Comparative Analysis of Lidar Retrievals:

Evaluating Lidar Performance with Normal Telescope Field Stop versus Tilted Slit Solution

Livio Belegante [(a)], Doina Nicolae [(a)], Anca Nemuc[(a)], Cristian Radu[(a)], Razvan Pirloaga[(a)], Victor Nicolae[(a)], Gabriela Ciocan[(a,b)], Jeni Vasilescu [(a)]

(a) National Institute of Research and Development for Optoelectronics INOE, Magurele, Ilfov, Romania

(b) Faculty of Physics, University of Bucharest, Magurele, 077125, Romania

Presenting author e-mail address: belegantelivio@inoe.ro

SCAN ME

Abstract

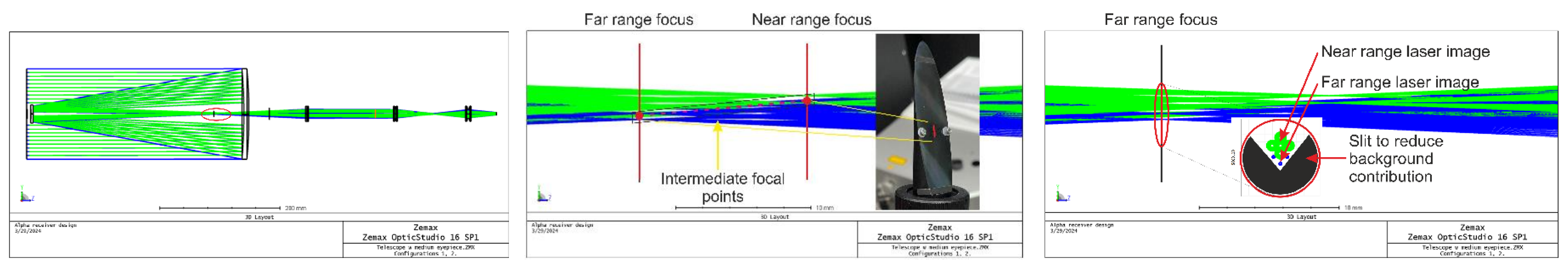
- Lidar systems, although highly effective tools for atmospheric profiling, encounter significant limitations for operation during daytime due to ambient light (primarily skylight). The intense illumination from the sky/sun limits the capability of the lidar receiver, leading to limited performance due to increased noise levels of the collected signals.
- Although the tilted slit solution was developed many years ago, and it is already implemented by several lidar instruments, the advantages of using such a technique are not published. The paper intends to present a comparative study between lidar retrievals performed with and without the tilted slit solution to better quantify the advantages of using such a technique for lidar retrievals.

The challenge

The operation of conventional lidar systems face limitations, particularly during daytime operation when ambient skylight (mostly coming from the sun) overwhelms the receiver, leading to decreased signal to noise ratio (SNR) and reduced data quality.

To overcome this issue, several solutions have been implemented: narrow bandpass filtering, reduced telescope FoV, additional rotational Raman channels for daytime extinction, increased laser energy. A slit solution designed to replace the conventional telescope field stop will mechanically limit the amount of undesired background light entering the receiving block. This approach requires accurate control of the lidar alignment and optical setup.

Figure 1: Zemax Optical Simulations. Green pattern » near range light collected from 300m; Blue pattern » far range light collected from 3 km.



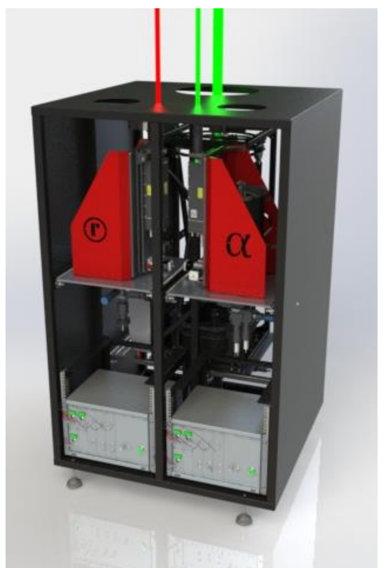
a: Raytrace for a typic range light collected from 3 km.al lidar channel

b: tilted slit solution, position of the near range (green) and far-range (blue) focal and intermediate focal points

c: reduced field stop solution, image pattern in the telescope focal (far range) and reduced field stop to decrease background contribution

