# Universal Algorithm Implementation to Commercial Ceilometers

Julianna Posey[1], Ruben Delgado[1], Vanessa Caicedo[2]
[1] University of Maryland, Baltimore County, Department of Mechanical Engineering, Baltimore, MD, USA
[2] Joint Center for Earth Systems Technology, Baltimore, MD, USA

## Introduction

- A radiative diurnal surface heating cycle directly influences the mixing of particles in the lowest part of the troposphere. This zone, characterized by its contact with the earth's surface, is called the planetary boundary layer (PBL).
- A ceilometer is a ground-stationed remote sensing device that employs LIDAR systems to report cloud layer heights and aerosol backscatter within the PBL.

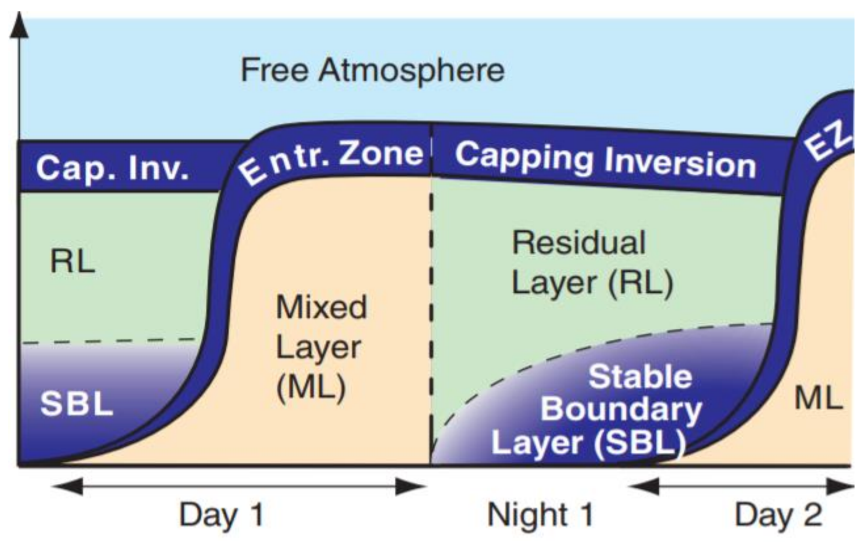


**Figure 1.** PBL dispersal over one diurnal cycle. (Stull, 2000)

## Objective

The implementation of commercial ceilometers (Vaisala, Lufft, and Campbell) and their respective software in gathering atmospheric aerosol backscatter and mixing layer height (MLH) data has resulted in a variety of inconsistencies due to temperature dependencies, unrealistic signals, and background noise. With the application of universal algorithms for retrieval, the ceilometers assessed can be considered suitable to provide consistent national air quality monitoring.

## Methods

- Aerosol backscatter data was collected from ceilometers in the Baltimore-Washington area.
- Signals were initially processed through firmware and software unique to each ceilometer in order to correct background noise, range, and overlap.
  - Lufft CHM15k: Lufft Viewer
  - Campbell Scientific CS135: Viewpoint
  - Vaisala CL 51: BL-View
  - Vaisala CL31 : CL-View
    - CL-View only retrieves cloud height data– a vendor Matlab algorithm for transforming to MLH data was not available for this study.
- Additional improvements were applied for further corrections and enhanced quality:
  - Cloud signals were identified and removed prior to MLH retrieval.
  - SBLs and RLs were identified and retrieved through height detection limits.
  - A continuation parameter prevented atypical significant jumps in MLH.
- Automated methods for commercial MLH retrieval were compared to MLHs retrieved from radiosonde data.
- MLHs were retrieved again from the commercial data through three automated methods:
  - Haar Wavelet Transform
  - Second Derivative
  - Cluster Analysis

## Ceilometer Mechanics

The Vaisala and Campbell ceilometers employ similar LIDAR single-lens designs. The lens is an inclined mirror with a central hole. A laser emits a pulse of light and particulates/aerosols (e.g. $PM_{2.5}$, dust, smoke, clouds) in the atmosphere scatter the light. Backscatter light transmits through the hole and is returned to the sensitive photo receiver by reflecting from the outside edges of the mirror.

