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Instrument temperature dependence of the Vaisala CL51 signal

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Abstract: In order to use automatic low-power lidars and ceilometers (ALC) for quantitative aerosol monitoring, the various instrument models from different manufacturers need certain corrections for their measurements. Especially the Vaisala CL51 shows a very strong instrument temperature dependent signal distortion with range. Similar patterns of dark measurement signal distortions as function of instrument temperature led to a first promising approach for a background correction by using a look-up table. Possible reasons for remaining distortions need to be investigated further.

1. Introduction

In recent years, the potential of automatic low-power lidars and ceilometers (ALC) for quantitative aerosol profiling is being investigated [1,2]. Due to its low-cost, low-maintenance and eye-safe operation at a single wavelength, a large number of instruments is deployed in large networks of weather services and also at single institutes. If well calibrated with QA/QC procedures continuously applied, ALCs could be used for monitoring the aerosol distribution on a larger scale with high spatial and temporal coverage [1, 3]. This would benefit air quality monitoring as well as tracing elevated aerosol layers from e.g., Saharan dust or volcanic ash and enable the synergistic use of ceilometers together with e.g., photometers.

There is a large variety of ALCs from different manufacturers, that differ not only in price but also in their performance. Thus, necessary correction and calibration procedures have to be developed for every single model to standardize and harmonize their output, even among different firmware versions [4]. Within ACTRIS (www.actris.eu), procedures for operating, monitoring and calibrating these instruments are established to make use of this big potential.

In this work, a widely deployed instrument, the Vaisala CL51 model, is used to demonstrate the need for so-called dark measurements for ALCs to correct for effects of instrumental noise on the measured attenuated backscatter.

2. Instrument and data

The Vaisala CL51 (see Table 1) emits short laser pulses with an Indium Gallium Arsenide (InGaAs) laser diode of 110 ns length at 910 nm wavelength with a high repetition frequency of 6.5 kHz. An APD in analog mode is used to detect laser light backscattered from a range up to 15.4 km with a variable temporal and vertical resolution. To stabilize the instrument at 37°C in cold environments, the laser transmitter is heated, an option for cooling, however, is not implemented. The laser pulse energy, window transmission and laser temperature are recorded as housekeeping data. With the latter, however, it is not clear where exactly it is measured but it is assumed that it is also correlated with the temperature of the detector unit.

Figure 1. Vaisala CL51 ceilometer on the rooftop of the Meteorological institute of LMU Munich. Here, a so called optical termination hood is used for a dark signal measurement.

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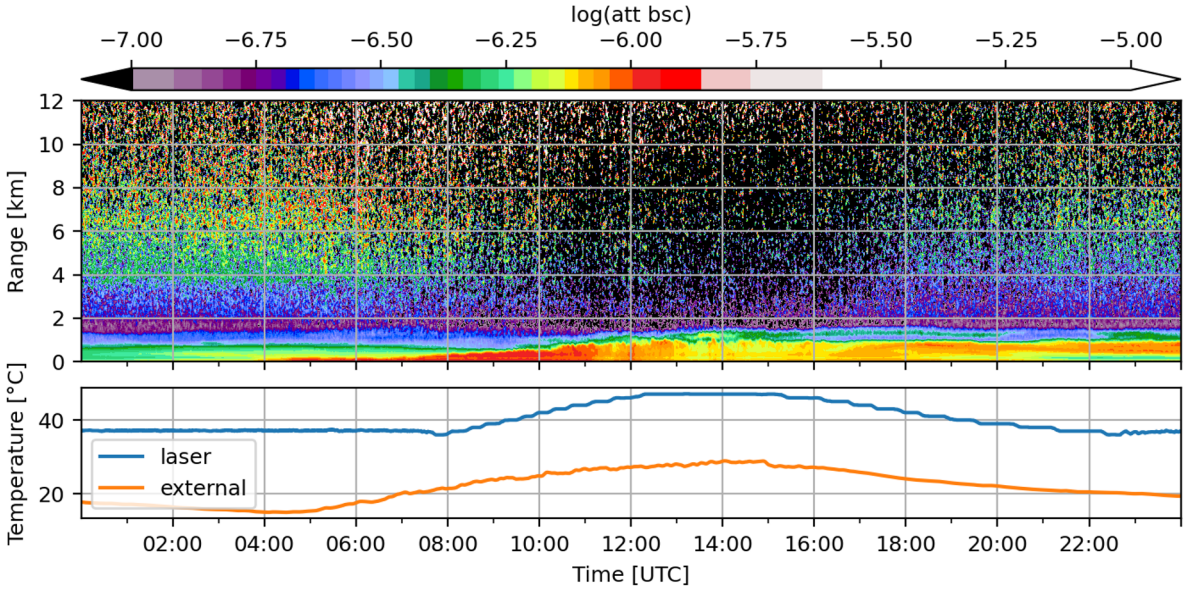

