WP20–JRA1: Lidar and sunphotometer – Improved instruments, integrated observations and combined algorithms

Deliverable D20.8: Recommendations for the improvement of daytime lidar capabilities within the network – Summary of guidelines for the network resulting from Task 20.1

1. Previous activity in WP20.1

In the deliverable D20.5 "Report on the implementation and test of optimized techniques for daytime Raman lidar observations" the outcome of the comparison of different lidar configurations used for the retrieval of the aerosol extinction coefficient exploiting the Pure Rotational Raman Spectrum (PRRS) has been provided. The study was based on the use of theoretical optical ray-tracing and spectroscopy simulations. Several configurations for the receiver of a Rotational Raman Lidar for daytime conditions were compared: they are based on the use of narrow-bandwidth filters plus edge filters, grating spectrometers, and broadband filters. Hybrid solutions making use of filters and gratings at the same time had been considered as well.

To show the performances of the different lidar receiver configurations, a blind test was performed. We calculated the night-time and daytime aerosol extinction profiles for the selected options starting from a known scenario. The atmospheric scenario used as the reference profile is represented by one of the night-time measurements observed with the MUSA lidar at CNR-IMAA Atmospheric Observatory – CIAO (15.72 E, 40.60 N , 760 m a.s.l., Potenza, Italy).

Results showed that the configurations based on the use of two grating spectrometers are highly reliable in the retrieval of extinction profiles both during night-time and daytime conditions (Serikov et al., 2010), while those based on the use of interferential and edge filters (also based on the exploitation of the fixed depolarization ratio of the RRL spectrum of 75%, see Reichardt et al., 2012 and Wandinger et al., 2012) can be operated in an efficient way, but only if the rejection of the Rayleigh backscattered signal is on the order of 10^{-5}. Hybrid solutions based on the use of one grating spectrometer and an edge filter to suppress the Rayleigh backscattering show good performances and they proved to be an opportunity to reduce the number of degrees of freedom in the lidar receiver with respect to the double-grating configurations, though this option needs to be more extensively tested and assessed. A last alternative approach is to select a portion of the RR spectrum characterized by low temperature sensitivity inside one of the spectral branches using broadband filters. Centering the filter transmission band near the temperature insensitive lines of the RR spectrum decreases the temperature sensitivity of the RR scattering cross section to a level appropriate for tropospheric extinction measurements.

According to the simulations described in the D20.5, broadband channels can be implemented only if using a filter with a high rejection of the elastically backscattered radiation in the spectral region within ±0.2 nm from the Rayleigh scattering wavelength and if a sufficient stability with temperature can be achieved. An alternative solution is to get the full PRRS and to reject the Rayleigh backscattered signal up to 10^{-5} using a notch filter with a bandwidth smaller than 0.2 nm.

The techniques developed and described above to improve Raman lidar daytime capabilities are not only based on efficient receiver systems and spectral selection units, but also on the use of receivers able to minimize the region close to the ground level where the lidar signals are affected by the incomplete overlap between the lidar source and the receiver FOV, which creates problems to the retrieval of aerosol optical properties. The study of different telescope solutions, reported in the D20.5, has shown that the Schmidt-Cassegrain is the only telescope able to compare with refractor telescopes and should be preferred to other reflectors. Anyhow, in order to design a more compact tool, aspheric lenses must be preferred, though they are limited as most of the refractor telescopes to the commercially available lens size, typically lower than 2 inches. Larger customized lenses might have a very high cost.

2. Test with broadband filters

The retrieval of the aerosol extinction coefficient using a lidar receiver for the detection of the PRRS based on a double-grating spectrometers has already proven to be robust in the recent past (Serikov et al., 2010). An example is provided by the system running since 2010 in the framework of the Barbados Cloud Observatory, a joint project of the Max Planck Institute for Meteorology in Hamburg and the Caribbean Institute for Meteorology and Hydrology. Quicklooks of routine measurements and retrievals of aerosol and water vapor are available at http://barbados.zmaw.de/lidarql.

In the past, Rotational Raman Lidar configurations based on the use of the interferential filters and the exploitation of the fixed depolarization ratio of the RRL spectrum of 75% (Reichardt et al., 2012; Wandinger et al., 2012) have been mainly used for the detection of temperature and only more recently, in a limited way, for the retrieval of the aerosol extinction coefficient, and they need a more extensive evaluation.

A recent novelty is represented by the use of brodband filters. A practical implementation of rotational Raman measurements has been reported in the last ACTRIS WP2/WP20 joint workshop in Lille, in October 2014. The implementation has been done in two existing lidars (the NASA/GSFC multi-wavelength Raman lidar and the LOA multi-wavelength Raman lidar by Dr. Igor Veselovskii, Physics Instrumentation Center, Troitsk, Moscow Region) to obtain measurements of aerosol extinction and backscattering at 532 nm. Two interference filters of 2.3 nm width are used to select a spectral range characterized by low temperature sensitivity within the anti-Stokes branch of the RR spectrum. The filters have been manufactured by Alluxa, CA, USA. The transmittance curve is reported in Fig. 1. The laser line is at 532.12 nm. The suppression of the elastic scattering at 532.12 nm is realized with an optical depth >4 per filter, i.e. an overall optical depth >8 (Veselovskii et al., 2015b).