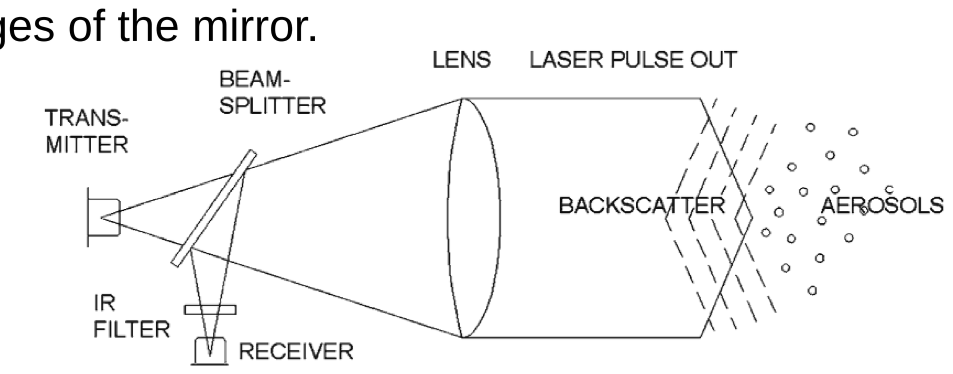


**Figure 2.** Single-lens component design. (Münkel, et al., 2007)

## Commercial Firmware

To retrieve raw aerosol backscatter, each ceilometer has a specific firmware and software to collect layer heights while correcting noise and overlap. Detection improvement is not immediately available because users cannot manipulate the firmware's retrieval. However, users must select the MLH from the aerosol layers.

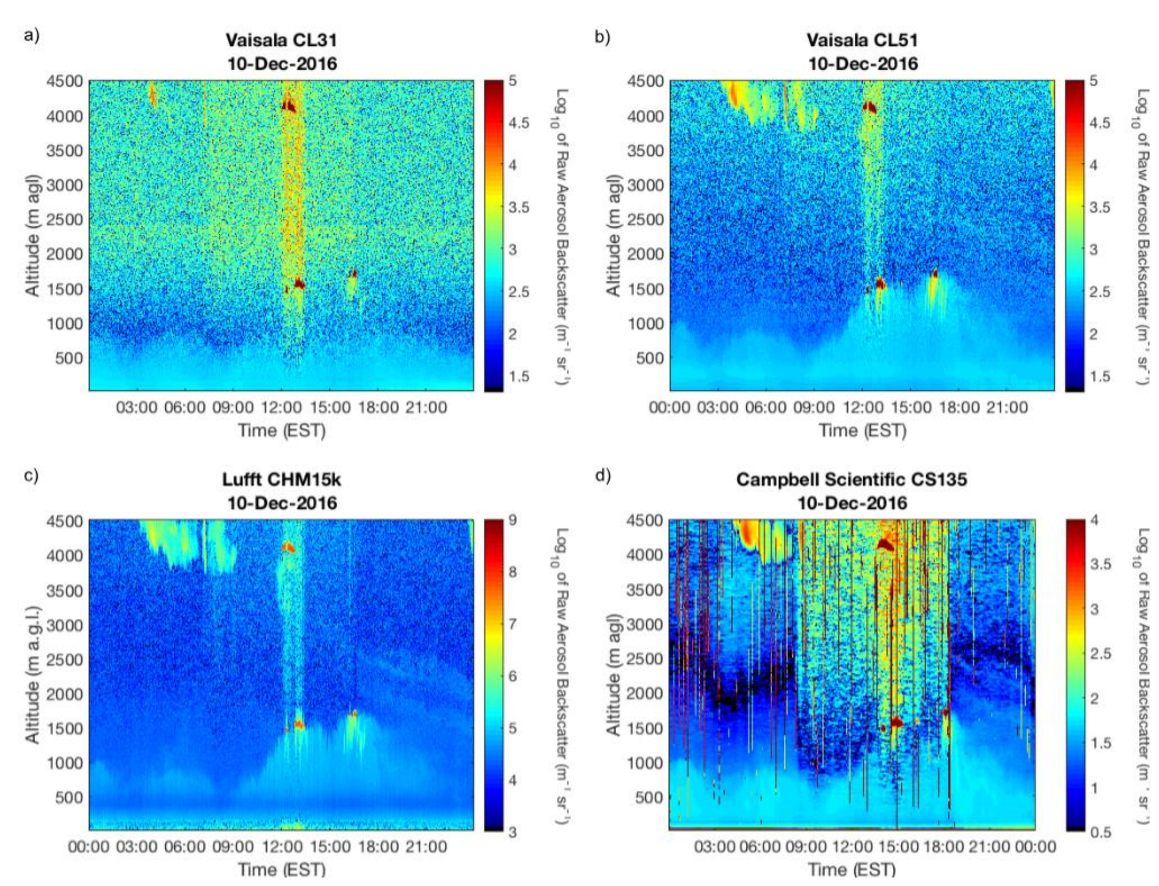


**Figure 3.** Firmware-only retrieval, December 10, 2016.

All LIDAR systems encounter an overlap in a zone near the surface. This is due to distorting geometric and optical effects from the laser beam not overlapping with the the telescope field of view.

