plots of cloud base height versus time to determine their location within the data scatter and the accuracy of this quality control check.

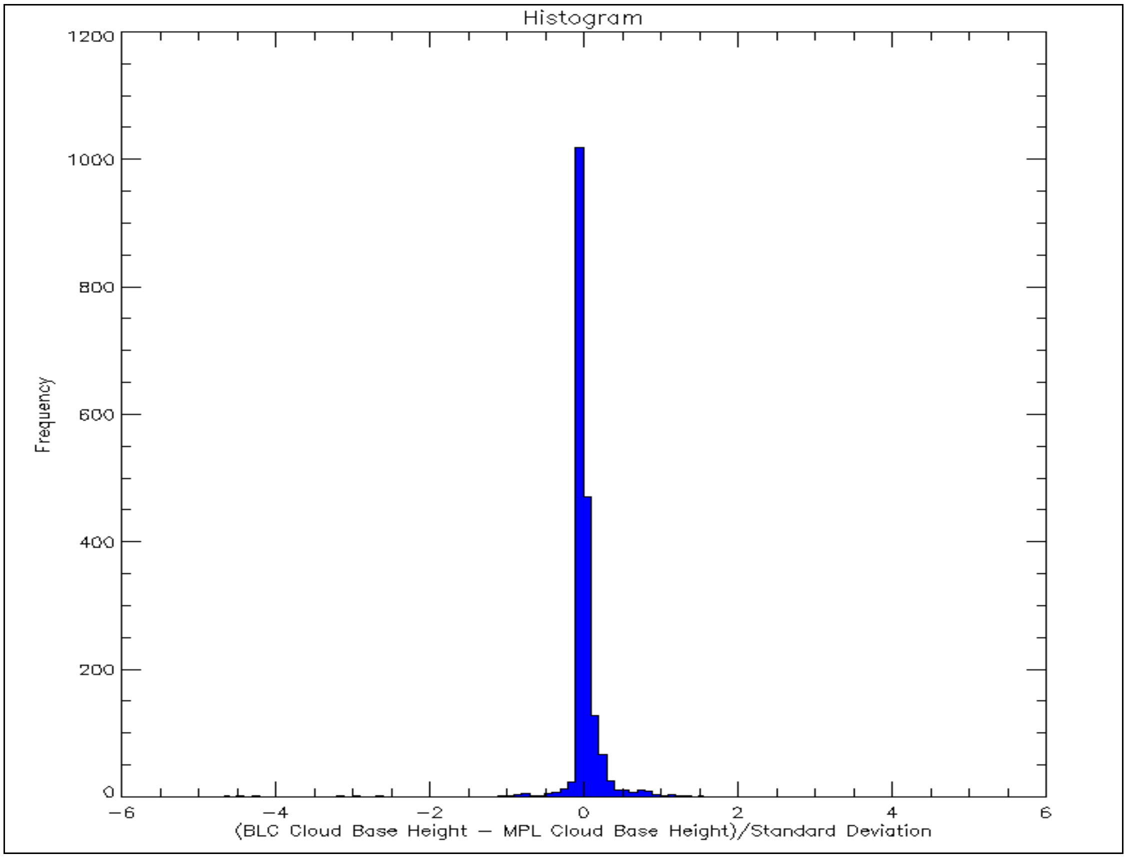

Figure 2. A quality control histogram used to identify outliers from 14 March 2000.

3. Qualitative Analysis

a. Central Facility

The MPL reports the presence of low clouds inadequately, and in disagreement with the BLC and the MMCR. Figures 3, 4, and 5 show reported cloud base height for the BLC, MPL, and MMCR on 15 March 2000. As seen in Figures 3 and 4, the MPL fails to report the low clouds seen by the BLC, but reports a higher cloud base starting at 1300 UTC. This corresponds to a period of higher reflectivity as shown on the MMCR plot (Figure 5). It can also be seen from these figures that the MPL reports scatter in the atmosphere, while the BLC does not pick up this scatter. During most days, the MPL picks up more scatter than either the BLC or the MMCR. Also, under clear skies or thin cirrus clouds, the MPL may report cloud bases that are actually boundaries in the atmosphere, such as moist or dry layers, particle-laden regions, or the top of the planetary boundary layer, and are not clouds. However, under the presence of low and middle clouds, the MPL generally does not detect boundaries.

Comparison plots of the BLC and MPL cloud base heights reveal that the MPL is superior when reporting high cloud bases, especially thin cirrus. The data also reveals that the BLC's ability to detect high clouds is variable depending on the temperature and ice content of the clouds. Cirrus clouds that contain more ice are resolved less frequently by the BLC than those that have a greater amount of water. Also, since cirrus clouds with greater ice content tend to occur more frequently in cooler temperatures, the BLC may pick up higher cloud bases under warmer conditions. Furthermore, this instrument tends to report non-flat cloud bases higher, and with less variation, than both the MMCR and MPL.

In spite of the above differences, both the MPL and BLC were found to report similarly and in good agreement with the MMCR during episodes of flat-based cumulus clouds and stratus clouds. The MPL performed reasonably well under the presence of drizzle, as long as the cloud bases were high enough to be picked up, but the BLC does not detect clouds accurately during drizzle.

b. Blackwell Facility

Comparison plots of cloud base height between the VCEIL and MPL (not shown) reveal a pattern similar to that shown between the MPL and BLC. As with the BLC, the VCEIL's ability to detect cirrus clouds is dependent on the ice content and temperature of the cloud. When the VCEIL picks up cirrus clouds, it usually reports these cloud bases too high. Also, the VCEIL reports excessive height and too little variation for non-flat based clouds. The MPLs at both sites performed similarly.

