EARLI09 - DIRECT INTERCOMPARISON OF ELEVEN EARLINET LIDAR SYSTEMS

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ABSTRACT

Eleven EARLINET lidar systems were directly compared during EARLI09 in Leipzig, Germany, in may, 2009. The measurement and signal comparison strategies are presented and some examples shown.

1. INTRODUCTION

An absolute calibration technique for lidar systems for the whole measurement range and for their performance in the presence of aerosol layers does not exist. Especially in the very important near range containing the boundary layer aerosol lidar systems suffer from electronic saturation effects and the uncertain optical overlap function. Added to this are in general non-linear analogue signal distortions depending on changing near range aerosol load and signal strength. The direct intercomparison of the signals of different collocated instruments is the only generally accepted, objective way to assess the overall performance of individual lidars in the presence of aerosols.

In the frame of the European Aerosol Research Lidar Network [1]: Advanced Sustainable Observation System (EARLINET-ASOS [2]) eleven EARLINET lidar systems were collected in Leipzig, Germany, between May 07 and May 28, 2009 (EARLI09, EARLINET Lidar Intercomparison 2009) for direct intercomparison. The systems came from the institutes of the authors of this paper.

Scientific lidar systems are continuously changing, be it deliberately due to upgrades, tests or repairs, or unintentionally due to environmental effects or ageing. Particular attention must be paid when systems are moved, as it was the case for most of the systems in this campaign. Furthermore, some of the participating lidar systems were brand-new or had been upgraded recently and had not been tested extensively before the campaign. With this in mind, we wanted to have preliminary comparison results at hand as soon as possible after each common measurement session in order to detect and remove system faults immediately.

For the comparison of so many quite different lidar systems with overall 115 individual signals, dedicated strategies for the measurements and for the analysis are necessary, on which we will focus in the following, concluding with some comparison examples.

2. SYSTEMS

Fortunately all compared lidar systems used Nd:YAG lasers. But the number of measured signals per system ranges between one and thirty, some systems use two or three receiver telescopes for near and far ranges, and many signals are split electronically in an analog and a photon-counting part or in low and high count rate signals. We call each optical path ending at an individual detector a *channel* and each electronic trace a *signal.* Eventually several signals from high and low count rate parts and partly different channels have to be combined to a single *profile*, which can be used for the inversion of the height resolved optical properties of aerosols. In EARLI09 we have to deal with 115 signals from 79 channels combining to 54 profiles and resulting in 11 different aerosol properties, which are the backscatter coefficients at 355, 532 and 1064 nm, the extinction coefficients at 355 and 532 nm measured at vibrational and rotational Raman lines and with the high spectral resolution technique at 532 nm, the linear depolarisation ratios at 355 and 532 nm, and the water vapor content from the 355 nm vibrational Raman line.

Each photon detector in a lidar system has its individual optical path (channel) with individual range dependent transmission characteristics, and, when electronically split, with different electronic distortions. Therefore the first step of an intercomparison should be the comparison on signal level to detect all the problems, the validity range and the uncertainties of each signal part before combining them to profiles.

The large diversity of the lidar systems is visible in figure 1, where the unsmoothed, range corrected, over 45 min summed photon counting signals at 387 nm are shown for some systems, with a span of detection power over almost three orders of magnitude and quite different near and far range limits. It is above the scope of this paper to go into more details of the individual lidar systems.

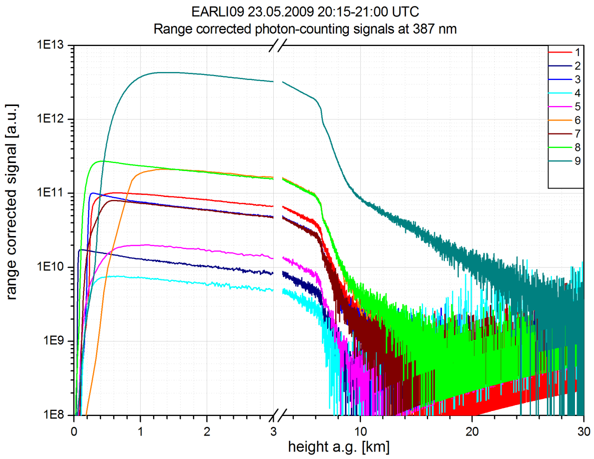

Figure 1: Range corrected sums of photon counts over 45 min at the individual range resolutions (3.75 to 60 m) of several EARLI09 lidar systems at 387 nm.