Methodology

- The **Alpha lidar** is a state-of-the-art instrument designed to meet the operational and data quality requirements of the ACTRIS research infrastructure [4].
- Engineered for continuous operation, this instrument delivers a full set of optical products that includes daytime backscatter, daytime extinction and nighttime extinction at three wavelengths, and three depolarization products (**3β, 3α-daytime, 3α-nighttime, 3δ**).
- The Alpha lidar system comprises two distinct components: an operational segment and an experimental segment. The operational portion consists of three lasers and three telescopes, with each emitter-receiver pair specifically targeting different atmospheric characteristics. The first receiver is responsible for capturing data related to elastic and Raman scattering channels, while the second receiver is dedicated to depolarization channels at 532nm and 355nm. Similarly, the third receiver focuses on depolarization channels at 1064nm. Additionally, alongside the primary lidar units, the instrument incorporates an experimental High Spectral Resolution Lidar (HSRL) unit utilizing the Iodine filtering technique at 532nm [4].
- To achieve a good SNR, the two depolarization telescopes were equipped with a tilted slit solution [5]. Due to its modular design, the tilted slit modules could be easily replaced with normal field stops for this comparative analysis (Fig.2).



Since the 532 nm channels are most affected by the background radiation (Fig.3.a-b), the study will focus mostly on the 532 nm depolarization channels. The comparison was made for two case studies with similar atmospheric conditions (noon measurements with clear sky 11:00 UTC). The two cases are 2023-05-02 (no slit), 2023-07-12 (tilted slit).

The measurement' dates was chosen based on several factors like atmospheric conditions and AOD values at 500 nm. The time gap between the selected dates is also caused by factors related to alignment and quality assurance required after each update of the optical configuration [2]. The position of the sun relative to the geometry of the telescope was also considered for the case study dates.

Fig.3.a-b presents the modeled solar spectra for the specific latitude: 44.3 (based on Bird and Riordan, 1984 - kastenyoung1989 airmass model).

The data indicates that for the specific timeframe, the total sun irradiance at sea level is around 1.7 Wm-1nm-1 @ 532 nm for 2023-05-02 and 1.65 Wm-1nm-1 @ 532 nm for 2023-07-22. The airmass is 1.11 and 1.15 respectively for the two dates, while the solar zenith is 29.59° and 25.67°. The sun-photometer AOD at 532 nm is 0.109 and 0.3 respectively. Under these considerations, we can estimate that the amount of stray sunlight entering the telescope volume is similar from the sun geometry perspective but could be considered three times smaller for the 2023-05-02 case (based on the 500 nm AOD).

Figure 3: Solar spectra for the specific latitude: 44.3 (based on Bird and Riordan, 1984 - kastenyoung1989 airmass model [6]. a) 2023-05-02; b) 2023-07-12

