Aerosol Vertical Profiles from the Space-Borne Lidar CALIOP and the Ground-Based Raman Lidar at Lecce (Italy): Intercomparison Study

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ABSTRACT

Lidar measurements co-located in space and time with space-borne lidar CALIOP measurements are regularly performed at the Physics Department of Universita' del Salento since June 2006. Preliminary results on the comparison of CALIPSO level 2 aerosol backscatter coefficient profiles (β(*z*)) to nighttimes ground-based, Raman-lidar β(*z*) profiles are presented in this study. In particular, 3 selected study cases representative of measurements performed in cloudy- and clear-sky conditions are addressed. Accordance on top and base heights of cloud and aerosol thick layers (>1 km) is generally satisfactory. But, thin aerosol layers may not be even detected. It is shown the best agreements between satellite- and ground-based β(*z*) profiles may not occur with spatially closest profiles, as a consequence of the high variability over space and time of aerosol properties. Results on the comparison of CALIOP lidar ratios (LR) to Raman lidar LR values are also presented.

1. INTRODUCTION

The characterization of aerosol properties is crucial to understand their direct and indirect radiative effect on the Earth-Atmosphere budget. However, the understanding of aerosols effects on climate is particularly difficult because aerosols are of quite different type and shape, ranging from desert dust to urban pollution, and because aerosol concentrations vary strongly over time and space. The aerosol remote sensing from long-term operation satellites provides a means to achieve a global and seasonal characterization of aerosols. Satellite sensors provide global images of the entire Earth and allow resolving the spatial patterns resulting from the spatial inhomogeneities of aerosol sources and the temporal patterns resulting from the short lifetimes of aerosols, which are on the order of a few days to a week [1]. The last generation of satellites carrying instruments such as the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Multiangle Imaging Spectroradiometer (MISR) reveal the big interest of the scientific community in getting worldwide aerosol characterizations. However, passive remote sensors such as MODIS and MISR are not able to provide information on the aerosol vertical distribution: a rather important parameter to proper quantify aerosol effects on climate. The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) provide now days the best opportunity to address the 4-dimensional distribution of aerosol and clouds on a global scale [2]. A two-polarization Lidar system referred as Cloud and Aerosol Lidar with Orthogonal Polarization (CALIOP) on board of CALIPSO provides vertical information on aerosol and clouds. The CALIOP laser transmitter consists of two identical diode-pumped Nd:YAG lasers that operate at 1064 nm and 532 nm. The receiver subsystems measure the backscattered signal intensity at 1064 and the two orthogonal polarization components at 532 nm [3]. Comparisons with ground-base lidar observations are required to increase and validate the accuracy of aerosol optical properties retrieved from CALIOP's measurements. In particular, ground-based lidar measurements must be performed when CALIPSO overpasses the ground-based lidar site within a maximum distance of 80 km and within a maximum time difference of the 2 hours, in accordance with the scientific CALIPSO team requests.

Lidar measurements co-located in space and time to space-borne lidar CALIOP measurements are regularly performed at the Physics Department of Universita' del Salento, within the ESA-CALIPSO Project (Contract N° 21487/08/NL/HE), to contribute to the validation of CALIOP products. This paper presents preliminary results on the comparison of nighttimes CALIOP and ground-based Raman-lidar measurements. An overview of the validation approach is given in Section 2. Results and conclusion are in Section 3 and 4, respectively.

2. VALIDATION APPROACH

The complete documentation on CALIPSO operation and level-1 and level-2 CALIOP data is available from the NASA Langley Research Centre Atmospheric Science Data Centre (http://eosweb.larc.nasa.gov). The attenuated backscatter coefficient profile at 532 nm, i.e. the range corrected lidar signal for less than of a calibration constant, represents the main product of level-1 CALIOP data [3]. Level-2 CALIOP products provide the vertical location of aerosol and cloud layer boundaries and backscatter coefficient (β(z)) vertical profiles at 532 nm in addition to the assumed lidar ratio (LR(z)) profile. In this paper, we perform direct profile-to-profile comparisons of β(z) and LR(z).