3. MEASUREMENT STRATEGY

All lidar systems were collocated within about 100 m distance on a flat terrain, which made it very likely that they all measured the same atmospheric volume within the averaging time. Two sessions with three hours of measurement time each were scheduled for every day of the three campaign weeks, possibly one at day and one at night, in the hope to find at least a 30 min period in each session with stable atmospheric conditions and with all lidar systems working properly. To be as flexible as possible in the final comparison periods regarding the availability of the systems and the variability of the weather conditions, the raw signals were averaged over one minute periods. The three hour data sets from all systems had to be delivered within hours after each session to a common data base server via an especially installed LAN between all lidar systems.

4. SIGNAL PROCESSING AND COMPARISON

In order to avoid differences in the raw signal processing by different software, all participants delivered data sets of raw signals without any preprocessing. Each data sets includes a header with all information necessary for the further processing of the signals as explained below. Some basic, fixed parameters of each signal had been collected before the campaign in a system data base. Using the header and data base information, all signals were then preprocessed by a modified version of the *Single Calculus Chain* (SCC, [3]) software developed in the frame of EARLINET-ASOS for the common processing of EARLINET lidar signals. Using the information of the individual data headers the preprocessor performs trigger delay shift, dead time correction, background subtraction, range correction, and, after selection of a comparison period, the summing of the appropriate signals. If wished by the users the preprocessor also combines near and far range signals, photon counting and analog signals (gluing), and parallel and cross polarized signals into a total profile using given calibration ranges or values. The output signals have the original range resolutions between 3.75 m and 60 m.

To be able to compare the signals point by point, the signals were first re-binned (summing of rangebins with linear interpolation at the edges) to a common height resolution of 60 m and to common height levels considering the individual system altitudes and the lidar zenith angles, the latter being 5° at maximum. The signal noise at higher altitudes must be reduced by further re-binning stepwise increasing up to about 2.5 km rangebins when necessary (progressive smooth). Inspecting those signals, a range is found where the signals deviate least, and all signals are normalized in this range (figure 2).

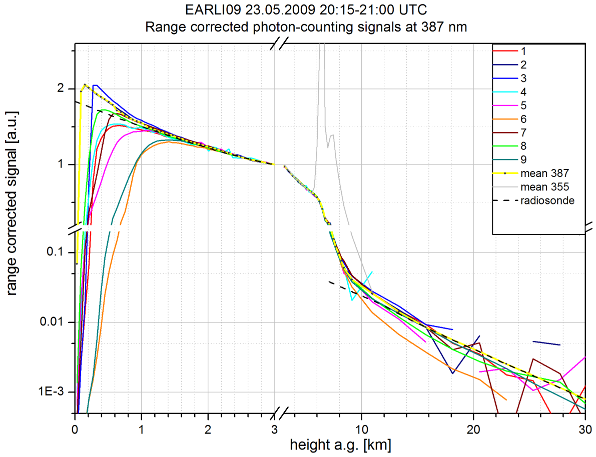

Figure 2: Range corrected lidar signals at 387 nm as in figure 1, but progressively smoothed and normalized between 2.5 and 3.5 km, including the mean 355 nm signal to show the cloud layer, and the Rayleigh signal at 387 nm fitted at the normalisation range and additionally at 15 km. Please note the axis breaks and the change to log scale.

Next a mean signal has to be constructed from the best parts of all signals as a common reference, which should

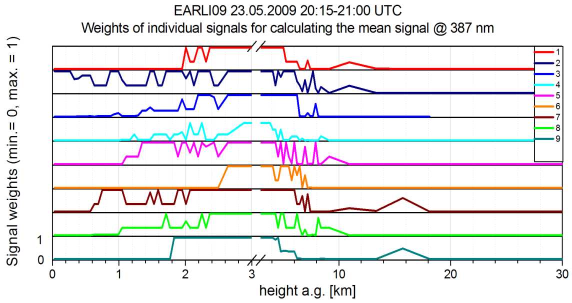

Figure 3: Signal weights for the calculation of the mean signal from signals in figure 2. Colors corresponding to figure 2.

