Assessment of overlap function retrievals using ALHAMBRA dual multispectral Raman lidar

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Abstract: The determination of overlap functions in lidar systems is essential for accurate aerosol profiling, particularly in the near-field range overlap between the telescope field of view and laser beam arise. Despite the various methods proposed, obtaining accurate results remains a challenge, especially under heterogeneous aerosol conditions. This study evaluates different experimental approaches, including Klett-Fernand and Raman inversion methodologies, along with a direct methodology that benefits from having near- and far-range telescope signals from the same lidar system. By analyzing data from the ALHAMBRA dual multiwavelength Raman lidar system, the effectiveness and limitations of these approaches are assessed. The results underscore the importance of accurately retrieving overlap functions for atmospheric vertical profiling and highlight the potential of new possible approaches to decrease uncertainties associated with lidar inversion algorithms and lidar ratio assumptions.

1. Background

An accurate determination of overlap function in lidar systems is crucial for reliable aerosol profiling, particularly in the near-field range where lidar signals experience varying alignment between the emitted laser beam and the receiver's field of view. This effect is so influential that the study of important exchange processes in the lower layers of the troposphere may become unfeasible [1]. Also, inaccuracies in a lidar's overlap function can lead to errors in automatically detecting the planetary boundary layer or low clouds [2]. Several methods, including theoretical, ray-tracing approaches, have been proposed to determine the overlap function [2-4]. However, obtaining accurate results remains a challenge, especially under heterogeneous aerosol conditions. The dependence on atmospheric conditions and the complexity of measuring system parameters, represents significant constraints. To overcome these limitations, several experimental approaches to determine the overlap function have been subsequently developed. This paper aims to show in detail the pros and cons of the application of two approaches using Klett-Fernand [5] and Raman [6] inversion methodologies together with a direct methodology which only requires elastic signals provided by both near- and far-range subsystems.

2. Instrumentation

The ALHAMBRA dual multiwavelength Raman lidar system is deployed at the UGR urban station in Granada, Spain, as part of the AGORA (Andalusian Global Observatory of the Atmosphere). It belongs to the European Aerosol Research Lidar Network (EARLINET) and recently integrated into Aerosol Remote Sensing ACTRIS infrastructure.
ALHAMBRA consists of two subsystems. The near-field subsystem focuses on the atmospheric boundary layer (ABL) and includes elastic detection at 1064, 532, and 355 nm and N_2 vibrational Raman (VR) detection at 532 and 355 nm. The far-field subsystem extends to the low stratosphere, covering elastic detection at 1064, 532, and 355 nm, as well as N_2 rotational Raman (RR) detection at 1064, 532, and 355 nm. Each subsystem includes

water vapor detection (ω) at 355 nm. The linear particle depolarization ratio (δ) can be determined at 532 and 355 nm. Figure 1 presents a scheme of the system (Raymetrics S.A.). Both the far- (left) and near-field (right) subsystem are shown. This scheme offers views from both the front face and the top perspective. Additionally, Table 1 summarizes several important features for both subsystems such as configuration type, telescope diameter, focal length, field of view and full overlap height. By having the near-field subsystem, the total overlap height can be significantly reduced to approximately 200 meters above ground level, improving lowermost layers monitoring.

Table 1. Summary of some important Alhambra's features for overlap determination.

Subsystem	**Near-field**	**Far-field**
Configuration	Bi-axial	Co-axial
Main mirror diameter (mm)	200	400
Focal length (mm)	1000	4000
Field of view (mrad)	2.5	0.9
Full overlap height (m)	200	800

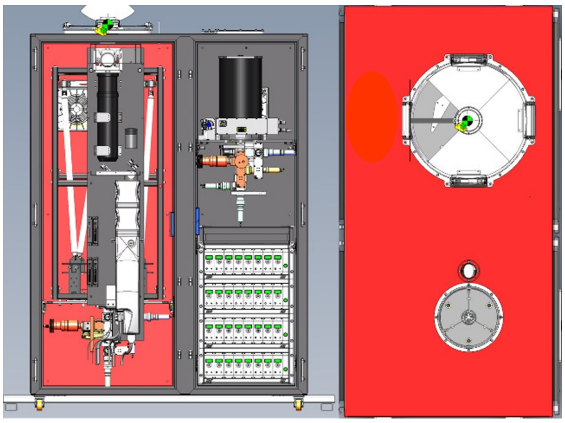

Figure 1. Scheme of the ALHAMBRA dual multiwavelength Raman lidar. The system front face features the far-field and the near-field subsystem. Also, the lidar system's top view show the co-axial far-field subsystem is situated at the top and the bi-axial near-field subsystem at the bottom.