Figure 2. Time-height cross section of the attenuated backscatter from Vaisala CL51 in Munich, 08 September 2023 (first panel). CL51 laser and ambient air temperature (second panel).

Table 1. Vaisala CL51 key parameters

Parameter	Value
Optical design	coaxial
Laser	InGaAs laser diode
Wavelength	910±10 at 298K
Pulse repetition rate	6.5 kHz
Pulse length	110 ns
Pulse energy	3 µJ
Peak laser power	~27 W
Average laser power	19.5 W
Filter Bandwidth	50% pass band 36 nm
Laser divergence	±0.15 x ±0.25 mrad
Telescope FOV	±0.56 mrad
Detection type	APD analog
Filter center wavelength	915 nm
Measurement range	0-15400 m
Range resolution (set)	10 m
Temporal resolution (set)	30 s
Overlap height	90% at 230 m

The instrument (see Figure 1) is operated at the Meteorological Institute of the Ludwig-Maximilians-Universität in Munich (48.148° N, 11.573° E, 539 m altitude) following standard operation procedures (SOPs) defined within ACTRIS with a temporal and vertical resolution of 30 s and 10 m, respectively and the noise_H2 parameter set to "on". Data is recorded using the Vaisala CL-View software and processed to level 1 by using the RAW2L1 tool for the harmonization of various ALC data formats [5].

3. Laser temperature-dependent lidar signal

In Figure 2, a time height cross section of the attenuated backscatter is shown in logarithmic scale for the 08 September 2023 in the first panel with corresponding laser temperature and ambient air temperature in the second panel. On this day, no clouds but a well-developed atmospheric boundary layer up to 1km was present. The air temperature reached 29 °C, leading to an increase of the laser temperature from 37°C at around 08:00 UTC up to 47°C between 12:20 UTC and 15:20 UTC with a following decrease back to 37°C until 22:20 UTC. Besides a strong increase of the attenuated backscatter above 2 km, apparent for all measurements of this CL51 model, a change of this pattern is visible during the strong laser temperature increase resulting in a signal drop above 2 km. To better emphasize this characteristic, the vertical profiles of 2-hour averages of the attenuated backscatter are shown in Figure 3 with corresponding laser temperatures color-coded from colder (blueish) to warmer (brownish) temperatures. This behavior can be observed for all days with laser temperatures rising above the stabilized temperature of 37°C and its extent is highly dependent on the temperature level.

This strong signal variation will not influence the detection of clouds with their much higher signal levels or prevent the use of the ALC for atmospheric boundary layer (ABL) height

determination in which height the changes of the signals are smaller. But using this ALC for quantifying aerosol layers in higher altitudes is almost impossible. Thus, a correction is needed in order to enhance the CL51 capability for aerosol monitoring.

