Optimization of the multiwavelength Raman Lidar during EARLI09 campaign

C. RADU*, L. BELEGANTE, C. TALIANU, D. NICOLAE
National Institute of R&D for Optoelectronics INOE 2000, 409 Atomistilor Str., PO Box MG-5, Magurele, Bucharest

Both air quality and climate studies require information about the vertical distribution of aerosols, as well as about their interactions with other atmospheric components (gaseous precursors, water vapor, ozone). Lidars are laser-based instrument which uses the induced backscatter signal to retrieve optical characteristics of the atmosphere. Quantitative data requires optimized instruments and algorithms. During EARLI09 (EArlinet Reference Lidar Intercomparison campaign 2009), the multiwavelength Raman lidar of INOE was upgraded and tested against other 15 instruments. This paper presents early results of this campaign.

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1. Introduction

Earth radiation budget is strongly affected by atmospheric aerosols and clouds. Aerosol concentration in the atmosphere can vary over a wide range, being influenced by altitude, time, and location. The vertical structure of the profiles is complex and changing continuously [1]. The global energy balance is influenced by aerosol particles directly by scattering, and much less by incoming solar radiation absorption. Recent studies on the impact of aerosols by direct and indirect effects on the radiative forcing in a global average show that they are of the same order of magnitude as the warming effect [2]. Lidar measurements provide optical (and in some cases also microphysical) properties of particles with high spatial and temporal resolution [3] as vertical profiles.

Lidar (Light Detection And Ranging) is an active remote sensing technique based on the emission of laser pulses (few ns) into the atmosphere and the analysis of the return signal. Upon the emitted and selected wavelength at the detection, different characteristics of air pollutants can be measured. The photons scattered by the atmospheric particulates are collected by an optical telescope (Fig. 1). To ensure a good wavelength selection of the lidar signals, narrow-band interference filters are used, one for each detected wavelength. The selected radiation is focused on a photomultiplier (PMT) – for visible and UV light, respectively on an avalanche photodiode (APD) – for IR light, to convert the optical signal into electrical signal. The distance between the lidar system and the atmospheric target can be calculated measuring the delay time between the emitted and the received laser pulses. Thus, range resolved measurements of the desired air pollutants or atmospheric parameters can be obtained.

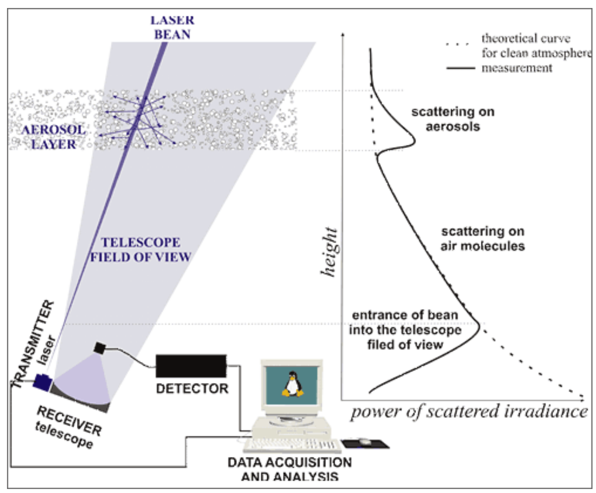

Fig. 1. The Lidar principle.

2. Lidar system description

The Lidar system used for measurements has 7 emmision channels, 4 elastic (1064, 532p, 532c and 355 nm), 2 nitrogen vibrational Raman channels (607 and 387 nm) and one water wapor channel (408 nm). The emitted output energies per pulse are between 50 and 90 mJ (but is optimized for 355 nm wavelength – 60 mJ), with a 10 Hz repetition rate and 3.75 m spatial resolution. The backscattering signals are collected through an optical telescope Cassegrain type 400 mm diameter, and further acquired and digitized in the analog and/or the photon counting mode using Licel fast transient recorders and then transferred to a computer for storage and analysis. Because Nd:YAG lasers have prove their efficiency from energetic and pointing stability point of view, most of aerosol lidar systems are built starting from the fundamental and the 2^{nd} and/or 3^{rd} harmonics of the Nd:YAG laser.

The Lidar system is composed by 3 main components: the transmitter, the receiver and the detection and processing unit.

The transmitter is used to generate light pulses and send them into the atmosphere. Lidar systems require pulsed lasers since at the receiver only a very small amount of generated light is detected. The advantages of pulsed lasers over other light sources are short intense pulses extremely narrow spectral width and low divergence. To minimize the background noise, a lidar system must have a low divergence laser beam and a small field of view (FOV) telescope. The larger is the area of the sky that the detector system views the larger is the FOV and the higher is the measured background. This is apply mostly on daytime measurements [4] when scattered light coming from the sun represents main source of background noise.

