P2.5 EVALUATION OF AN MPL CLOUD DETECTION ALGORITHM AS A REFERENCE FOR CEILOMETER TESTING WITHIN THE ASOS PI PROGRAM

Aaron J. Poyer*
Science Applications International Corporation
Sterling, VA. 20166

1. INTRODUCTION

The current standard cloud height indicator (CHI) for the Automated Surface Observing System (ASOS) is the National Weather Service (NWS) CT12K laser ceilometer (CT12K). This ceilometer detects clouds to a height of approximately 12,000 feet.

In late 1998, the manufacturer discontinued production of the CT12K. The vendor agreed to support the existing ASOS ceilometers through 2007. New ceilometers will need to be deployed to the ASOS network starting by the end of 2007. To support the acquisition and qualification of a replacement ceilometer, which is now specified with a range of 25,000 feet (Poyer, 2006), it was determined that a research LiDAR (Light Detection And Ranging) sensor would be necessary to establish reference cloud heights for assessment of the candidate replacement ceilometer (Poyer, 2007a). The ASOS PI Program has acquired a Micro Pulse Lidar (MPL), which has algorithms capable of cloud base detection beyond the specified range of the ASOS replacement ceilometer.

The MPL Cloud Detection Algorithm was compared to the cloud detection of the NWS CT12K under conditions with uniform, non-ragged cloud bases. A statistical analysis of reported cloud heights was conducted to ensure that the definitions of the lowest cloud bases in terms of rate-of-extinction/penetration depth are comparable between the two instruments. Comparisons of cloud bases detected by the MPL's cloud detection algorithm were compared to cloud bases reported by the reference as a means to validate the MPL as an independent reference for measuring cloud height and coverage. Cases were collected in all conditions.

All analysis was performed using the human verified reference data available for each time period and individual event. Data analysis was performed utilizing post processing software and statistical analysis spreadsheet software to conduct a mathematical comparison between the heights reported from the MPL cloud detection algorithm and those from the human verified reference sensor. Events were grouped based on the type of weather occurring during the event. These groups include periods with precipitation of varying intensities and type, as well as periods with no precipitation.

* Corresponding author address: Aaron J. Poyer,
NOAA NWS Sterling Field Support Center
43741 Weather Service Rd, Sterling, VA 20166
e-mail: aaron.poyer@noaa.gov

2. TEST APPROACH

2.1 Test Location

Testing was conducted at the Sterling test site Sterling, Virginia operated by the NWS Sterling Field Support Center. Thirty-second data were collected from all test sensors using a personal computer based data acquisition system (DAS). Data from in-situ human observations and all ASOS sensors at Sterling were available for use in post-processing.

2.2 Sensors

2.2.1 NWS CT12K Laser Ceilometer

The CT12K, Figure 1, the standard ASOS cloud height indicator, along with human observers was used as the primary reference during this phase of the testing. The CT12K uses a dual lens arrangement to determine cloud base height; one optical path for the transmitter and a separate optical path for the receiver. The transmitter is a Gallium Arsenide (GaAs) pulsed semiconductor diode, operating at a wavelength of 904nm. The receiving unit is a Silicon Avalanche photodiode with an interference filter centered at 904nm. The sensor is equipped with a heater/blower unit to prevent snow and ice accumulation on the window glass of the instrument cover. The CT12K was certified for use by the NWS as a result of testing in 1989-1990 (NWS1990).

Figure 1 NWS CT12K Laser Ceilometer

2.2.2 Sigma Space MPL-4B-527 Micro Pulse Lidar

The MPL-4B-527 Micro Pulse Lidar, Figure 2, uses a single lens arrangement to detect cloud bases. The single lens is shared by both the transmitting and receiving units. The transmitter is a neodymium yttrium lithium fluoride (Nd:YLF) pulsed laser diode, operating at a wavelength of 527nm. The receiving unit is a 178mm diameter Maksutov Cassegrain telescope with a focal length of 2400mm which collects received energy to a Silicon Avalanche photodiode for photon counting. The sensor is installed in an environmentally controlled enclosure, Figure 3, containing the laser, the laser controller, and the data acquisition systems. A climate control system (HVAC) is mounted externally and connected by a duct to provide heating and cooling to maintain an operationally acceptable temperature range. The HVAC unit and electronically controlled Kapton® strip heaters, mounted to the interior of the window glass, are used to reduce fogging and moisture build-up on the glass. The ASOS PI team added an external blower to assist in clearing the window glass of dust, remnant precipitation, and other environmental debris. The MPL-4B-527 has an advertised maximum range of 196,850 feet above the surface.