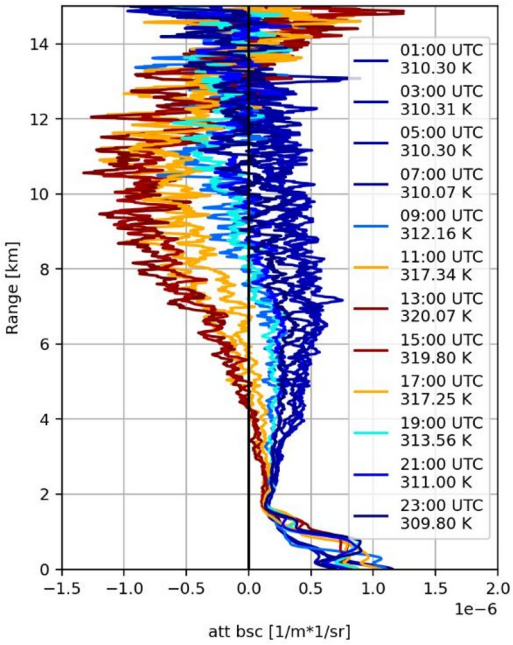

Figure 3. Profiles of the range-corrected lidar signal of the Vaisala CL51 (2 hours averages) corresponding to measurements in Figure 2 with temperatures color-coded.

4. Correction approach

Lidar signals are affected by different noise sources which can be external (e.g., solar radiation) or internal (e.g., electronic). Solar background noise is a range independent component whereas electronic noise sources are instrument related and result in range dependent signal distortions.

Correcting for such lidar signal distortions is an important step in lidar data processing and usually done for aerosol high-power lidar (AHL) as part of QA/QC procedures [5]. For ALCs, however, only the background signal originating from solar radiation is corrected in the manufacturers firmware but no correction is applied for dark signal distortions. Within the framework of ACTRIS, the necessity of dark measurements for background correction is currently investigated for different ALC models.

For conducting dark measurements with the Vaisala CL51, the manufacturer provides a so-called optical termination hood (CLTERMHOOD, see Figure 1) as an optional part for indoor service. This conical cylinder is built in a way to fully extinguish the outgoing laser beam in order to measure only the remaining dark signal. These dark measurements were performed with a duration of two hours at LMU on a bi-weekly basis with different ambient air temperatures resulting in measurements covering a larger range of laser temperatures. By using all obtained dark measurement signals, a simple look-up-table (LUT) can be created with vertical profiles of the attenuated backscatter as function of laser temperature ranging between 309.5 K and 318.5 K. In Figure 4, a strong varying shape of the corresponding dark signal can be seen for different laser temperatures, showing a similar pattern to the atmospheric measurement signal in Figure 3.

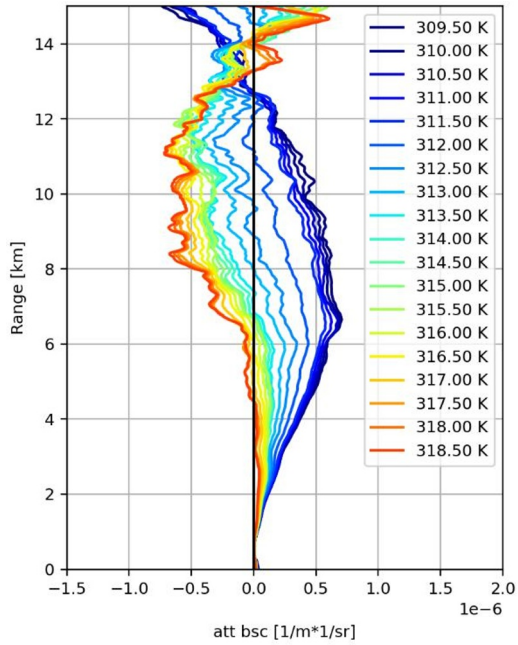

Figure 4. Profiles of the attenuated backscatter of dark measurements from the Vaisala CL51 interpolated to laser temperatures between 309.5 K and 318.5 K.

