Comparisons of the Micropulse Lidar and the Belfort Laser Ceilometer at the Atmospheric Radiation Measurement Southern Great Plains Cloud and Radiation Testbed Site

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Introduction

The general goal of the Atmospheric Radiation Measurement (ARM) Program is to improve general circulation and related models of the atmosphere for global and regional prediction (DOE 1990). In order to achieve this goal, the ARM Program is collecting a prodigious volume of data at its first Cloud and Radiation Testbed (CART) in the Southern Great Plains of the United States. Some quantities, such as cloud base height, can be measured by a variety of different means. The ARM Program currently has two active systems that provide measurements of the cloud base height, the Micropulse Lidar and the Belfort Laser Ceilometer. This paper provides an initial comparison of these two instruments.

Basic Instrument Information

The Micropulse Lidar (MPL) is an eye-safe instrument that utilizes a laser operating at 2.5 kHz. The signal is averaged in one-minute intervals. The vertical resolution is 300 meters, with the minimum cloud base height detectable at 270 meters above ground level. The maximum altitude at which a cloud can be detected is 15,000 meters. The altitudes given are in the center of the bins.

In addition to reporting cloud base height, the MPL also reports "fog." This condition is triggered by low-level clouds (below the minimum altitude detectable by the instrument), and condensation or obstructions on the window of the instrument.

The Belfort Laser Ceilometer (BLC) is also an eye-safe instrument. It is a laser-based system, where the signal is averaged to produce a sample every 30 seconds. The vertical resolution of this instrument is 10 meters. The lowest altitude at which clouds can be detected is 15 meters, while the maximum altitude is 7800 meters.

Initial Analysis

The time period selected to do the comparisons between the instruments was April 4, 1994, through May 8, 1994. In this window, there were 36,920 MPL samples, of which 13,935 were indicated as clear, 20,262 were indicated as cloudy, and 2,723 were indicated as foggy. Since the BLC has a maximum range of 7800 meters, the MPL cloudy cases were divided into two groups, those above and below 7800 meters. The former were removed from the analysis. Thus there were 4599 measurements that were removed, leaving 15,663 cloudy MPL measurements for analysis, along with the clear and foggy cases. For these samples, we selected the closest BLC observation in time to the MPL observation, with the stipulation that the chosen sample was within one minute of the MPL observation.

As one would hope, when the MPL indicated clear, the BLC agreed 98% of the time. However, the BLC indicated clear when the MPL indicated cloudy 23% of the time. Recall, we are only using the MPL cloudy observations where the cloud base height is less than 7800 meters. The percentage of time this happens tends to increase with MPL altitude; however, since the number of observations in the higher MPL bins is low, it is hard to draw any concrete conclusions here. Plots of the number of MPL observations in each of its cloudy bins and the percentages that the BLC indicates as clear for each MPL bin are given in Figures 1 and 2.

To facilitate the comparison of the cases where both instruments indicated clouds, the BLC data was binned in such

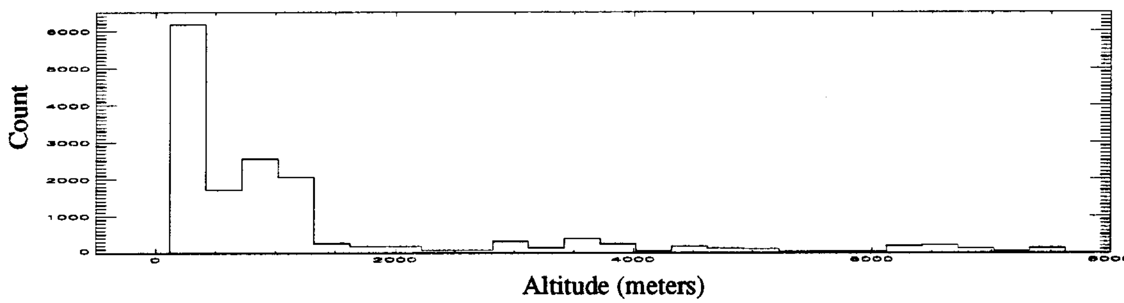

Figure 1. Number of MPL observations in each of its altitude bins - cloudy cases only.