The ground-based Raman lidar, hereafter denoted UNILE-lidar, is located in the suburb of Lecce's town (40º, 20' N, 18º, 6' E) and it is based on a frequency tripled Nd-YAG laser (355 nm). The UNILE Raman-lidar provides during night-time operation, extinction coefficients, β(z), and LR(z) vertical profiles at 355 nm. Column-averaged Angstrom coefficient (Å) values retrieved from the AERONET sun-sky photometer operating at the lidar site (http://aeronet.gsfc.nasa.gov, Lecce_University) and 7-day analytical backtrajecto-

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ries are used to select the Å value that allow getting β(z) profiles at 532 nm from the UNILE-lidar β(z) profiles at 355 nm. It is worth mentioning that UNILE-lidar measurements performed within a time interval Δt = 50 minutes, centred to the time of the closest CALIOP overpass, are averaged to retrieve β(z) profiles to be compared to the corresponding ones by CALIOP.

3. Results

Profile-to-profile inter-comparison results on the 3 selected study-cases are following.

3.1 Cloudy-sky study-case: September 16, 2006

Figure 1 (blue line) shows the backscattered coefficient profile at 355 nm retrieved from UNILE Raman-lidar measurements performed on September 16, 2006 from 00:34 to 01:24 UTC. We observe from Fig. 1 that aerosol particles are located up to ~ 4 km of altitude. The large β(z) signal from 7.6 to 11.3 km is due to the presence of clouds. CALIOP level-2-40 km data retrieved from measurements performed at 00:59 UTC and at a horizontal distance from the UNILE-lidar site d_{C-U} = 11.1 km, also reveal the presence of a cloud layer from 8.2 to 11.5 km, as it turns out from Fig. 1 (red line) that represents the vertical profile of CALIOP level-1 attenuated backscatter coefficient at 532 nm. The difference on cloud layer top-height by CALIOP and the UNILE-lidar is lower than 2%. Conversely, Fig.1 indicates that CALIOP estimates the cloud layer base about 7% higher than UNILE, in accordance with previous studies [4].

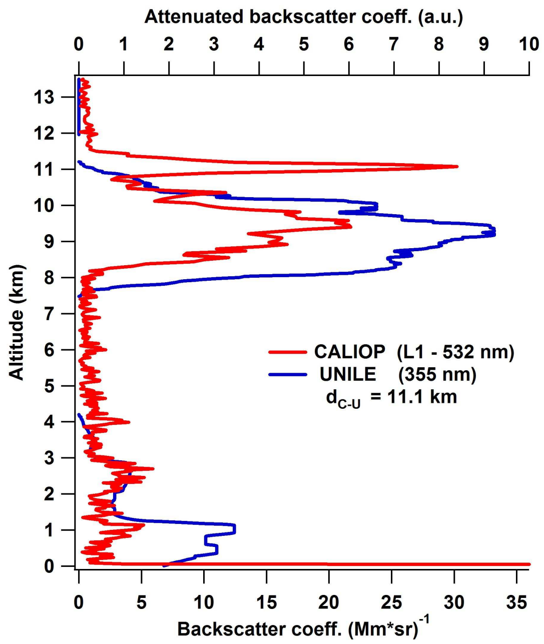

Figure 1. Vertical profile of CALIOP level-1 attenuated backscatter coefficient (red line) at 00:59 UTC and of the UNILE-lidar β(z) at 355 nm (blue line), retrieved by measurements performed from 00:34 to 01:24 UTC. d_{C-U} represents the horizontal distance of CALIOP from the UNILE-lidar site.

The attenuated backscatter red profile of Fig. 1 reveals a poor sensitivity of CALIOP to detect aerosol layers below a thick cloud layer [4]. This last comment is also supported by Fig. 2 that shows the level-2-40 km backscatter coefficient profile (red line) retrieved by CALIOP at 00:59 UTC and at a distance d_{C-U} = 11.1 km.

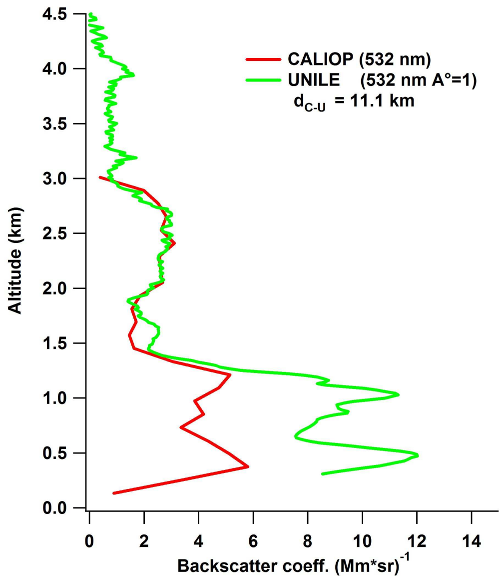

Figure 2. Vertical profile of the backscatter coefficient at 532 nm retrieved by CALIOP measurements at 00:59 UTC (red line) and by UNILE Raman lidar measurements performed from 00:34 to 01:24 UTC (green line).