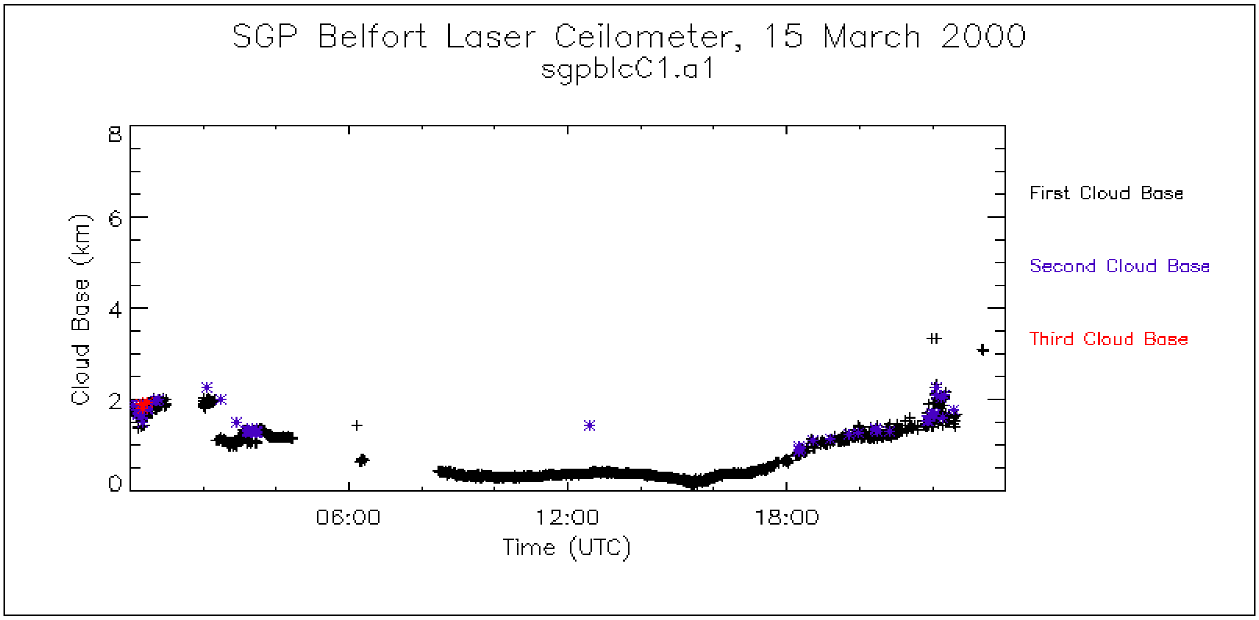

Figure 3. Cloud base height from the Belfort Laser Ceilometer on 15 March 2000, showing low clouds from 0800 UTC to 2200 UTC (image from Mace, 2003).

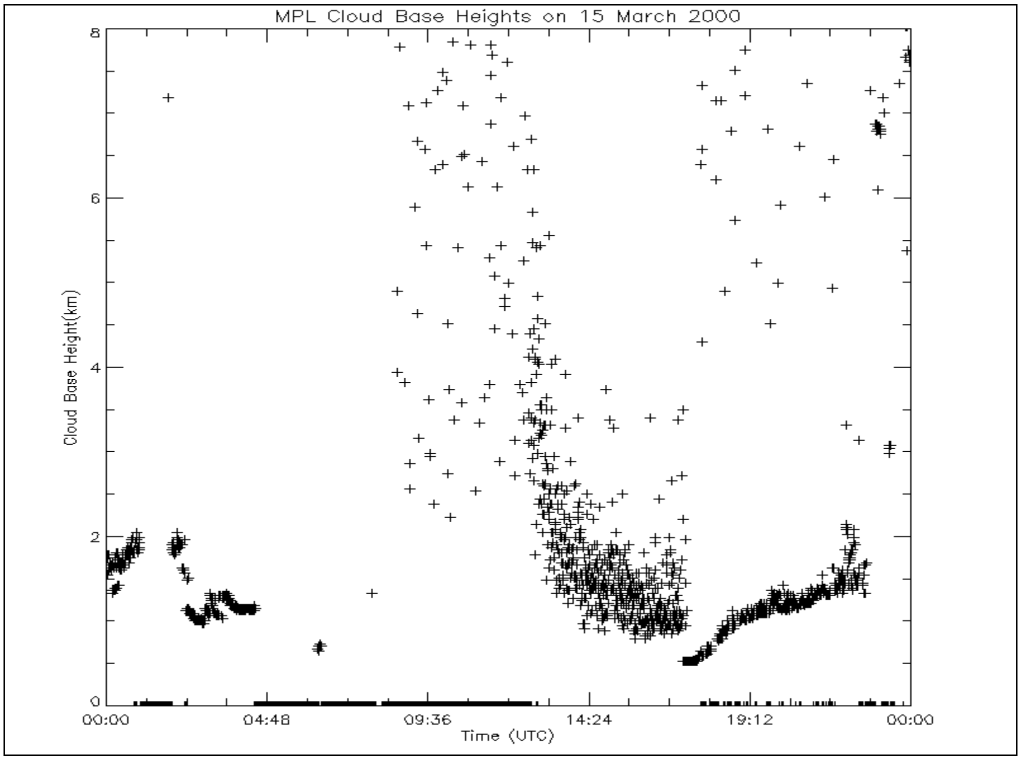

Figure 4. Cloud base height from the Micropulse Lidar on 15 March 2000, showing low clouds in the early and later parts of the day, but missing clouds during 0800 UTC to 1300UTC.