Figure 2 Sigma Space MPL-4B-527

Figure 3 Sigma Space MPL-4B-527

3. TEST METHODOLOGY AND DATA ANALYSIS

The purpose of this test was to compare cloud bases detected by the MPL's cloud detection algorithm cloud bases reported by the available references as a means to validate the MPL for use as an independent reference for measuring cloud height and sky cover during evaluation of NWS candidate ceilometers.

3.1 Difference Between Reported Cloud Base Height

This metric determines the difference between the lowest reported cloud base height from the MPL and the references (Human/Pilot Balloon, NWS CT12K/Human). A positive number is representative of a higher cloud base being reported by the MPL, with a negative number being the converse.

Difference = MPL CBH – Reference CBH

CBH = reported Cloud Base Height (feet above ground), this refers to either the sensor reported cloud base height or the human observed cloud base height.

3.2 Data Analysis

All analysis was performed using the human-verified reference data available for each individual event. Data analysis was performed utilizing standard statistical methods. Events were grouped based on the type of weather that occurs during the event. These groups included events with no precipitation, and events with precipitation (rain, drizzle, freezing rain, and freezing drizzle, ice pellets or snow). A separate comparison was also performed on the entire data set with all events included.

All cloud base heights used in the comparison utilized the existing CT12K reference ceilometers for data comparison. Event logs, when observers were present for other observational duties, were kept to note any situations of interest and any visible phenomena which may have altered the performance of the sensors from a mechanical or environmental standpoint were photographed, when possible.

4. RESULTS

The MPL at the Sterling test site was compared to the reference and analyzed using the metric in section 3.1 (Difference Between Reported Cloud Base Heights). In addition to the analysis of the cloud detection algorithm, performance of the system was monitored for anomalous behavior.

During the test period the MPL was configured in the Co-Polarization mode. It was discovered that this mode resulted in artificial (false positive) cloud "hits" due to nocturnal boundary layer and other meteorological phenomena involving high levels of moisture within 2 Kilometers of the surface, particularly in the overnight and early morning hours. The MPL is capable of running in two modes, co-polarization, used for this test, and a mode utilizing a liquid crystal digital interface as a means of polarizing the signal both linearly and circularly, one scan for each polarization alternating every 30-seconds. Based on the findings of this test the MPL was switched to an alternating polarization mode. The use of this polarization option has shown the potential to reduce the number of false positives during events with high amounts of low and midlevel moisture. With a decrease in the impact of these conditions the comparability of the MPL's cloud detection algorithm to reference cloud measurements may be greatly increased. The need for an automated reference for further evaluation of the ASOS replacement ceilometer warrants further study of the impact that polarizing the MPL's signal has on the MPL's reported cloud height values. Note: data available was minimal above 12,000 feet for this test due to the limited number of observer verified time periods collected, future analysis will include a greater number of human observations for heights throughout the range of the ASOS replacement ceilometer.

The data was separated into three height categories: below 2,000 feet; 2,000 to 12,000 feet; and above 12,000 feet. Data was further separated into days with no precipitation occurring and days where precipitation occurred at any point during the day (000000 LST to 235930 LST) regardless of precipitation type, intensity or duration. Data was only compared when both the reference and the MPL were reporting a cloud height.

Table 1 represents the total number of 30-second samples, 73,097, and the percentage, 60.54%, of samples which were within 10% of the reference cloud heights reported for all days during the entire testing period.

Table 2 represents the number of 30-second samples, 35,986, and the percentage, 62.42%, of samples which were within 10% of the reference cloud heights reported during non-precipitation days over testing period.

Table 3 represents number of 30-second samples, 37,111, and the percentage, 58.71%, of samples which were within 10% of the reference cloud heights reported during precipitation days over the entire testing period.

5. CASE STUDY

During the 2007 winter season, The MPL was monitored for performance of interest regardless of whether it fit the categories used for the MPL's cloud detection algorithm evaluation.

	< 2,000 FEET	2,000 – 12,000 FEET	> 12,000 FEET	TOTAL
TOTAL SAMPLES	2,056	69,990	1,051	73,097
DIFFERENCE < 10%	0	44,101	152	44,253
PERCENT < 10%	0.00%	63.01%	14.46%	60.54%
DIFFERENCE > 10%	2,056	25,889	899	28,844
PERCENT > 10%	100.00%	36.99%	85.54%	39.46%

Table 1 Comparison between MPL and all available references during all available days.