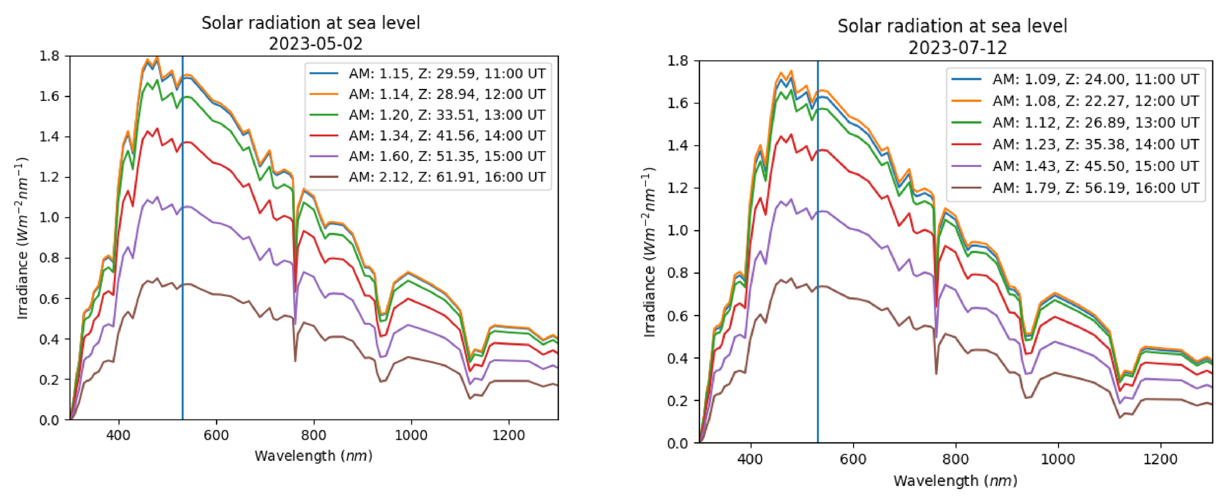


Figure 2:Normal field stop vs tilted slit. Upper-left: normal circular field stop; Up-right: field stop inside the telescope; Lower-left: tilted slit solution; Lower-right: tilted slit installed inside the telescope.

References

[1] V. Freudnethaler, Optimized background suppression in near field lidar telescopes, , ISTP2003, 2003.

[2] Freudenthaler, V., Linné, H., Chaikovski, A., Rabus, D., and Groß, S.: EARLINET lidar quality assurance tools, Atmos. Meas. Tech. Discuss, https://doi.org/10.5194/amt-2017-395 2018.

[3] Piironen and E. W. Eloranta, "Demonstration of a high-spectral-resolution lidar based on an iodine absorption filter," Opt. Lett. 19, 234-236, 1994.

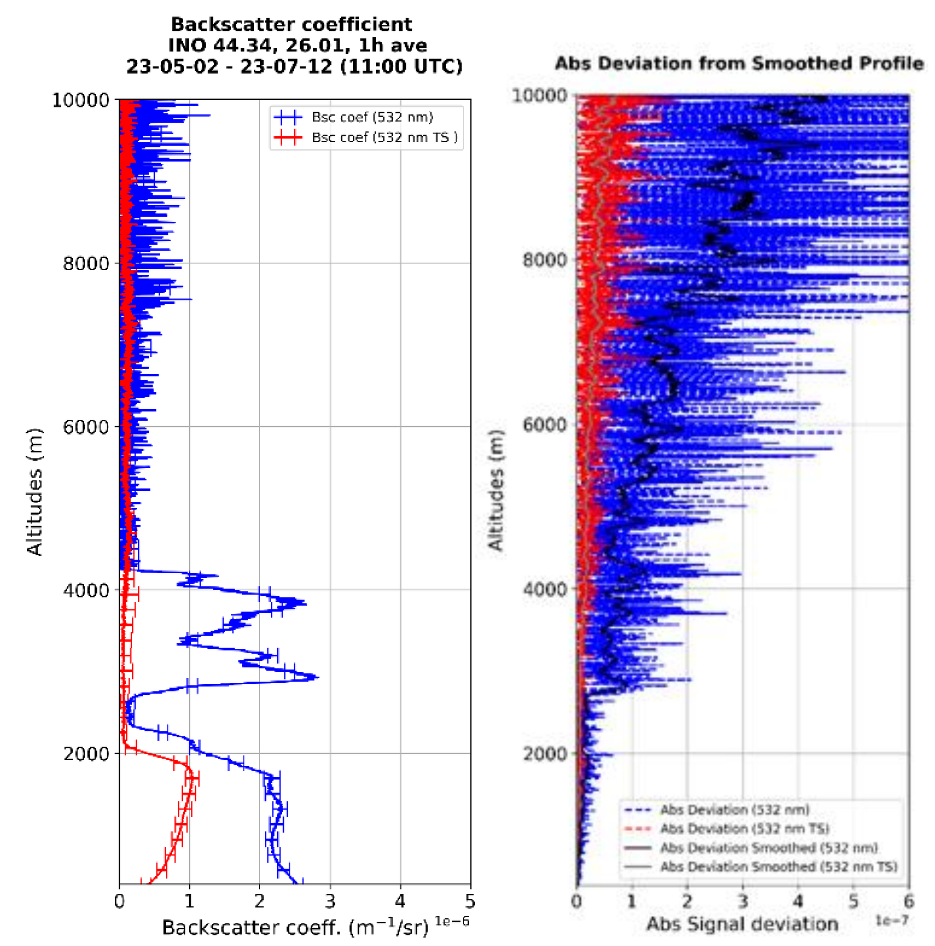
[4] L. Belegante et, al., Alpha-lidar: A State-of-the-art Continuous Daytime Depolarization Raman Lidar, ELC2020, Granada, Spain, , https://granada.congresoseci.com/elc2020/elc2020_scientific_program_v20201111!!, 2020.