Another issue is related to laser beam divergence. The best way is to ensure that the entire laser beam falls within the FOV of the detector system. For that, the divergence of the laser beam should be sufficiently small (even most lasers have very low divergence), so that it remains within the FOV of the receiver system in all ranges of interest. To increase the beam diameter and decrease the divergence of a laser beam, only a simple telescope arrangement can be used. Using a beam expander (a small telescope) an adequate well-collimated laser beam for transmission into the atmosphere is obtained.

The aim of the **receiver** is to collect and further process the scattered laser light and then direct it onto a photodetector, which is a device that converts the light to an electrical signal. The primary optic is the optical element that collects the light scattered back from the atmosphere and focuses it to a smaller spot (Fig. 2). The size of the primary optic is an important factor in determining the effectiveness of a lidar system. A larger primary optic collects a larger fraction of the scattered light and thus increases the signal measured by the lidar.

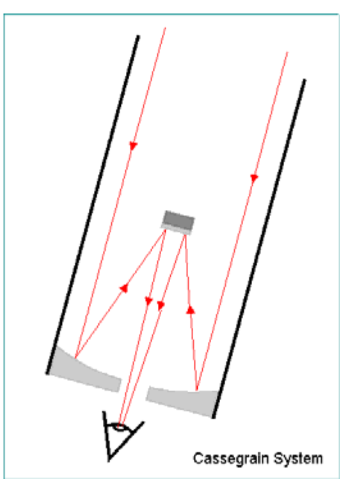

Fig. 2. The optical path in a Cassegrain telescope.

Signal detection and recording take the light from the receiver system and produces a permanent record of the measured intensity as a function of altitude. The detector role is to convert the light into an electrical signal, the recorder being an electronic device or devices, with the purpose to process and records this electrical signal.

Photomultiplier tubes (PMTs) are generally used as detectors for incoherent lidar systems which use visible and UV light. The PMTs convert an incident photon beam into an electrical current pulse [5] large enough to be detected by sensitive electronics.

The output of a PMT can be recorded electronically in two ways. The first technique is called photon counting and counts individually the pulses. The second technique, analog detection, involves measuring and recording of the average current due to the pulses. The most appropriate method for recording PMT output depends on the rate at which the PMT produces output pulses, which is proportional to the intensity of the light incident on the PMT.

The received signal is recorded by a powerful data acquisition system such as a transient recorder. This type of acquisition instrument has advantage that combine the analog part of the acquisition and photon counting part. The dynamic range is increased by a powerful A/D converter (12 Bit at 40 MHz) with a 250 MHz fast photon counting system.

The Licel transient recorder is comprised of a fast transient digitizer with on board signal averaging, a discriminator for single photon detection and a multichannel scaler combined with preamplifiers for both systems.For analog detection the signal is amplified according to the input range selected and digitized by a 12-Bit-20/40 MHz A/D converter.

At the same time the signal part in the high frequency domain is amplified and a 250 MHz fast discriminator detects single photon events above the selected threshold voltage. 64 different discriminator levels and two different settings of the preamplifier can be selected by using the acquisition software supplied. The photon counting signal is written to a 16-Bit wide summation RAM which allows averaging of up to 4094 acquisition cycles.

3. Methodology

The aim of EARLI09 campaign – EArlinet Reference LIdars campaign 2009 - was to compare reference and non-reference mobile lidar systems in EARLINET (European Aerosol Research Lidar Network) [6] in various atmospheric conditions and also to validate all channels showing acceptable deviations. In combination with the validation of algorithms, this validation ensures the quality of output data of a particular channel.

Our multiwavelength lidar (RALI system) was present at this intercomparison campaign, as a non-reference EARLINET lidar system. The instrument was set up inside a van and transported without disassembling the optical part or the laser.

This campaign was organized in Leipzig, Germany at the Institute for Tropospheric Physics between 4 and 29 May 2009. During 24 days of measurements, 16 lidar systems belonging to 12 groups from all over the Europe were operating on a specific schedule. Four of the systems are EARLINET reference systems, 6 are EARLINET non-reference systems (including ours) and 4 systems outside EARLINET. The measurements were take place in 3 hours sessions when the weather allowed, with a 1 minute time resolution.

In order to reduce the high voltage supply for PMTs some neutral filters were required to be mounted in front of PMTs for the each wavelength. Thus, for 532 nm was added a 0.5 OD neutral filter, for 355 nm 0.1 and 0.3 OD and for 1064 nm one 0.2 OD neutral filter. Then the HV supply was lowered to 750V and the display scale for the recorded signal from 500Mv to 100mV.

The lidar system was optimized by increasing the telescope's field of view (from 1mrad to 1.7mrad) because the overlap was too high in comparison to other lidar systems. That was done by keeping the 400mm telescope and adjusts the field stop diameter (from 4mm to 7mm). After these settings were performed, the minimum range achieved was 700m and the maximum range approx. 20000m (depending on the channel). No problems were recording for channels functioning or data pre-processing, conversion and submission. The reducing of overlap was necessary because the photon counting part of the detection system record the upper part of the troposphere, but the lower altitude was in a ‘blind’ area, without possibility to record any data.