	< 2,000 FEET	2,000 – 12,000 FEET	> 12,000 FEET	TOTAL
TOTAL SAMPLES	574	34,669	743	35,986
DIFFERENCE < 10%	0	22,344	120	22,464
PERCENT < 10%	0.00%	64.45%	16.15%	62.42%
DIFFERENCE > 10%	574	12,.325	623	13,522
PERCENT > 10%	100.00%	35.5%	83.85%	37.58%

Table 2 Comparison between MPL and all available references during non-precipitation days.

	< 2,000 FEET	2,000 – 12,000 FEET	> 12,000 FEET	TOTAL
TOTAL SAMPLES	1,482	35,321	308	37,111
DIFFERENCE < 10%	0	21,757	32	21,789
PERCENT < 10%	0.00%	61.60%	10.39%	58.71%
DIFFERENCE > 10%	1,482	13,564	276	15,322
PERCENT > 10%	100.00%	38.40%	89.61%	41.29%

Table 3 Comparison between MPL and all available references during precipitation days.

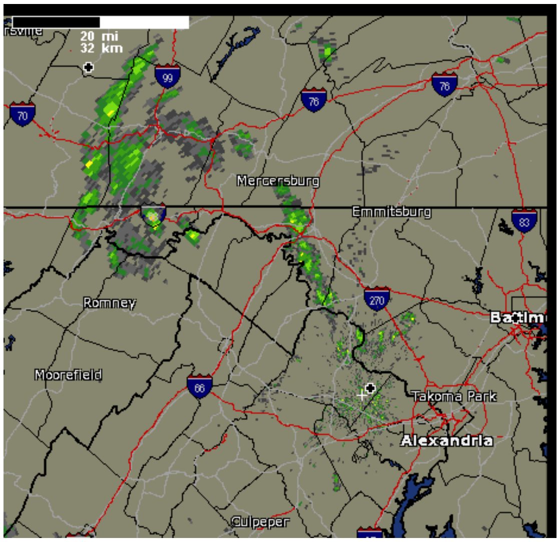

Figure 4 Sterling, VA. NEXRAD 06:05EDT 07/27/07

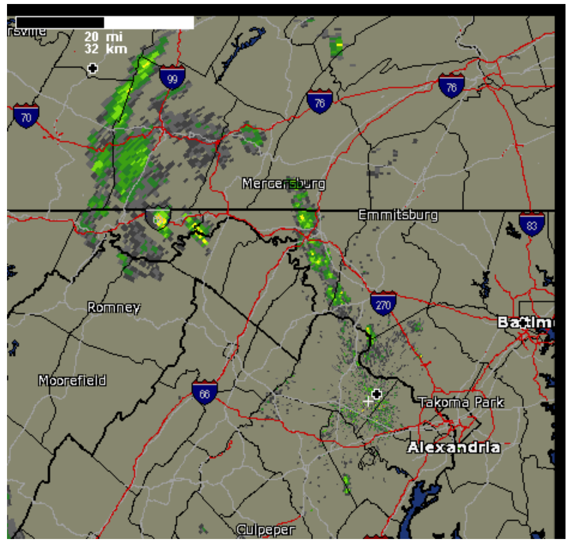

Figure 5 Sterling, VA. NEXRAD 06:09EDT 07/27/07

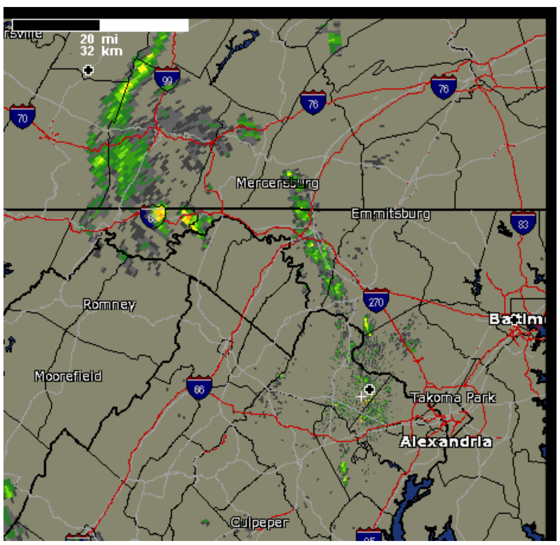

Figure 6 Sterling, Virginia. NEXRAD 06:14EDT 07/27/07

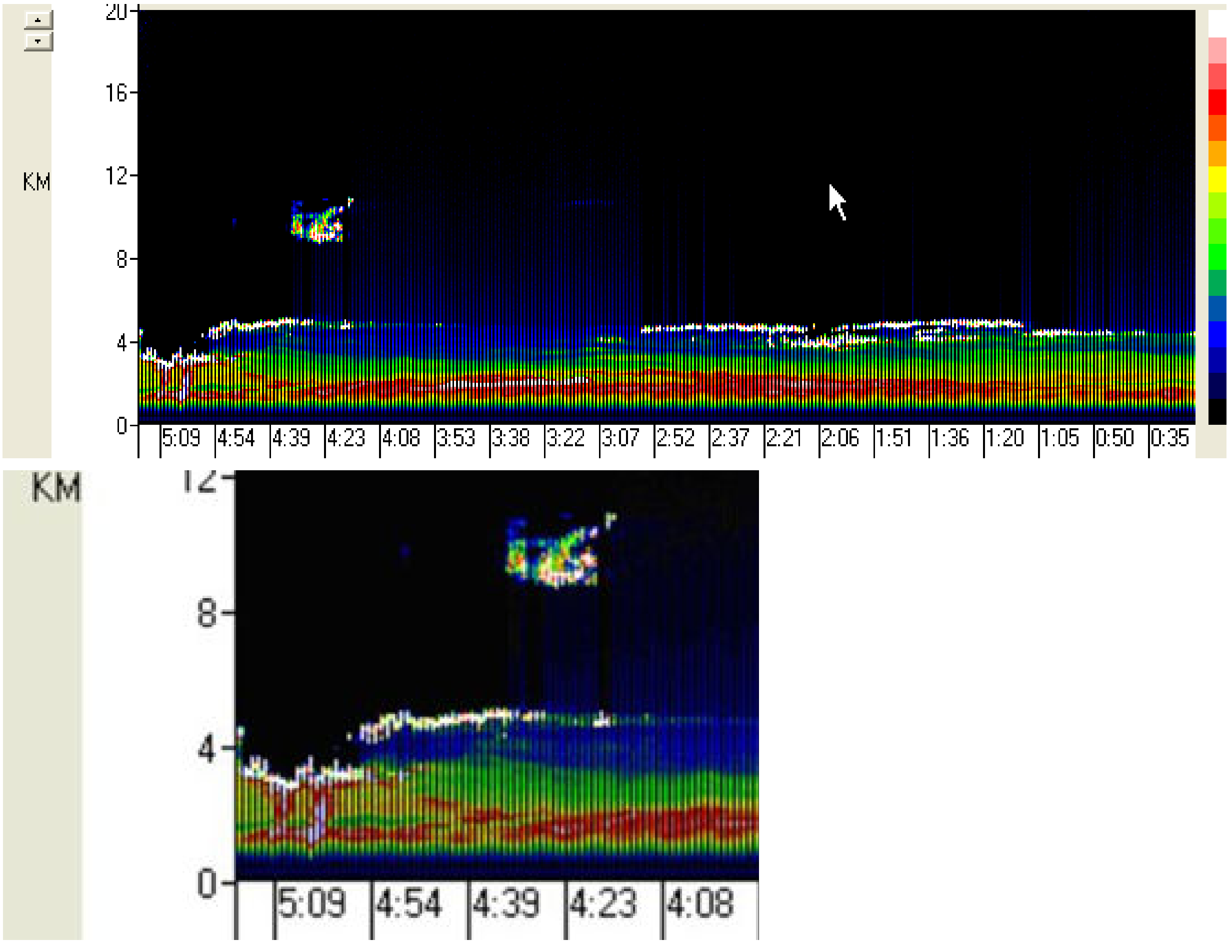

Figure 7 MPL Graphical display of backscatter morning of 07/27/07

This case study shows the MPL's ability to pick up minute detail in fast moving weather phenomena. A rapidly advancing cold front was tracking toward Sterling on the morning of July 27, 2007. This particular situation had rapidly lowering clouds which rose as quickly as they came. Precipitation was in the form of virga from this system and never reached the ground. The MPL range normalized backscatter graphical display, Figure 7, shows the change in cloud heights and moisture due to the frontal passage, timed nearly precisely with the co-located NWS Sterling (LWX) NEXRAD radar, Figures 4-6. While the MPL's cloud detection algorithm may not be as directly usable as was originally hoped, the abilities of the backscatter profile to detect such a fast moving feature are very promising. The ability of the MPL to detect this change in clouds and moisture gives the observer one more tool to assist in real-time cloud observations in support of the ASOS replacement ceilometer evaluation.