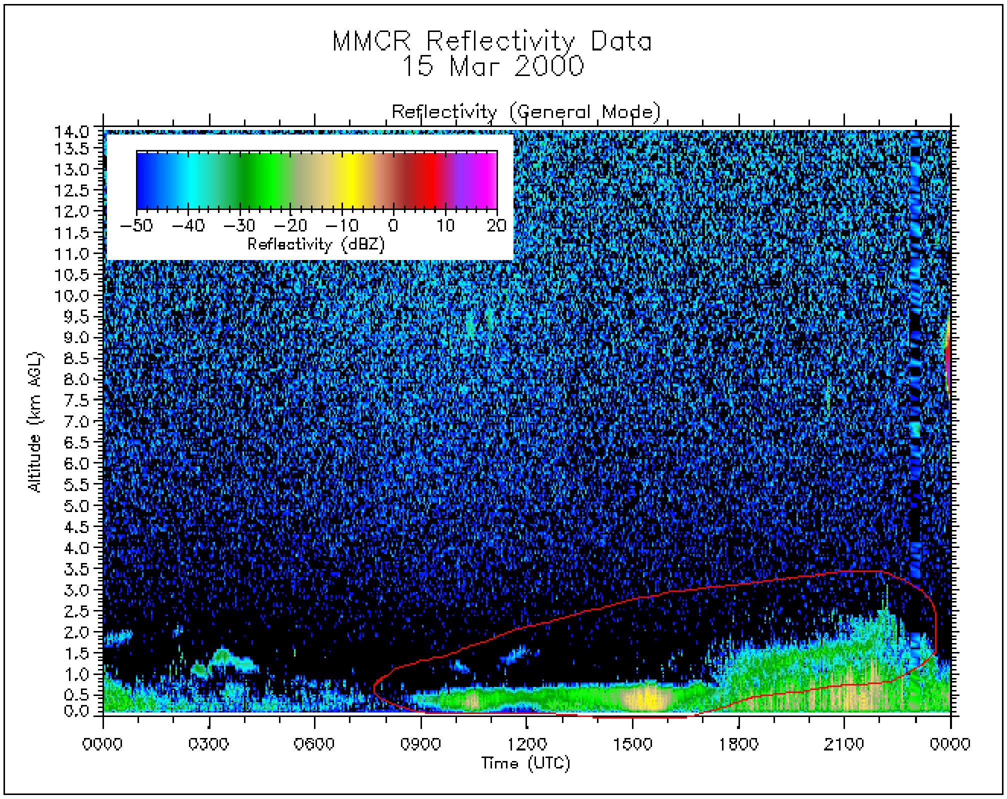

Figure 5. Vertical extent of clouds from the Millimeter-Wavelength Cloud Radar on 15 March 2000, also showing low clouds from 0800 UTC to 2200UTC (image from Atmospheric Visualization Collection, 2003).

4. Statistical Analysis

Statistical comparison of cloud base heights was performed in several stages for both the Central and Blackwell Facilities. The first stage was to compute statistics for all days and times during the IOP (5-21 March 2000) and then perform hypothesis tests. Differences between mean cloud base height for the MPL and BLC at the Central Facility fluctuated from 0.351 km to 11.329 km, yet only two hypothesis tests resulted falsely, both at the 95% confidence level. The likely cause for these results is the standard deviation, S(D). S(D) values ranged from 1.223 km to 5.383 km, which is fairly large. In fact, the two false results occurred on a clear day (20 March 2000) when the MPL was reporting a boundary, and a cirrus cloud episode (9 March 2000) where the BLC was not detecting the clouds.

Statistics for the Blackwell Facility were similar to the Central Facility, however only one hypothesis test gave a false result at both the 95% and 99% confidence levels. The false result occurred on 9 March 2000, where the VCEIL, similar to the BLC, was unable to detect the cirrus clouds. Differences between mean cloud base heights were smaller than those calculated for the Central Facility, but still ranging from 0.088 km to 5.182 km, and standard deviations were large, varying from 0.099 km to 3.657 km.

Linear correlations calculated for each day and time were low, varying from -0.497 to 0.041 at the Central Facility and –0.198 to 0.273 at Blackwell. Scatterplots (not shown) for each day and time revealed no obvious correlation. Therefore, in an attempt to improve the statistical comparison, data were examined to sort out periods of rain, since neither of the instruments are reliable during rain. Also, specific cloud episodes such as cirrus, cumulus, low stratus (bases up to 2 km), and middle stratus clouds (bases between 2 and 5 km) were identified for further statistical comparison. Table 1 lists the days and time periods of each cloud case for each facility.

After separation into cloud cases, the data were screened to account for instrument limitations. Both ceilometers accurately report low clouds, but are inferior to the MPL when detecting high clouds. Therefore, data above 7.35 km (the maximum detectable cloud base height for the BLC) was eliminated. Determining the lower limit proved to be more difficult. Qualitative analysis illustrated that the MPL is less effective in detecting low clouds, and that the lower limit of its detection capabilities lies between 0 and 1 km. In order to determine the lower limit, the mean cloud base height was calculated with the lower limit set to 0 km for every dry day during the IOP and then recorded. The lower limit was then increased by 0.1 km and the mean calculated again. This process was repeated until the mean cloud differed from its original value, in order to determine a threshold where the MPL cannot detect low clouds. This threshold value was determined to be 0.5 km, and data below this was eliminated from the statistical analysis.

Next, a lag correlation analysis was performed for each instrument and cloud case. Lag correlations compare the data from successive time steps. Since data are taken every 30 seconds for the MPL and BLC, and every 15 seconds for the VCEIL, autocorrelations should be fairly high; when this drops to an acceptable level, the analysis determines how far it is necessary to go to find an independent observation. A lag correlation of 0.1 was used as a threshold to locate an independent observation and to calculate an effective number of observations (N/lag). Then, the standard deviation was recomputed using this effective number of observations, and new statistics were calculated.

a. Low Stratus Cases

Statistics calculated for low stratus cases (shown in Table 2) at the Central Facility led to the true hypothesis at the 95% and 99% confidence levels. Differences between mean cloud base height from the MPL and BLC varied between 0.0479 km and 0.6205 km, an improvement from the original statistics. Also, linear correlations improved, now ranging from 0.171 to 0.914. Separating cases where cloud bases are above 0.5 km leads to even higher correlations of 0.84762 and 0.8883. However, standard deviations increased drastically, ranging between 2.004 km to 15.006 km, due to dividing by the smaller effective number of observations.