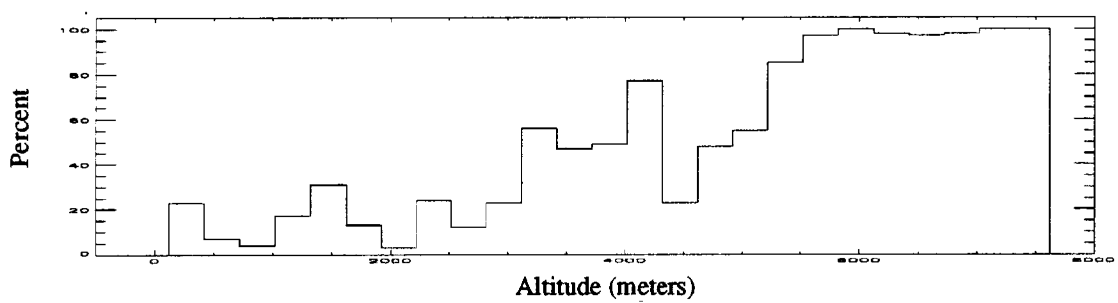

Figure 2. Percentage of BLC observations that are clear in each MPL altitude bin - cloudy cases only.

a way to match the MPL bins. (The lowest BLC bin, instead of ranging from 270 to 420 meters as the MPL does, ranges from 15 to 420 meters.) Then, a confusion matrix was created, comparing the BLC output against the MPL output.

A confusion matrix is a method of comparing two sources of similar quantitative information. It assumes that one method provides the "true" quantity; the other source is then compared to the first to show where it becomes "confused." For each given true quantity, the fraction of the time that the other method reported each of the quantities is calculated. These fractions make up the confusion matrix. If both methods agreed perfectly, then the confusion matrix would be an identity matrix.

Without loss of generality, the MPL was chosen to be "truth." Then for a given MPL height bin, say the one at 570 meters, the percentages of the time-corresponding BLC outputs in each bin are computed. In our example, for the 1709 MPL samples in this bin, the corresponding BLC samples indicated clear 7% of the time, 570 meters 29% of the time, 870 meters 61% of the time, 1170 meters 2% of the time, and 1470 meters for the remaining 1% of the time. A histogram plot of this confusion matrix is given in Figure 3.

If both instruments were operating identically, the highest bars would be down the main diagonal. We can see that there is a trend of this sort. However, there is also a high percentage of cases where the BLC indicates clear when the MPL reports a cloud.

Concentrating only on the cases where both instruments observed clouds, the residuals (BLC - MPL) were plotted. These were organized into bins using the MPL's observed height, thereby remaining consistent with the confusion matrix. The residuals were calculated using the original BLC values (Figure 4). The mean residual was 210.68 meters with a standard deviation about the mean of 335.88 meters. The median residual was 194.82 meters. While the mean and standard deviation do not support the hypothesis that the residuals are not zero, there is visual evidence that the BLC reports clouds slightly higher than the MPL.

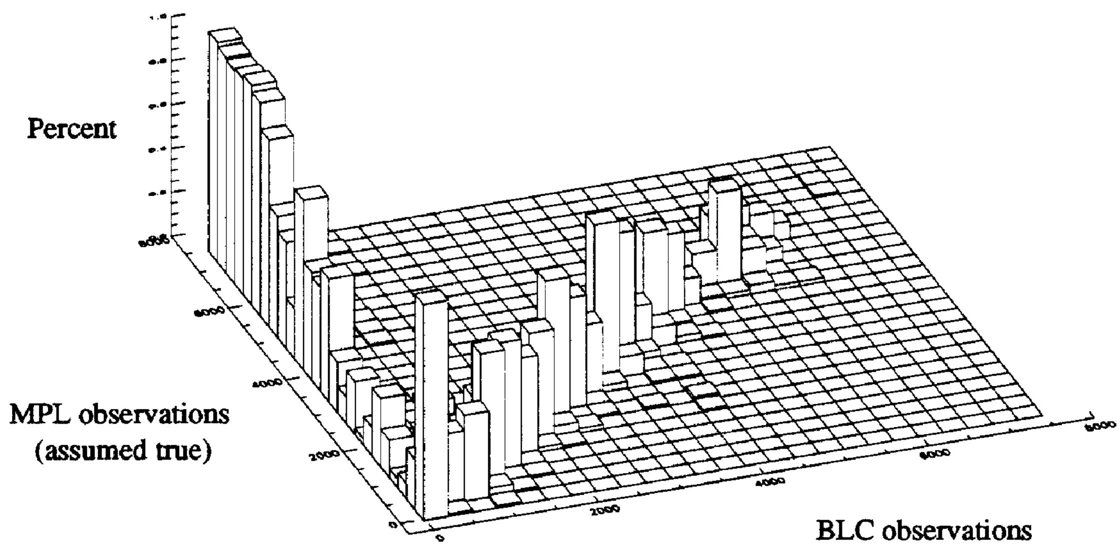

Figure 3. Confusion matrix ofthe BLC measurements against the MPL measurements. The first bin on both the x and y axis (at 0) are for clear samples.