[5] A.I. Abramochkin, and A.A. Tikhomirov, Optimization of a lidar receiving system.2. Spatial filters, Atmos. Ocean. Opt. Vol. 12, No. 4, p.331-342, 1999.

[6] R. Bird and C. Riordan, "Simple solar spectral model for direct and diffuse irradiance on horizontal and tilted planes at the earth's surface for cloudless atmospheres", NREL Technical Report TR-215-2436 doi:10.2172/5986936, 1984.

Results

Figure 4: The backscatter profiles and absolute signal deviation. a) Backscatter profiles at 532 nm with tilted slit: red, normal field stop: blue. b) Absolute signal deviation relative to the smoothed signal red-grey for tilted slit setup and blue-black for normal field stop.



The backscatter profiles for the two dates at 532 nm (with and without the tilted slit) indicate a significant improvement in the case of the tilted slit setup. Fig.4.a shows a comparison between the two backscatter profiles (one hour average).

Fig.4.b presents the absolute signal deviation relative to the smoothed backscatter signal (SG filter, window length: 51, poly order: 3) and the smoothed absolute signal deviations (black and grey curves). Considering that the additional noise between the two signals is generated by the additional stray light reaching the detection, we can have a quantitative estimate of the effects of the tilted slit on the SNR. The data indicates that the deviations are greatly improved for the tilted slit setup.

Table 1: Signal deviation for two altitude ranges

Optical setup	Averaged absolute signal deviation (*1e-7)	
	8-10 km	6-8 km
Tilted slit	0.46	0.31
No tilted slit	3.11	1.77

Discussions

Based on the analyzed data, we can estimate an improvement of the signal quality in case of the tilted slit to be more than **6 times better** for the given altitudes even if we disregard the effects of different AOD 500 nm for the two cases. If we can consider that the AOD 500 nm is mostly caused by the contribution of the lower troposphere and if we estimate that three times larger AOD 500 nm indicates three times less background light reaching the telescope, we estimate that the signal quality in case of the tilted slit solution is more than **15 times better** for the investigated altitudes.

Conclusions

This study highlights the importance of overcoming the limitations of conventional lidar systems during daytime operation, particularly in the presence of ambient sunlight. Through a comparative analysis of lidar retrievals using two different field stop solutions, we show a significant improvement in data quality. Even if this technical solution is available since several years for lidar applications, a quantitative assessment of these differences brings an added value in highlighting the importance of implementing such a solution.

Acknowledgements

This work is supported by the European Commission under the Horizon 2020 – Research and Innovation Framework Programme, through the ATMO-ACCESS Integrating Activity under grant agreement No 101008004, by the Core Program within the National Research Development and Innovation Plan 2022-2027, carried out with the support of MCID, project no. PN 23 05 and through Program 1-Development of the national research development system, Subprogram 1.2 - Institutional performance - Projects to finance the excellent RDI, Contract no.18PFE/30.12.2021.

ILRC 2024 CLRC