Hypothesis tests for the Blackwell Facility were similar. Test results were true at both confidence levels, and differences between mean cloud base heights varied from 0.0396 km to 1.049 km. Standard deviations were also very large, ranging from 3.237 km to 25.209 km, but correlations improved, now varying from 0.3371 to 0.4602 when cloud bases below 0.5 km occurred, and 0.8128 to 0.9119 when cloud bases remain above 0.5 km for the entire period. Comparison plots previously revealed that these two instruments perform similarly for low stratus clouds.

b. Cumulus Cloud Cases

There were two outcomes from the statistical analysis of the cumulus cases at the Central and Blackwell Facilities, listed in Table 3. For the flat-based cumulus case, differences in mean cloud base height were small, even smaller than the low stratus case. Also, linear correlations were fairly high, but standard deviations were much smaller than in the above low stratus cases. Hypothesis test results were true for both facilities at both confidence levels.

For the non-flat based cumulus case, differences in mean cloud base height were much larger and agreed with the above low stratus cases for both facilities. The correlation at the Central Facility was high, but much lower at Blackwell. This is due to increased discrepancies in cloud base height between the VCEIL and MPL, as opposed to the BLC and MPL, seen in Figures 6 and 7 (cumulus clouds are occurring in the early half of the day, and the later part is a cirrus case)**.** The BLC and MPL at the Central Facility are reporting similar cloud bases, whereas the VCEIL is reporting a higher base with almost no variation. However, hypothesis tests were true for both confidence levels and both facilities, due to large standard deviations.

c. Cirrus Cases

Statistics for the cirrus cases at both facilities are listed in Table 4. Correlations are extremely low at Blackwell, and much higher at the Central Facility. Differences between mean cloud base heights at the Central Facility agreed closely with the low stratus cases, but are larger at Blackwell. This is probably because the MPL is detecting a boundary at Blackwell on 21 March 2000, which is affecting the mean. Standard deviations were large for these cases as well, so therefore all hypothesis test results were true at both confidence levels.

In addition, statistical comparison of the cirrus case on 13 March 2000 does not fully describe the differences occurring between the instruments at both facilities. It can be seen from Figures 6 and 7 that the cirrus case spans the later portion of the day. The plots for both facilities demonstrate that both ceilometers are reporting a middle cloud base between 1900 UTC and 2000 UTC, yet are unable to detect any of the cirrus clouds above 4.5 km. Since correlations can only be calculated when both instruments are reporting clouds, they do not reflect the inability of both ceilometers in detecting these cirrus clouds.

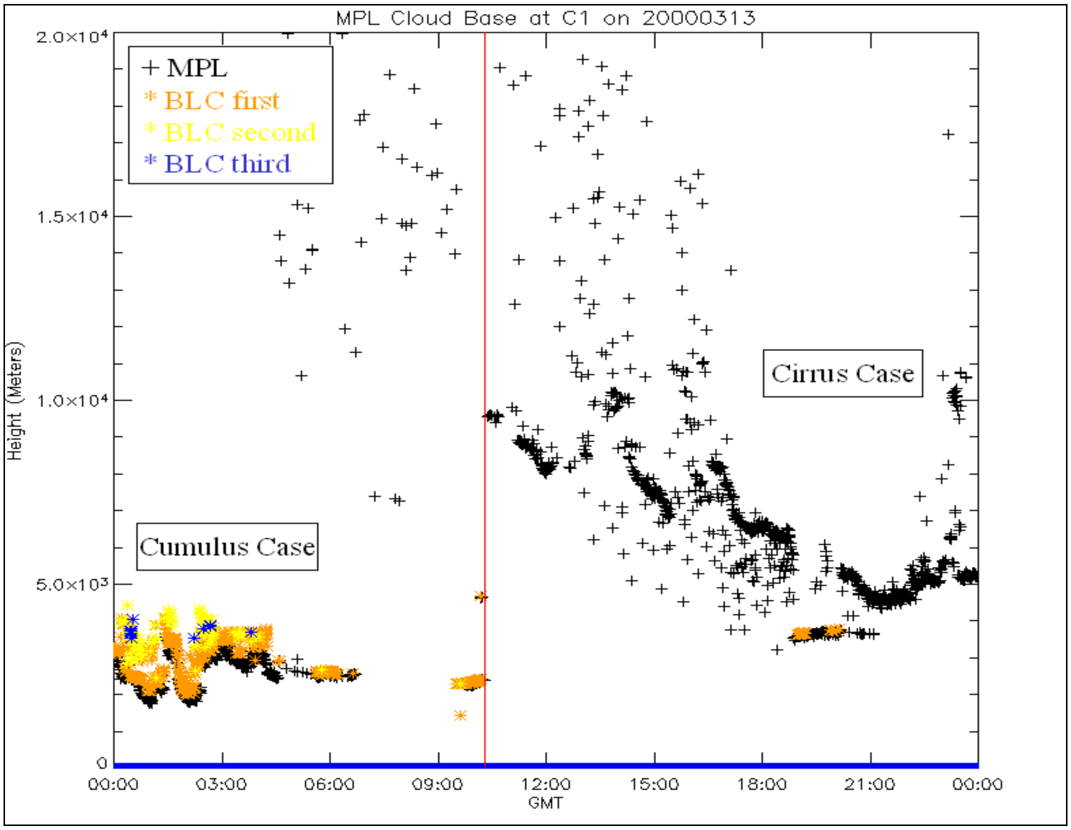

Figure 6. Micropulse Lidar and Belfort Laser Ceilometer cloud base heights at the Central Facility on 13 March 2000, showing both cumulus and cirrus cloud episodes.