The solid green lines in Fig. 2 represents the β(z) profile at 532 nm calculated from the UNILE-lidar β(z) profile at 355 nm by assuming a column-averaged Angstrom coefficient value Å = 1. Statistical errors on β(z) values are less than 5% up to ~2 km and less than 30 % above. We observe from Fig. 2 that base and top height of the aerosol layer extending from 0.2 up to 3 km retrieved by CALIOP and UNILE lidar measurements are in satisfactory accordance.

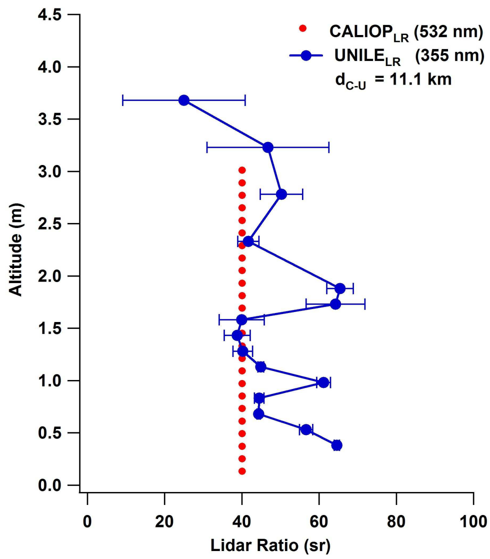

Figure 3. *Vertical profile of LR values retrieved by UNILE Raman lidar measurements at 355 nm (blue*

line) and assumed in CALIOP retrieval algorithm (red dots)

However, the differences between CALIOP- and UNILE-β(z) values that are on average of 10±14% from 1.8 up to 3 km of altitude, get of 50±9% from 0.3 up to 1.2 km of altitude. The assumption of a lidar ratio LR = 40 sr, constant with altitude from 0.133 up to 3 km (Fig. 3, red dots), to retrieve the CALIOP-β(z) profile, probably also contributes to the large differences between the two profiles of Fig. 2 at altitudes smaller than 1 km. Figure 3 (blue line) shows the LR profile at 355 nm retrieved by UNILE Raman lidar measurements. Horizontal bars represent uncertainties on lidar ratio values. LR values depend on aerosol optical and microphysical properties and the Raman-lidar profile at 355 nm of Fig. 3 indicates that aerosol properties vary with altitude. Conversely, the aerosol layer from 0.133 up to 3 km of altitude is considered made by a uniform layer of dust particles in accordance with CALIOP retrieval algorithm. 7-day analytical back trajectories by NASA GSFC (http:// www.aeronet.gfsc.nasa.gov/) indicate that on the night of September 16, 2006, air masses from north-west Africa are advected over south-east Italy above ~1.5 km of altitude. But, lower altitude air masses cross north-west Europe before getting to south-east Italy and several studies have revealed that polluted-dust particles are on averaged monitored over the Mediterranean basin during dust outbreaks.

3.2 Clear-sky study-case: August 20, 2008

Figure 4 (green line) shows the backscatter coefficient profile at 532 nm retrieved from UNILE Raman-lidar measurements performed on August 20, 2008 from 00:36 to 01:26 UTC by assuming a column averaged Angstrom coefficient value Å = 1. The blue line in Fig. 4 that represents the LR(z) profile at 355 nm retrieved from UNILE Raman lidar measurements, indicates that a rather uniform aerosol layer extends from about 1 up to 3 km of altitude. The solid (dotted) red line in Fig. 4 represents the level-2-40 km backscatter coefficient profile retrieved by CALIOP at 01:01 UTC and at a distance d_{C-U} = 31.6 km (10.2 km). Figure 4 reveals that the CALIOP β(z) profile retrieved from measurements performed at a larger distance from the UNILE lidar site (solid red line) is in better accordance with the UNILE β(z) profile than the one retrieved 10.2 km away from the ground-based lidar. The differences between the UNILE-β(z) profile and the CALIOP-β(z) profile retrieved at a distance d_{C-U} = 31.6 are on average of 10±9% from 1.3 to 2.9 km. Conversely, the differences between the green- and the red-dot-profile of Fig. 4 are on average of 31±25% from 1.3 to 2.9 km. This last result that is probably due to the high variability over time and space of aerosol particles may indicate that the air masses sampled by the UNILE-lidar from 00:36 to 01:26 UTC, have optical and microphysical properties closer to the ones sampled by CALIOP 31.6 km away from the UNILE-lidar site. Last comment is supported by Fig. 5 showing the UNILE–lidar β(z) profiles retrieved from measurements performed from 00:46 up to 01:16 UTC (dashed green line) and from 01:16 up to 01:47 UTC (grey dotted line), in addition to CALIOP β(z) profiles. Figure 5 shows that the vertical structure of the UNILE–β(z) profiles changes within few minutes. In addition, Fig. 5 shows that the UNILE-lidar measurements performed at later times: from 01:16 up to 01:47 UTC (grey dotted line), provide a β(z) profile in better accordance with the one retrieved by CALIOP 10.2 km away from the lidar site (red-dot profile): the differences between the to profiles are on average of 21±20%.