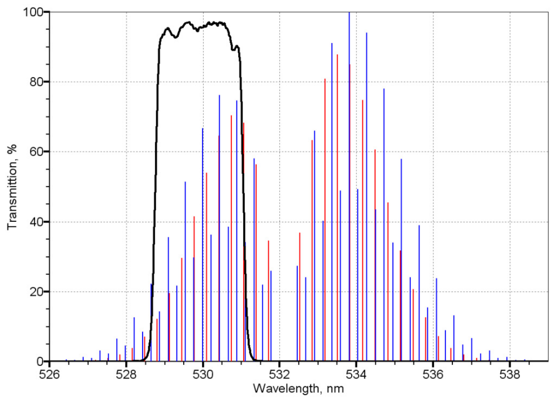

Figure 1: PRRS of nitrogen (blue) and oxygen (red) for T = 300 K. The black line shows the transmittance of the interference filter used in the experiment. In this case, the laser line is at 532.12 nm (Veselovskii et al., 2015b).

Simulations demonstrate that the temperature dependence of the scattering cross section does not exceed 1.0% in the 230-300 K range, making the accurate correction for this dependence quite easy. Moreover, variations in the atmospheric temperature profiles, in general, contribute with an error in calculated extinction of less than 2% for extinction values of 0.1 km^{-1} and greater (Veselovskii et al., 2015a; Veselovskii et al., 2015b).

Using the scattering cross sections provided by Fenner et a. (1973), we estimate that the scattered power in the RR channel is a factor of 15 higher than that of the nitrogen vibrational-rotational Raman channel at 608 nm. Thus, under skylight-limited conditions, the RR channel would provide a larger signal-to-noise ratio, if the width of the filter used for the vibrational-rotational Raman measurement is wider than approximately 0.15 nm.

The tests reported in Figure 2, in line with the outcome of the simulations presented in the deliverable D20.5, show that the Raman lidar using a broadband filter for the PRRS detection has the capability of providing 532-nm measurements and was used for regular observations. Figure 2 shows a case where the profiles of the aerosol extinction and backscatter coefficients at 532 nm are computed from both nitrogen vibrational-rotational Raman spectrum and PRRS. The maximal difference between the backscattering profiles was observed in the maximum of the scattering layer at approximately 1750 m height and did not exceed 2%, which is within the random uncertainty of the lidar measurements. The extinction profile is retrieved in both cases up to about 3.5 km in night-time conditions where most of the tropospheric aerosol is observed. This figure also demonstrates the improvement of the extinction calculation when the RR signal at 530 nm is used instead of that of vibrational scattering at 608 nm.

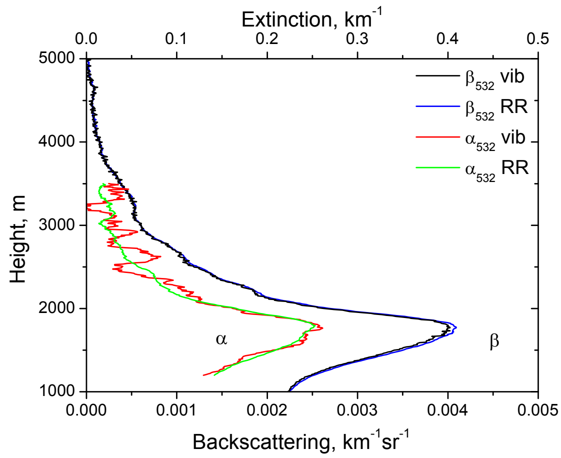

Figure 2: Extinction and backscatter coefficients at 532 nm computed from nitrogen vibrational Raman (vib) and from PRRS signal (RR).

3. Final recommendations

Aerosol extinction profiles are quite frequently measured with elastic-backscatter lidars using Fernald or Klett inversion techniques in which the lidar ratio and the extinction at a reference altitude have to be assumed. By using the nitrogen vibrational-rotational Raman signal, the retrieval of the aerosol extinction coefficient is possible with the single assumption about the wavelength dependence of the aerosol extinction. The use of pure rotational Raman scattering, instead of vibrational-rotational, removes the concern due to wavelength scaling, while simultaneously permitting measurements to take advantage of a much larger cross section and, therefore, making the retrieval of the aerosol extinction profiles also during daytime.

From the outcome of the simulation study reported in D20.5 and from the tests available in the literature, it is possible to come up with the following main recommendations:

1. the best performances, both for the background and the level of cross-talk suppression, are obtained with the double-grating spectrometers, with a cross-talk suppression better than 10^{-7};
2. good performances, both for the background and the level of cross-talk suppression, are also obtained with filter-based solutions, when the cross-talk suppression is better than 10^{-5};

3. good performances, both for the background and the level of cross-talk suppression, are obtained using broadband filtering, with a cross-talk suppression better than 10^{-8} (when two filters in a row are applied).

All these solutions proved to be efficient and represent a suitable way to detect the rotational Raman scattering for retrieving aerosol extinction profiles at daytime.

Also the hybrid solutions mentioned in the deliverable D20.5 should be considered for further assessment. However, in terms of providing recommendations for the improvement of daytime lidar capabilities within the network, the second or third solution should be preferred, because this would require for most of the lidar systems available in the ACTRIS infrastructure equipped with a Raman channel only the replacement of the Raman filter (the one in the channel dedicated to the detection of the vibrational-rotational Raman spectrum) and, if necessary, the corresponding beam splitter in front of it, and a readjustment of the channel optical gain without significant modification in the receiver design.

This result well fits with the final aim of the ACTRIS WP20.1, and this solution could be quickly implemented throughout the ACTRIS infrastructure with the consequent large potential to provide aerosol extinction profiles in the troposphere also during daytime and thus allow the related inversion of $3\beta+2\alpha$ optical data to particle microphysics. Further tests will be performed also at 355 nm in Potenza, at NASA/GSFC and in Moscow. These tests were expected by the end of ACTRIS, but they have been unfortunately postponed due to the delays in the delivery of the filters by Alluxa, CA, USA, now expected for mid-April. The results of the tests, which will be likely closed in Potenza by end of May 2015, will be in any case shared with the whole ACTRIS community and beyond, and they will be integrated in the recommendations provided in this document.

References

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