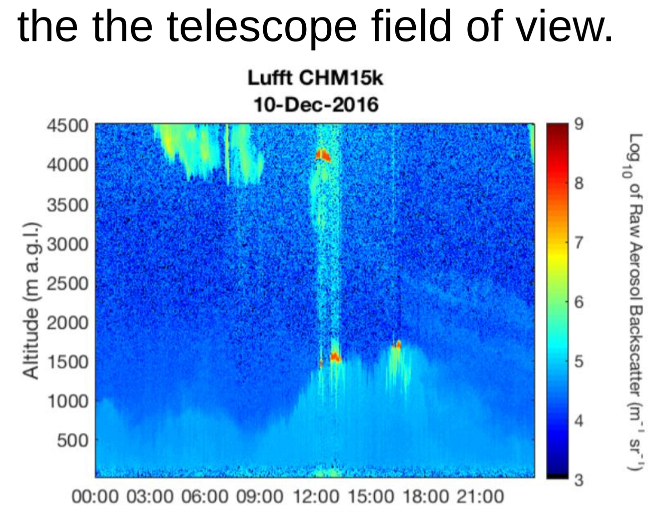


**Figure 4.** New overlap function visual for Lufft retrieval (Fig. 3c). Note the visible correction at altitudes of 350-500m.

In Figure 3c, significant overlap effects were evident. A new Lufft overlap function to correct the reported backscatter signal was required. This function was found to be influenced by ambient temperature changes. An automated homogeneous correction function (Hervo et al. 2016) was applied to the manufacturer function for further corrections to seasonal fluctuations, as shown in Figure 4.

## Results

**Table 1.** Correlation of commercial retrieval software to radiosonde PBL retrievals through comparison of detected thermal inversion locations.

| Ceilometer | Reporting Time | No. Layers |
|---|---|---|
| CL51 | 16 seconds | 3 |
| CHM15k | 15 seconds | 3 |
| CS135 | 2-120 seconds (varied) | 3 |
| **Ceilometer** | **PBL mid/top** | **R²** |
| CL51 | $y = 0.67 \pm 0.1x + 162.95 \pm 143$ | 0.61 |
| CHM15k | $y = 0.49 \pm 0.1x + 440.45 \pm 113$ | 0.51 |
| CS135 | $y = 0.59 \pm 0.1x + 227.9 \pm 98.1$ | 0.64 |
| **Ceilometer** | **PBL base** | **R²** |
| CL51 | $y = 0.57 \pm 0.14x + 509.96 \pm 146$ | 0.38 |
| CHM15k | $y = 0.58 \pm 0.10x + 554.8 \pm 106$ | 0.46 |
| CS135 | $y = 0.73 \pm 0.01x + 265.4 \pm 79$ | 0.72 |

Low correlations for all ceilometers in the identification of the middle and top of the PBL were found to be a result of large cloud signals. MLHs can be misidentified by the automated algorithms due to large gradients above clouds and the algorithm's inability to differentiate between a stable PBL and a convective PBL.

Campbell had the highest correlation for mixing layer heights– however, significant artifacts and noise were evident in raw aerosol backscatter visuals, as shown in Figure 5a.