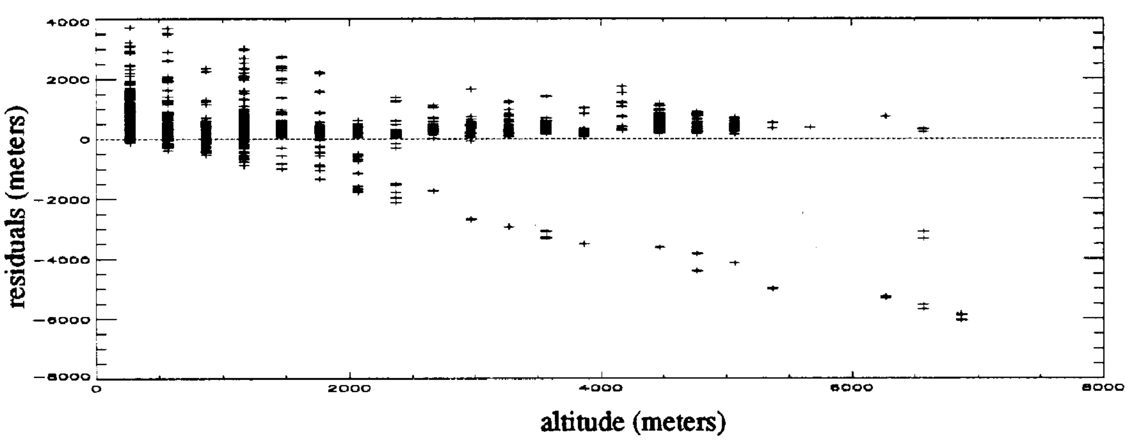

Figure 4. BLC - MPL residuals, grouped into bins by the MPL observations.

The large negative residuals drew attention. For several of these times, both instruments were observing low-level clouds at approximately the same height, but then the MPL seemed to "punch through" the low-level cloud to a higher cloud, while the BLC continued to note the presence of the low-level cloud. After one or two samples, the MPL again started to notice the lower cloud.

Finally, some statistics were gathered about the cases that the MPL indicated as "foggy." Of the 2723 foggy samples, the BLC indicated that 41% of these were clear, 48% were clouds in the 270 meter bin (from 15 meters up to 420 meters), 3% were in the 570 meter bin, and 4% in the 870 meter bin while the remaining 4% were dispersed among the higher bins.

Discussion

There are several items of interest here. First, the two instruments agreed pretty well when the sky is clear. "Cloudy" cases presented some problems, though. The two instruments did not agree well when the MPL sensed mid-level clouds. For these cases, the BLC often reported clear; however, there were a small handful of cases where the BLC reported a cloud significantly lower than the MPL. Of course, the spatial location of the instruments may account for some of these cases. However, it is more likely that this is indicative of the differences in power and sensitivity of the two systems.

The two instruments seemed to agree pretty well for low-level clouds, although there are cases when the BLC reported clear when the MPL reported a low cloud. However, the BLC often reported the cloud base slightly higher than the MPL.

Understanding the cases where the MPL indicates fog is not a trivial matter either. It is complicated because foreign matter on the lens results in the same value as fog. Since fog is usually indicated by the MPL in continuous periods, versus intermittent measurements that have other values dispersed within the period, one is unable to decide whether there was indeed fog from just these two instruments.

Comparisons with other independent methods with similar temporal and vertical resolution should help to illuminate these issues, and perhaps help identify the strengths and weaknesses of each of these two instruments. Possible candidates include the raman lidar and the cloud radar, both of which were at the CART site during this period.

Conclusion

Cloud base height is an important input in many atmospheric and general circulation models, and getting an “accurate” estimate of this value is critical. While this initial work shed little light on the strengths and weaknesses of the two instruments, it does point out areas that need further analysis. The two instruments certainly do not perform identically. Utilizing other methods to constrain or estimate the cloud base height is essential to help determine the capabilities of both of these instruments.

Reference

U.S. Department of Energy (DOE), 1990: *Atmospheric Radiation Measurement Program Plan*, DOE/ER - 0441, U.S. Department of Energy, Washington, D.C.