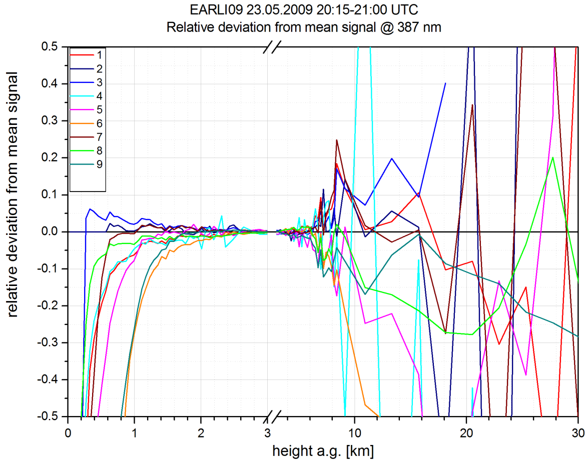

Figure 4: Relative deviations of individual signals of figure 3 from the mean signal. The deviations depend on the normalisation range (see text), which is between 2.5 and 3.5 km.

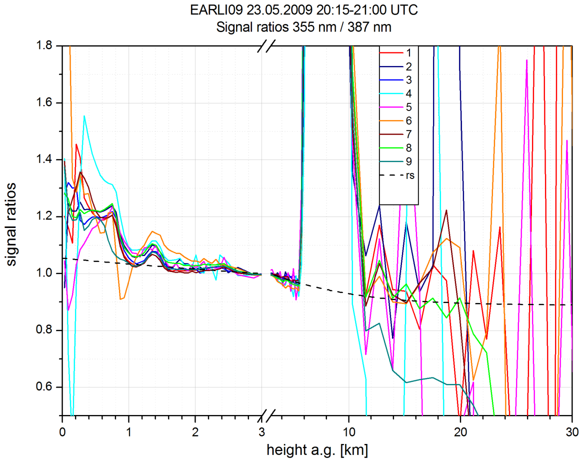

Figure 5: Ratios of the 355 nm and 387 nm signals (same as figures 1 to 3) of individual lidar systems (rs = Rayleigh signal), normalised between 2.5 and 3.5 km, for 23.05.09.

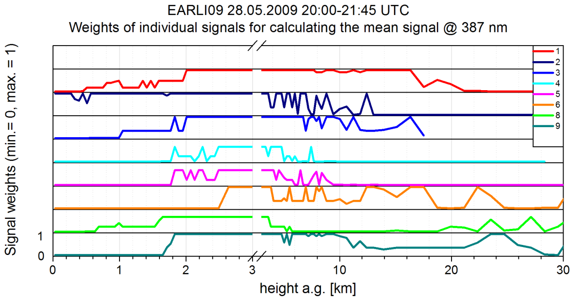

Figure 6: Same as figure 3 but for 28.05.09, without clouds.

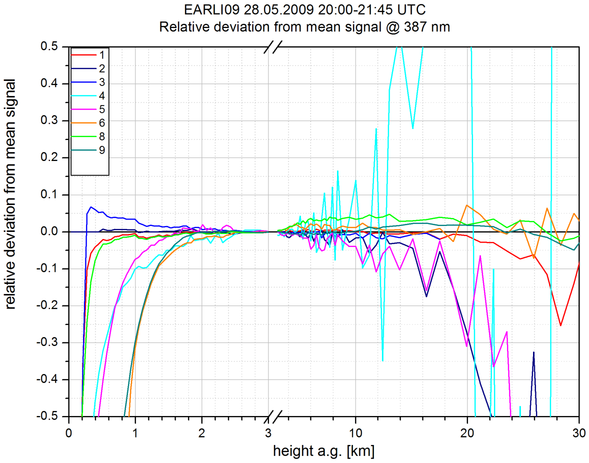

Figure 7: Same as figure 4 but for 28.05.09, without clouds.

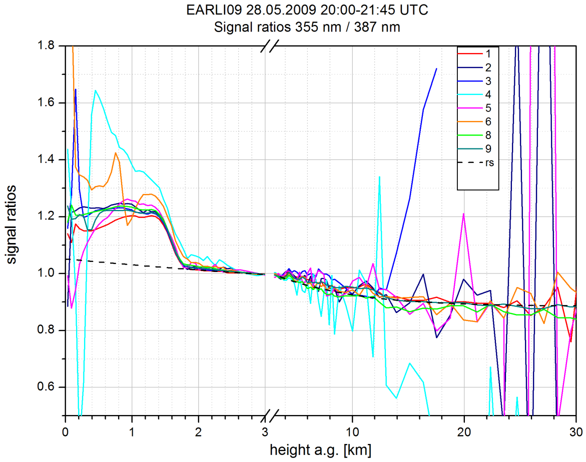

Figure 8: Same as figure 5 but for 28.05.09, without clouds.

be close to the unknown true signal. For this purpose each signal gets range dependent weights by an expert's guess reflecting its assumed accuracy, from which a first-guess, weighted mean signal is calculated. The expert's weights are then successively decreased by a routine proportional to the range dependent signal deviation from the first-guess mean signal, leaving high weights for good signal parts (figure 3).