To a proper comparison between different stations data, only raw data were submitted, then converted to NetCDF format and uploaded on the same server. That was a decision from campaign coordinators to exclude various contributions from data handling procedures (different in each group) and to evaluate only the instrument behavior. Raw data were pre-processed using the same software to exclude any external interference.

Another objective of the campaign was to test the Single Calculus Chain (SCC) [7] in order to establish processing of all data acquired, to adjust and improve instruments and data handling procedures.

But the work with such a variety of channels and data, the Single Calculus Chain needed supplementary parameters, which have been given in the header of the NetCDF files.

For each 3 hours measurement session, the following files have been submitted:

- 1 Lidar data file with: input parameters (some of them cannot be obtained without pre-processing the signals first); time series for all channels; time series for dark measurement
- 1 Gluing file with: the altitudes interval where the gluing between analog and photon counting will be done and the exact point (inside the gluing interval) where the 2 signals will be merged
- 1 Overlap file with the overlap function for each channel
- 1 Radiosounding file provided by IfT during EARLI09 campaign

Even if all the procedures were clear, data collection and conversion was not an easy task (especially for systems with many channels), because converting large amount of data require not only time to do the processing, but also high-speed processors. To a better assessment of the parameters fo including in data header, (like best interval for gluing, background interval, overlap function etc.), each group had to run its own pre-processing program. In case of our lisar system, RALI, a 12-channels instrument, with 3.75m spatial resolution and 16380 bins per channel, the computer processor was unable to upload in the memory the 3 hours session (180 profiles) all at once. Therefore, the pre-processor was re-designed to upload and evaluate each profile separately, before computing the average parameters.

A quantitative evaluation is necessary in order to accept or reject a particular channel which is not in agreement with EARLINET requirements. Since no lidar can be objectively calibrated, a solution is to consider the average of all normalized signals as the reference for a certain wavelength. If the signals considered have the same degree of confidence, this can be done, but during the EARLI09 campaign some of the systems will not work accurate enough even after optimization and therefore cannot provide trusted data. Thus, in order to avoid corruption of the reference signal, these channels should be excluded when averaging. Also, there are some instruments with “good” channels and “bad” channels as well, so they cannot be included(excluded) completely. For some channels the lower range is sufficiently good but the far range not, for others the far range is good but not the low range. Taking into account all these issues, the methodology was further developed in 2 steps.

First, the median signal of all similar channels is computed and considered reference. Next, for each channel the deviation by bin is calculated against the reference. Must be considered an altitude interval for which the average deviation is calculated, in relation with the application: for tropospheric aerosols, this interval should be bellow 14 km, but above 1 km in order to exclude overlap differences. Depending on the requirements, the threshold can be decreased (if the requirements are not so demanding) or increased. The final result of this procedure leads to failure of the test from some channels and their exclusion from the calculus in the second step.

But the signals that passed the test are averaged again and the deviations are computed against the new reference, now with more accurate approximation of the best signal.

For the entire altitude interval where the deviation of a particular channel is below the threshold, the conclusion is that the channel is providing accurate signals. This way, the best region of the best channels is evaluated.

4. Conclusions

During the EARLI09 campaign, the RALI lidar system was upgraded and tested against other lidar systems. This was an excellent opportunity to evaluate the Bucharest multiwavelength lidar system performances and also to optimize its operation and to test data handling procedures and programs. Our lidar system does not encounter any technical problems during the campaign, proving a good stability and accuracy.

One of the advantages of the RALI system consists in its compact design and easiness to install. Although were one of the most complex system (12 channels) used in this campaign, RALI system reach to an operating status in only 3 hours, including alignments, other lidar systems need to about 2 days to accomplish that.

During campaign, a complex procedure was developed and tested on the datasets submitted by each group involved in EARLI09. Our lidar system has passed the test for a threshold of 10% deviation from the reference signal, for all channels.

References

[1] Ansmann A. et al., Geophys. Res. Lett. **27**, 964 (2000).

[2] Forster, P., et al., 2007, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, H. L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, USA.

[3] A. Ansmann, et al., Applied Physics **B55**, 18 (1992).

[4] S. E. Bisson, J. E. M. Goldsmith, M. G. Mitchell, Appl. Opt. **38**, 1841 (1999).

[5] F. L. Pedrotti, L. S. Pedrotti, Introduction to Optics, 2nd ed., Prentice-Hall, Englewood Cliffs, NJ, 24, 1993.

[6] J. Bösenberg et al., MPI-Report 317, Max-Planck Inst. für Meteorology, Hamburg, Germany, 2003.

[7] EARLINET-ASOS III Annual Report, April 2009, www.earlinet.org.

* Corresponding author: cristim@inoe.inoe.ro