6. CONCLUSIONS

Overall evaluation testing of the Sigma Space Micro Pulse Lidar Cloud Detection Algorithm yielded 73,097 samples of data for a total of 36,549 minutes. The main goal of this evaluation was not met, however the experience gained through this test has lead to a potential solution through the use of the polarization mode available in the MPL's setup. Further testing will need to be completed to verify whether the polarized mode increases the comparability of the MPL's cloud base reports.

6.1 Difference Overall

The MPL cloud detection algorithm detected cloud base heights to within 10% of the reference 60.54% of the time.

6.2 Difference Non-Precipitation Days

The MPL cloud detection algorithm detected cloud base heights to within 10% of the reference 62.42% of the time when no precipitation was recorded during the testing day.

6.3 Difference Precipitation Days

The MPL cloud detection algorithm detected cloud base heights to within 10% of the reference 58.71% of the time when precipitation was recorded during the testing day.

6.4 Divergent Results

Performance of the MPL below 2,000 feet is suspect due to the minimum operational range of the sensor; therefore the values at this level are not necessarily meaningful. The percent difference for cloud detection above 12,000 feet may be biased by the ability of the MPL to better detect cloud bases above 12,000 feet than the current ASOS 12,000 feet ceilometer, (the raw scans of the CT12K can be as high as 12,500) which is at the maximum extent of its operational range.

7. RECOMMENDATIONS

Follow-on testing during the Fall 2007 through Winter/Spring 2008 will address the problems associated with the divergent data due to changing the operating mode of the MPL to utilize an alternating polarization which in preliminary exploration has shown to greatly reduce the number of false layers reported due to areas of high moisture near the surface, as well as temperature inversions associated with the nocturnal boundary layer. Analysis of the backscatter utilizing a modification of the Klett lidar inversion analysis (Gaumet, 1998) is also being explored as an alternative to the MPL's installed cloud detection algorithm.

During the testing phase it was decided that a blower should be installed to assist in clearing the window glass of precipitation and environmental contaminants. A blower was fabricated and attached to the exterior of the environmental enclosure on July 3, 2007. This should increase the detection capability during periods of light precipitation from mid-level clouds and during periods of dust settling from the ongoing construction projects both on-site and at the adjacent Dulles International Airport.

The improvement in reference data resolution will be addressed by utilizing more human observations which will increase the low number of comparisons available for heights greater 12,000 feet. This enhancement in dataset availability will be accomplished by increasing schedule coordination between all interested parties at the Sterling facility. Case studies of interesting events and situations will also be utilized to gain a greater knowledge of the MPL's potential as an automated cloud height reference through various techniques.

8. ACKNOWLEDGMENTS

This work was sponsored by the National Weather Service ASOS Program under Contract Number 50-DGNW-6-90001. Opinions expressed in this paper are solely those of the authors, and do not represent an official position or endorsement by the United States Government.

I would like to thank Richard Lewis, NWS, Jennifer Dover, SAIC, and Christopher Greeney, SAIC, for observations that supported the evaluation for this testing period. I also would like to dedicate this paper to the memory of Michael Salyards, NWS, for his numerous contributions to this and other ceilometer related testing.

REFERENCES

National Weather Service, 1990: K220 Phase II Test Final Report. Functional Performance Test of the Vaisala 12K Laser Ceilometer, June 1989 to February 1990. NWS Test & Evaluation Branch, Sterling, VA., Oct. 16, 1990. 101pp.

Gaumet, J.L., Heinrich, J.C., and Cluzeau, M., 1998: Cloud-Base Height Measurements With a Single-Pulse Erbium-Glass Laser Ceilometer. J. Atmospheric and Oceanic Technology, 15, 37-45.

O'Connor, E.J., Illingworth, A.J., and Hogan, R.J., 2004: A Technique for Autocalibration of Cloud Lidar. J. Atmospheric and Oceanic Technology, 21, 777-786.

Poyer, Aaron, Final Report for Assesment of Commercial-Off-The-Shelf Laser Ceilometers. SAIC/NWS, 2006.

Poyer, Aaron, Test Plan for Specification Compliance Testing of ASOS Replacement Ceilometer, 2007a. SAIC/NWS, 2007.

Poyer, Aaron, Final Report for Comparison Between Micro Pulse Lidar and Cloud Detection References Winter-Summer 2007. SAIC/NWS, 2007b.

Wauben, Wiel M.F., Automation of Visual Observations at KNMI; (II) Comparison of Automated Cloud Reports With Routine Visual Observations; The Symposium on Observations, Data Assimilation, and Probabilistic Prediction, 13-17 January 2002, Orlando, FL J.3.2.