3. Methodology

In 2002, Wandinger and Ansmann presented an iterative algorithm which operates independently of knowing specific lidar system parameters and functions effectively under both uniform and varying aerosol conditions. It relies on the assumption of identical overlap profiles for elastic backscatter and Raman channels, with the particle extinction-to-backscatter ratio (lidar ratio) being the main influencing factor. The impact of lidar ratio is reduced in clear atmospheric conditions. The difference between the aerosol-particle backscattering coefficients derived from Klett and Raman methods is then used to iteratively determine the overlap function.

An alternative explicit formulation was proposed by Comerón et al. in 2023 [4]. The methodology consists of deriving an explicit formula of the overlap function using both elastic and Raman signals. Neither an iterative procedure nor Klett and Raman inversions are required in this method.

Finally, using the advantage of having two subsystems measuring simultaneously within the same lidar system, an alternative approach is presented. It retrieves the overlap function as the near-to-far range telescope raw signal ratio at the same wavelength and detection mode.

4. Overlap retrieval assessment

We used data provided by ALHAMBRA to analyze different overlap function retrievals. Figure 2 shows the 1-hour average range-corrected signal (RCS) at 532 nm for 27th June 2023 at UGR station (AGORA). The purely rotational Raman channel at 531 nm for both iterative and explicit approaches was used.

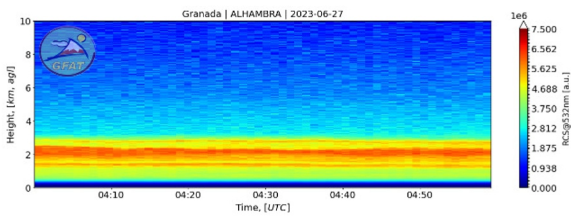

Figure 2. Range-corrected signal at 532nm over a nighttime hour average (04:00-04:59 h UTC) for 27th June 2023 at UGR station (AGORA).

The overlap functions obtained by means of iterative [3], explicit [4] and near-to far range approaches are shown in Figure 3.

The overlap function retrieved through iterative and explicit method are shown overlapping, with differences below 1%. By contrast, the near-to-far range overlap function values are below. The underestimation of the overlap function may alter the overlap correction significantly, resulting in changes in intensive aerosol properties at the lower layers.

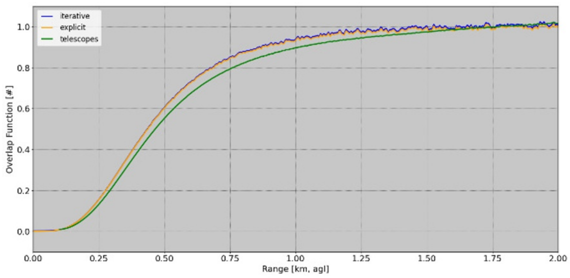

Figure 3. Overlap functions obtained by means of iterative, explicit, and near-to-far range algorithms.

In Figure 4 are shown the particle extinction and backscatter coefficients, and lidar ratio at 532nm retrieved with the overlap-corrected elastic and Raman signals using the overlap functions derived from iterative retrieval (blue), explicit retrieval (orange) and near-to-far range telescope retrieval (green). Looking at the extinction coefficient, both iterative and explicit approaches present a similar behavior, whereas near-to-far range telescope approach tends to larger values between 0.5 and 2 km and values below zero between 3 and 4 km. This may indicate an unproper correction of the overlap function. Lidar ratio profiles provide insight into the confidence level of the method employed. The overlap correction allows to improve the lowermost part of the lidar ratio profiles, allowing the identification of different aerosol sublayers according to the increasing lidar ratio trend with height.

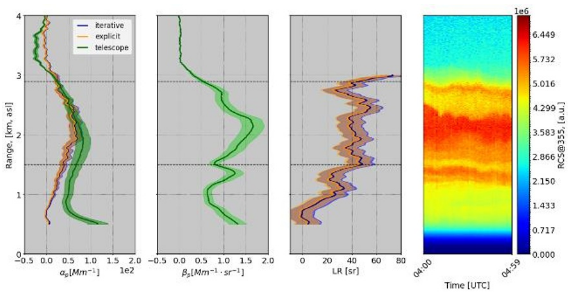

Figure 4. From left to right: particle extinction, backscatter, lidar ratio, and range-corrected signal at 532nm over a daytime hour average (04:00-04:59 h UTC) for 27th June 2023 at UGR station (AGORA).

5. Conclusions

Obtaining an accurate overlap function results to be of the utmost importance in order to provide a reliable atmospheric vertical profile at the near range.

The assessment of the overlap function retrievals has shown how both iterative and explicit approaches offer a similar reliability, not only regarding to minor differences found between overlap functions, but also providing a reliable overlap correction which can be observed in Raman extinction and intensive properties such as lidar ratio. By contrast, the alternative near-to-far range approach shows not to be as feasible as previous ones, especially once aerosol load decrease. Therefore, further research is required as it can potentially reduce the uncertainty resulting from the lidar relationship hypothesis.

6. Conclusions

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