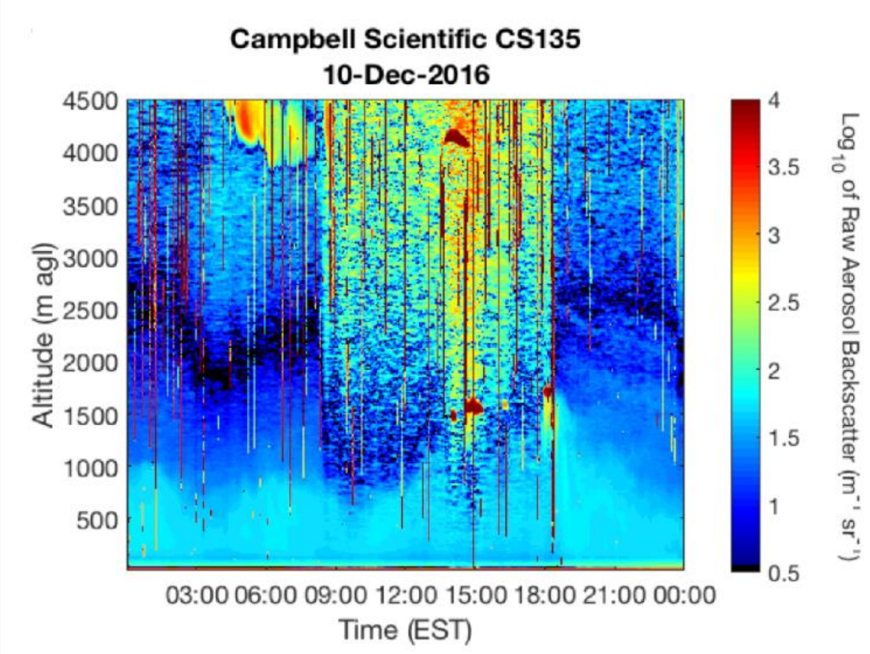


**Figure 5a.** Campbell CS135 raw aerosol backscatter retrieval on December 10, 2016.

To remove the artifacts and noise, the vertical profiles were clarified with a ninth order, 1-dimensional (in this case, the dimension is time) mean filtering method. The updated visual is shown in Figure 5b.

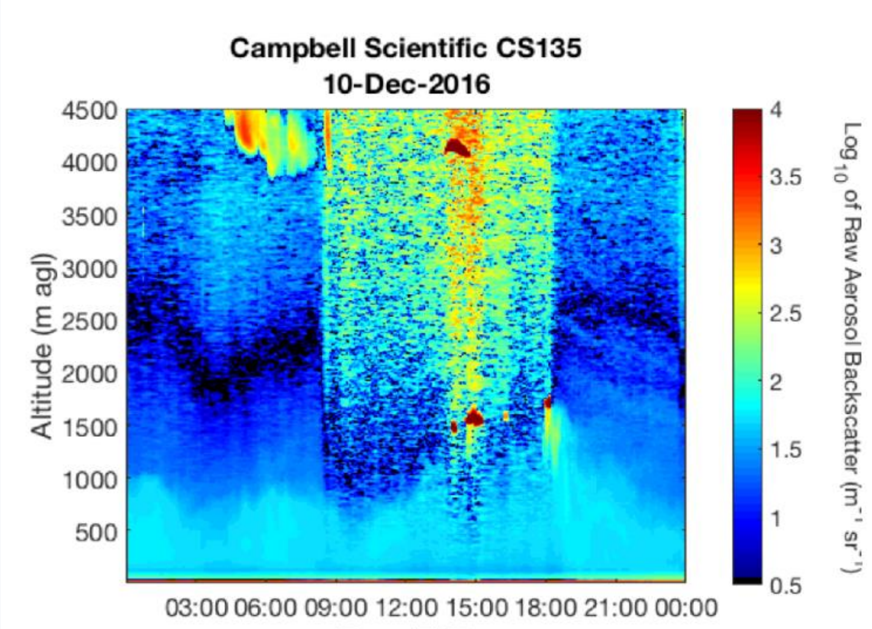


**Figure 5b.** Campbell CS135 raw aerosol backscatter retrieval with 1-D mean filtering on December 10, 2016.

## Conclusions

- Multiple steps of signal retrievals are necessary for significant backscatter corrections and MLH retrievals. Smoothing ceilometers through filtering will maximize signal-to-noise ratio (SNR) without distorting the signals received.
- Because commercial signals and retrievals are not the best, we created our own algorithms for further corrections.
- Identifying cloud signals and then applying an algorithmic method was found to provide corrections beyond what the firmware offered.
- Further communication with Campbell pertaining to software and design could lead to improvements in interference.

## Future Directions

The summer 2018 campaign resulted in the collection of summer time signals. Changing ambient temperatures between summer and winter can influence the electronic or optical mechanisms of the ceilometers. Therefore, different user-implemented methods may be more beneficial depending on instrumentation, season, and location. Further testing of raw aerosol backscatter is required for a greater understanding of the best application of the methods at hand.

## References

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