In the stratosphere, where an aerosol free range can be assumed, the mean signal can be replaced by a caclulated signal from actual radiosonde data (Rayleigh signal), fitted to the mean signal at an appropriate height (usually about 15 km). The radiosonde data are combined from actual local radiosondes for the lower part and from the temporally closest, higher reaching Lindenberg radiosonde (WMO ID 10393) up to 30 km. From this refined mean signal (figure 2) the relative signal deviations are calculated (figure 4). Different cloud optical depths in the signals of the lidar systems cause offsets in the deviations after the cloud layer (see figures 2 and 3).

Futhermore, the ratios of signals at different wavelengths of a lidar systems (signal color ratio) can be compared between systems as shown in figures 5 and 8 for 355 nm / 387 nm. In aerosol-free ranges these ratios, normalized in an appropriate range, should match the ratios of the corresponding Rayleigh signals (see figure 8, far range), which show the wavelength dependence of the backscatter and transmission. Deviations from the Rayleigh ratio are due to aerosols resembling the backscatter ratio, which should be the same for all lidar signals, or due to electronic signal distortions and saturation, wrong background subtraction, and different overlap functions for the wavelength pairs. Especially the latter problem adulterates the signal analysis in the overlap regime of a Raman lidar as described in [4].

5. DISCUSSION AND OUTLOOK

Comparing the results from the two days, where the same colors show the same lidar systems, we see more or less temporal changes of individual system performance (e.g. lidar 1 and 4 in the near range). We also realise the difficulty of constructing a mean signal as an absolute reference for the comparison.

As direct lidar intercomparisons are expensive and time-consuming, they cannot be done often, and alternatives must be found. For the far range the comparison with the Rayleigh signals (Rayleigh fit) turns out to be a good signal check, and for the near range the telecover test [5] has proven its suitability. During EARLI09 several telecover test were performed, which will enable us to evaluate the significance of this test in a more quantitative way. These two test are performed regularly with all EARLINET lidar systems. Furthermore the potential of the signal colour ratio test will be explored, and finally we will compare the products, i.e. extinction and backscatter coefficients, retrieved from the EARLI09 profiles.

6. ACKNOWLEDGMENTS

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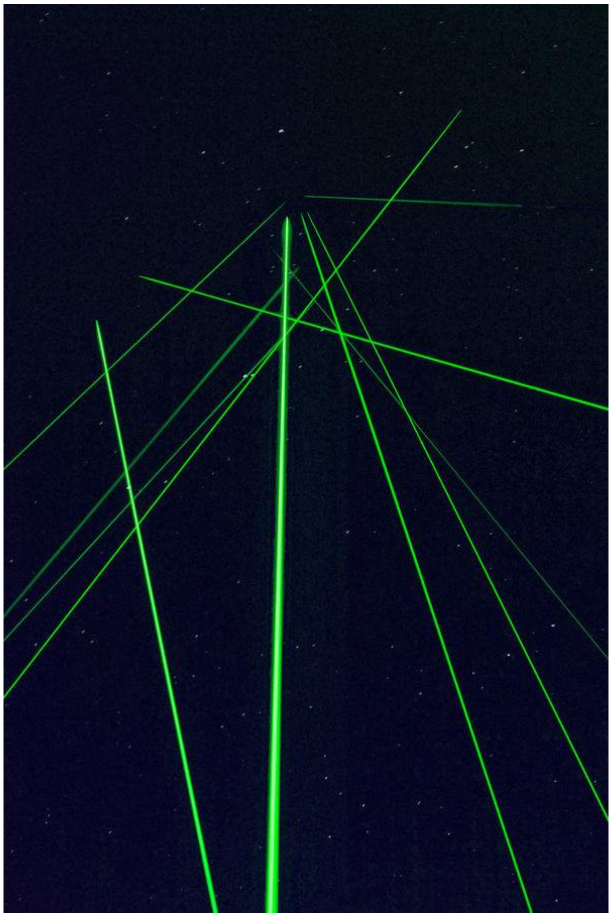

Figure 9: Green laser beams from ten lidar systems above the measurement site during EARLI09.
Photo: thomas.massmann@inqbus.de