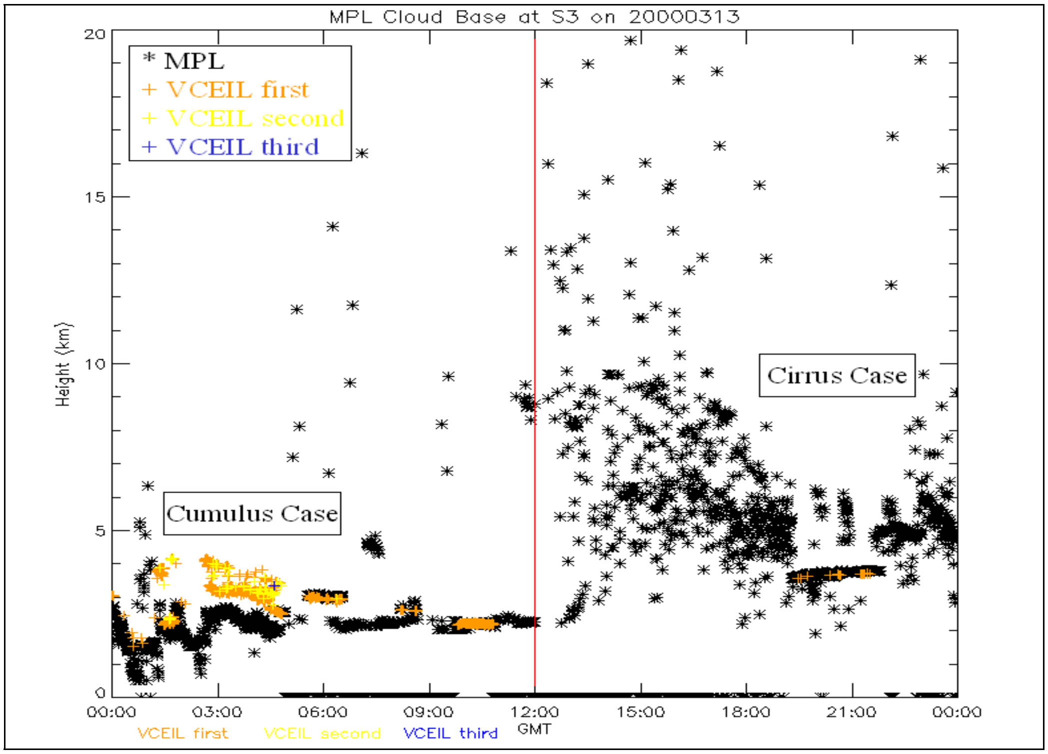

Figure 7. Micropulse Lidar and Vaisala Ceilometer cloud base heights at Blackwell on 13 March 2000, showing both cumulus and cirrus cloud cases.

d. Middle Stratus Case

The VCEIL did not detect the middle stratus clouds that occurred on 12 March 2000, so statistics were not computed for the Blackwell facility. However, the difference between mean cloud base heights for the Central Facility was fairly low, at 0.138 km. Also, the correlation was high, at 0.711. Hypothesis test results were true at both confidence levels, due to a large standard deviation of 8.377 km. However, analysis of the comparison plot revealed that the BLC was only reporting a small portion of the cirrus cloud deck, as seen on Figure 8. This may be due to the high ice content of these clouds, or their small vertical thickness. Overall, the statistics are inconclusive in this case.

5. Quality Control Check

Figure 9 shows an example of a quality control histogram performed for the Blackwell facility on 15 March 2000. Values that are more than three standard deviations away from the mean, are marked in red and circled as outliers. These outliers were also visible on the scatterplot from 15 March 2000, shown in Figure 10. Also, as can be seen from Figure 9, the MPL reports slightly higher than the VCEIL for low cloud bases, indicated by the center of the distribution being slightly off zero to the left. However, the distributions for the MPL and BLC were centered on zero, indicating that these two instruments report low cloud bases at approximately equal heights.

After displaying this data on a plot of cloud base height versus time, it was determined that the values marked in red were outliers and correctly flagged. However, the quality control check did not work for all of the cases. On days such as 13 March 2000, when clouds base heights are visibly unequal, distributions are skewed, and sometimes bimodal. On these days, cloud base heights that were three standard deviations away from the mean were not outliers. Therefore, more refinement would be needed in order to perform a quality control check on cases other than stratus (above 0.5 km, and flat based cumulus).