To test the LUT obtained in this way as a background correction, it was applied to the measurements from 08 September 2023 (Figure 2 and 3). The corrected signals are shown in Figure 5 and Figure 6 as time-height cross section and vertical profiles of the attenuated backscatter, respectively. The signal distortions could be significantly reduced in their extent, but show a slight overcorrection at cold temperatures and a still insufficient correction

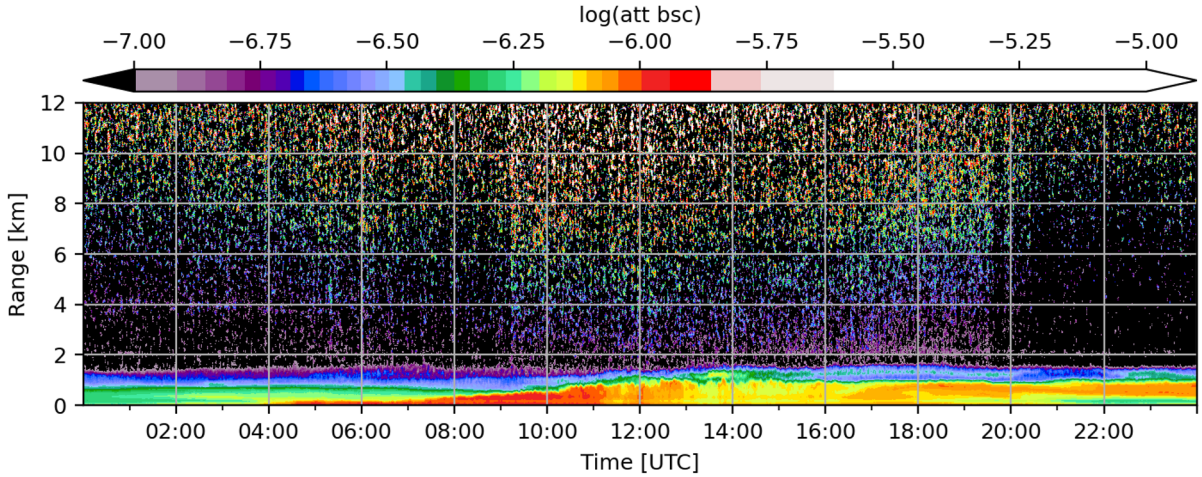

Figure 5. Same as Figure 2 but after applying a background correction using dark measurements of the Vaisala CL51.

at warm temperatures. The lack of even warmer temperatures than 318.5 K in the LUT could explain the imperfect correction for even higher temperatures on this day and needs a complementation with dark measurements at higher temperatures in the future. Further influences like laser wavelength drift with temperature and water vapor absorption correction must be investigated.

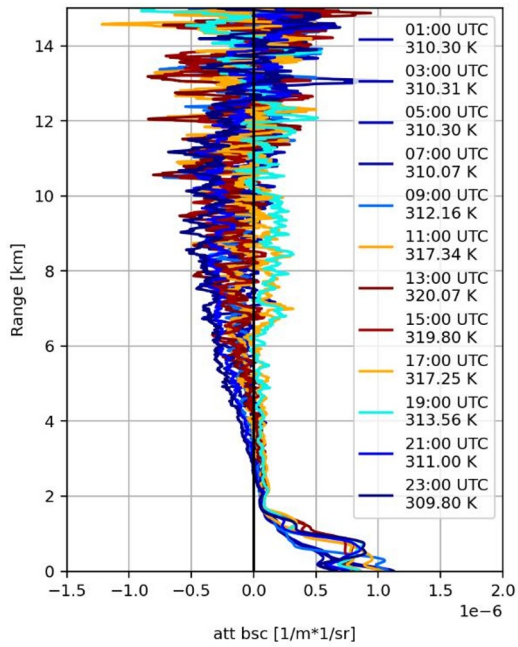

Figure 6. Same as Figure 3 but after applying a background correction using dark measurements of the Vaisala CL51.

5. Conclusion

The clear dependence of the CL51 measurement signal on the laser temperature, which is reflected in range-dependent signal distortions, illustrates the necessity of dark measurements for background correction for ALCs. Such measurements are particularly necessary when using ALCs for aerosol profiling, for which the first promising application for the CL51 is a first step. However, since not all technical details of ALCs are known, a correction is often associated with assumptions, as shown here by the incomplete correction of the CL51 signal. Additionally, considering the variety of models from different manufacturers and their characteristics, a correction must be developed, tested and applied for each individual model.

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