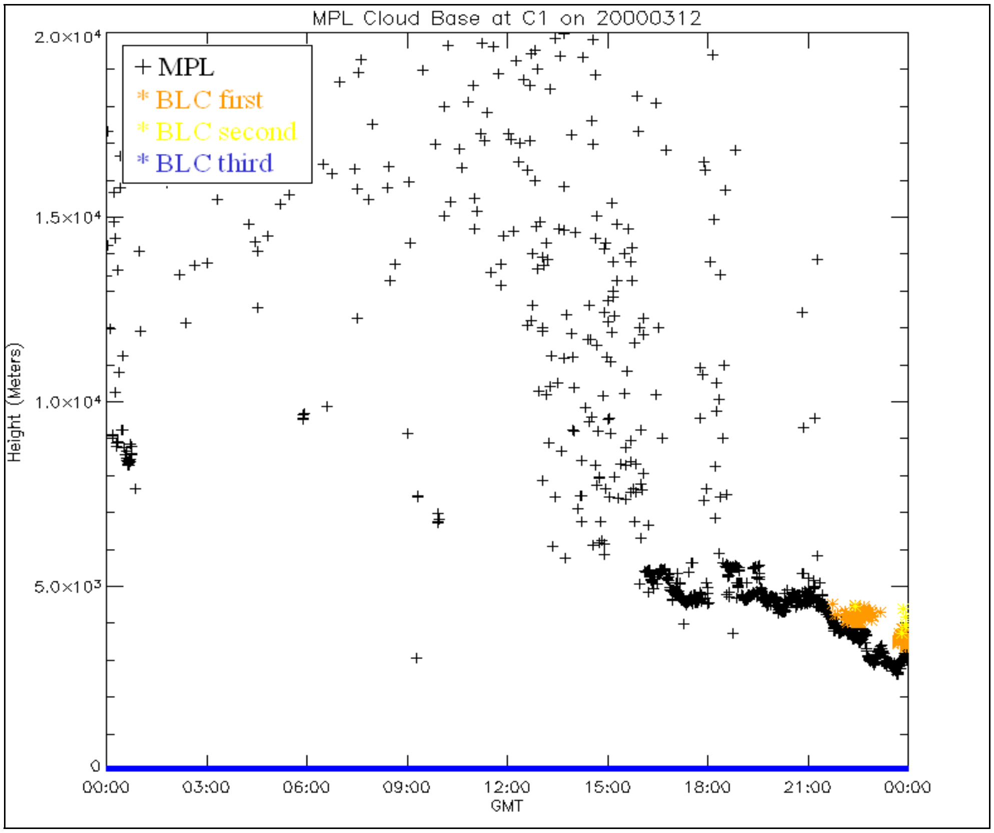

Figure 8. Middle stratus clouds on 12 March 2000, at the Central Facility

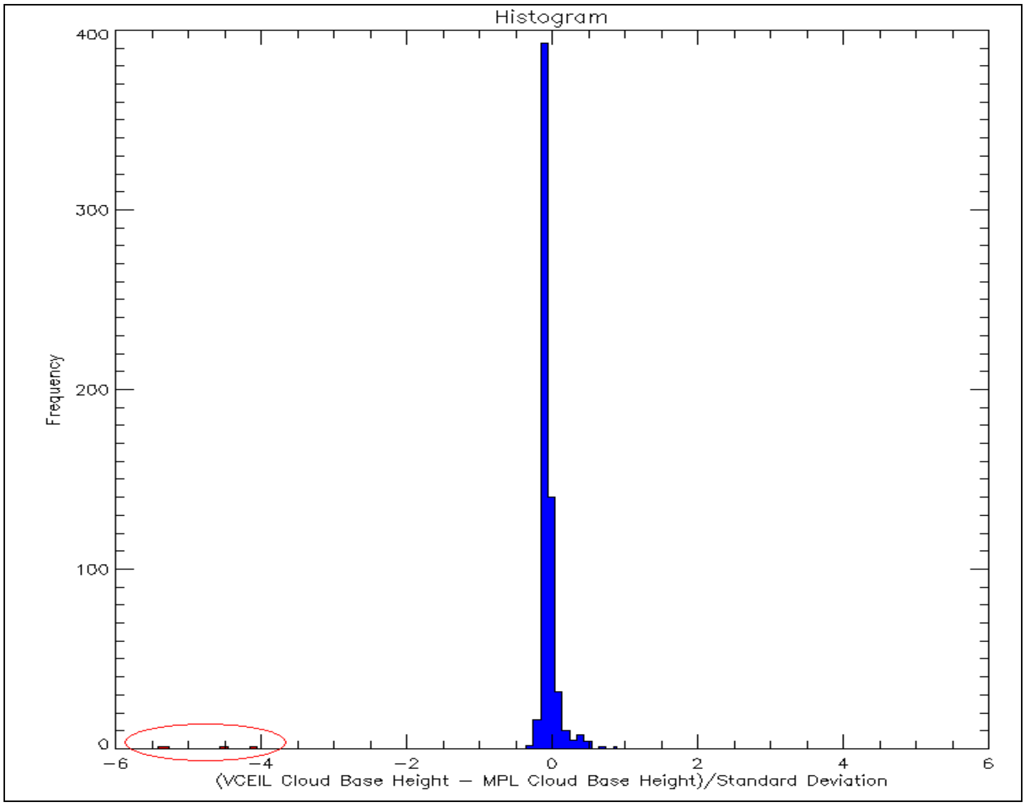

Figure 9. Quality Control Histogram from 15 March 2000, showing outliers

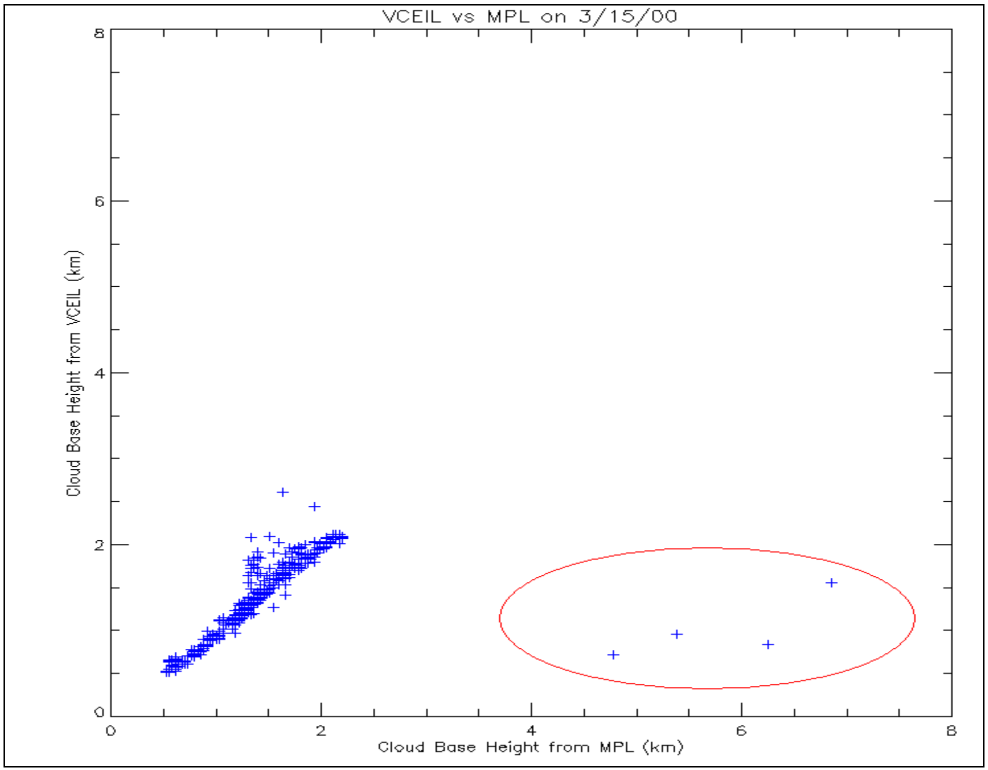

Figure 10. Scatterplot from the Blackwell Facility on 15 March 2000 which shows outliers circled in red.

6. Conclusions

Instruments that measure cloud base heights were compared for two different facilities, the Central Facility (MPL and BLC) and Blackwell Tonkawa Airport (MPL and VCEIL), to gain a greater understanding of when differences occur between these instruments. Qualitative comparison revealed that the MPL is superior to both the Belfort Laser and the VCEIL in reporting the presence of cirrus cloud bases, but inferior in detecting low clouds. This is likely because both ceilometers report clouds as a reduction in visibility to 100 m, and high clouds are generally thinner and don't necessarily affect visibility in the same way as stratus clouds. Also, both ceilometers report jagged cloud bases at a greater height than the MPL, and their ability to detect high clouds is dependent on the ice content of the cloud and the ambient temperature. The MPL reports more scatter than either Ceilometer, and under clear skies, may detect boundaries such as moist or dry layers in the atmosphere.

All three of these instruments perform poorly during periods of rain, as there are too many particles in the atmosphere that interfere with detection of actual cloud bases. However, these instruments are in good agreement with each other and with the MMCR, when reporting flat-based cumulus clouds and stratus clouds below 5 km.

Statistical comparison revealed that differences between mean cloud base heights were small for flat-based cumulus clouds and low stratus clouds above 0.5 km. Correlations were also large (0.8 and above) for these cases, and hypothesis test results were true. However, differences were larger for cirrus cloud episodes, low stratus clouds below 0.5 km, and the nonflat-based cumulus cloud case. Correlations were also much lower for these days, but hypothesis test results were still true due to large standard deviations in all calculations.

In addition, attempts to perform a quality control check revealed that identification of outliers is possible for cases in which cloud bases are in general agreement for both instruments. However, for cirrus and nonflat-based cumulus cases, distributions were skewed and more modification would be necessary in order to discriminate outliers. Furthermore, histograms illustrated that the MPL reports low stratus bases and flat cumulus bases slightly higher than the VCEIL, but in agreement with the BLC. More work would be necessary to complete a quality control check for all days and cloud cases.

In closing, these results address the performance of the MPL, BLC, and VCEIL under specific clouds and springtime weather conditions. Since analyzed data span only one month, instrument functionality may be different during other seasons or under greater ranges of temperature and humidity profiles. Clearly, additional analysis is necessary to evaluate the performance of these instruments for a larger range of conditions.

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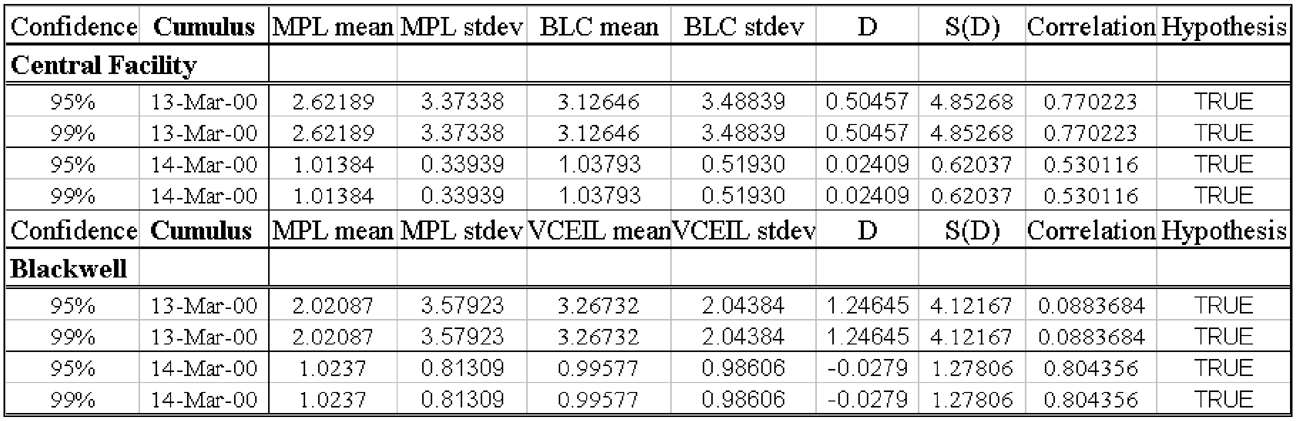
Classification	Case	Time	Hours	Notes
Low Stratus				
	7-Mar-2000	00:00 - 10:00	10	Initial base below 1 km
	15-Mar-2000	09:00 - 22:00	13	Instruments close
	19-Mar-2000	12:00 - 21:00	9	Cloud base < 1 km
	21-Mar-2000	11:00 - 20:00	9	Mostly low, a few middle
Cumulus				
	13-Mar-2000	00:00 - 04:00	4	Non-flat base
	14-Mar-2000	16:00 - 20:00	4	Flat base
Cirrus				
	13-Mar-2000	15:00 - 00:00	9	Two cloud bases
	21-Mar-2000	00:00 - 09:00	9	Boundary at Blackwell
Middle Stratus				
	12-Mar-2000	20:00 - 00:00	4	Central Facility only

Table 1. The dates and times of cloud episodes, for which statistics were calculated, during the Spring 2000 Cloud Intensive Observing Period.

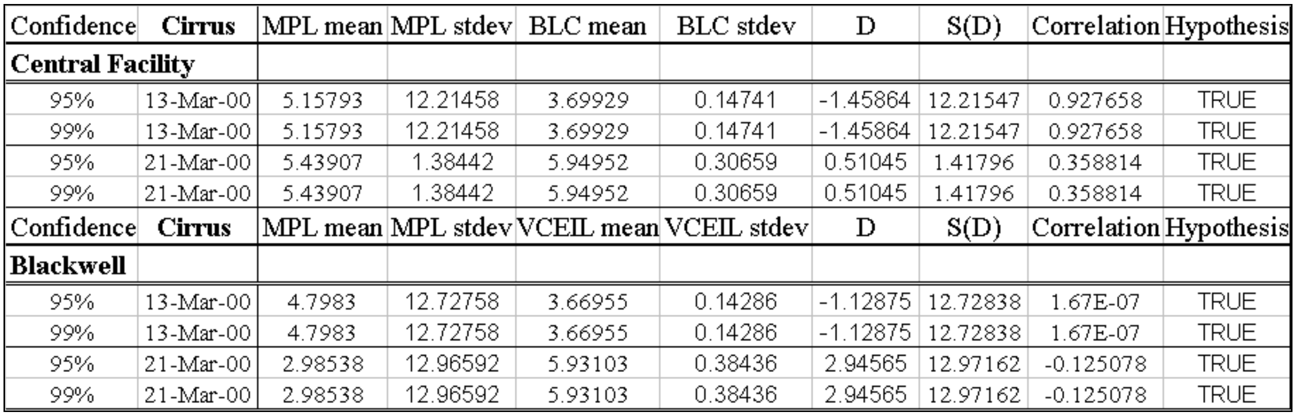
Confidence	Low Stratus	MPL mean	MPL stdev	BLC mean	BLC stdev	D	S(D)	Correlation	Hypothesis
Central Facility									
95%	7-Mar-00	1.49738	1.48463	1.54317	1.34566	0.04579	2.00373	0.84762	TRUE
99%	7-Mar-00	1.49738	1.48463	1.54317	1.34566	0.04579	2.00373	0.84762	TRUE
95%	15-Mar-00	1.73975	14.73754	1.11927	2.82719	-0.62048	15.00627	0.17097	TRUE
99%	15-Mar-00	1.73975	14.73754	1.11927	2.82719	-0.62048	15.00627	0.17097	TRUE
95%	19-Mar-00	0.88795	5.43289	0.605784	0.86126	-0.28217	5.50073	0.34429	TRUE
99%	19-Mar-00	0.88795	5.43289	0.605784	0.86126	-0.28217	5.50073	0.34429	TRUE
95%	21-Mar-00	1.21124	7.53641	1.40606	8.31831	0.19482	11.22461	0.88832	TRUE
99%	21-Mar-00	1.21124	7.53641	1.40606	8.31831	0.19482	11.22461	0.88832	TRUE
Confidence	Low Stratus	MPL mean	MPL stdev	VCEIL mean	VCEIL stdev	D	S(D)	Correlation	Hypothesis
Blackwell									
95%	7-Mar-00	1.60250	2.3545588	1.5629	2.22092787	-0.0396	3.23674	0.91186	TRUE
99%	7-Mar-00	1.60250	2.3545588	1.5629	2.22092787	-0.0396	3.23674	0.91186	TRUE
95%	15-Mar-00	2.14015	25.040435	1.09157	2.91250377	-1.04858	25.20925	0.46024	TRUE
99%	15-Mar-00	2.14015	25.040435	1.09157	2.91250377	-1.04858	25.20925	0.46024	TRUE
95%	19-Mar-00	1.15297	17.006074	0.58509	0.58405182	-0.56788	17.01610	0.33714	TRUE
99%	19-Mar-00	1.15297	17.006074	0.58509	0.58405182	-0.56788	17.01610	0.33714	TRUE
95%	21-Mar-00	1.54914	5.4342911	1.71742	6.65404716	0.16828	8.59115	0.81282	TRUE
99%	21-Mar-00	1.54914	5.4342911	1.71742	6.65404716	0.16828	8.59115	0.81282	TRUE

Table 2. Statistics for low stratus cloud cases at the Central and Blackwell Facilities.



Confidence	**Cumulus**	MPL mean	MPL stdev	BLC mean	BLC stdev	D	S(D)	Correlation	Hypothesis
Central Facility									
95%	13-Mar-00	2.62189	3.37338	3.12646	3.48839	0.50457	4.85268	0.770223	TRUE
99%	13-Mar-00	2.62189	3.37338	3.12646	3.48839	0.50457	4.85268	0.770223	TRUE
95%	14-Mar-00	1.01384	0.33939	1.03793	0.51930	0.02409	0.62037	0.530116	TRUE
99%	14-Mar-00	1.01384	0.33939	1.03793	0.51930	0.02409	0.62037	0.530116	TRUE
Confidence	**Cumulus**	MPL mean	MPL stdev	VCEIL mean	VCEIL stdev	D	S(D)	Correlation	Hypothesis
Blackwell									
95%	13-Mar-00	2.02087	3.57923	3.26732	2.04384	1.24645	4.12167	0.0883684	TRUE
99%	13-Mar-00	2.02087	3.57923	3.26732	2.04384	1.24645	4.12167	0.0883684	TRUE
95%	14-Mar-00	1.0237	0.81309	0.99577	0.98606	-0.0279	1.27806	0.804356	TRUE
99%	14-Mar-00	1.0237	0.81309	0.99577	0.98606	-0.0279	1.27806	0.804356	TRUE

Table 3. Statistics for cumulus cloud cases at the Central and Blackwell Facilities.



Confidence	**Cirrus**	MPL mean	MPL stdev	BLC mean	BLC stdev	D	S(D)	Correlation	Hypothesis
Central Facility									
95%	13-Mar-00	5.15793	12.21458	3.69929	0.14741	-1.45864	12.21547	0.927658	TRUE
99%	13-Mar-00	5.15793	12.21458	3.69929	0.14741	-1.45864	12.21547	0.927658	TRUE
95%	21-Mar-00	5.43907	1.38442	5.94952	0.30659	0.51045	1.41796	0.358814	TRUE
99%	21-Mar-00	5.43907	1.38442	5.94952	0.30659	0.51045	1.41796	0.358814	TRUE
Confidence	**Cirrus**	MPL mean	MPL stdev	VCEIL mean	VCEIL stdev	D	S(D)	Correlation	Hypothesis
Blackwell									
95%	13-Mar-00	4.7983	12.72758	3.66955	0.14286	-1.12875	12.72838	1.67E-07	TRUE
99%	13-Mar-00	4.7983	12.72758	3.66955	0.14286	-1.12875	12.72838	1.67E-07	TRUE
95%	21-Mar-00	2.98538	12.96592	5.93103	0.38436	2.94565	12.97162	-0.125078	TRUE
99%	21-Mar-00	2.98538	12.96592	5.93103	0.38436	2.94565	12.97162	-0.125078	TRUE

Table 4. Statistics for cirrus cloud cases at the Central and Blackwell Facilities.

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