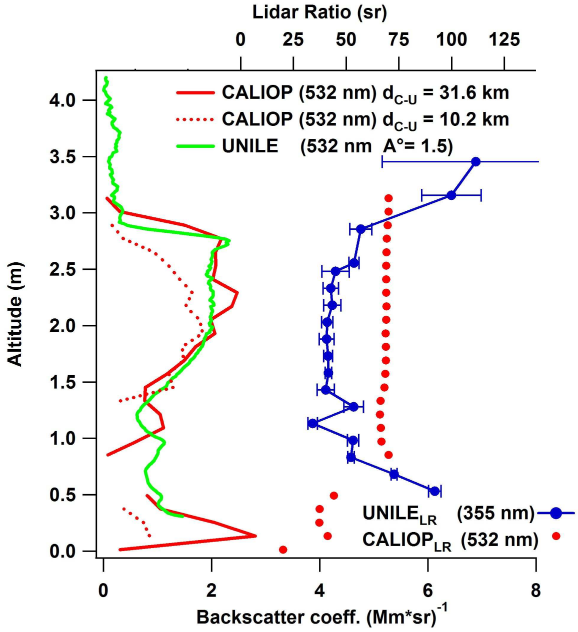

Figure 4. *Backscatter coefficient vertical profile by CALIOP at 01:01 UTC and at a distance d_{C-U} = 10.2 km (dotted red line) and a distance d_{C-U} =31.6 km (solid red line), and by the UNILE Raman lidar at 532 nm (green lines). Blue and red dots represent the vertical profiles of the lidar ratio by UNILE at 355 nm and by CALIOP at 532 nm, respectively.*

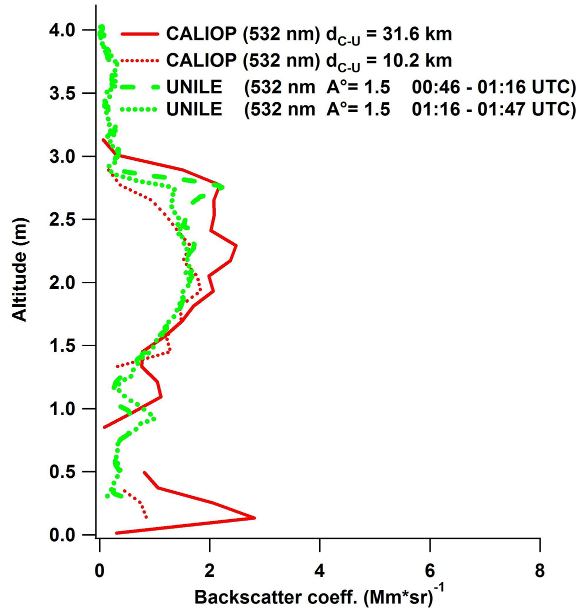

Figure 5. *Backscatter coefficient vertical profile at 532 nm by CALIOP at 01:01 UTC and at different d_{C-U} distances and by the UNILE Raman lidar at different sampling time intervals.*

3.3 Clear-sky study case: October 7, 2008

Figure 6 (grey line) shows the backscattered coefficient profile at 532 nm retrieved from UNILE Raman-lidar measurements performed on October 7, 2008 from 00:36 to 01:26 UTC by assuming a column averaged Angstrom coefficient value Å = 1.5. The blue line in Fig. 6 that represents the UNILE LR(z) profile at 355 nm, indicates that the optical and microphysical properties of the aerosol particles located from about 0.5 up to 2 km are quite dependent on altitude: aerosol located from 0.8 to 1.4 km are characterized by a lidar ratio at 355 nm spanning the 35-50 sr range. Conversely, aerosol particles located from 1.6 to 2.0 km are characterized by UNILE-LR values spanning the 65-97 sr range. The solid red line in Fig. 6 represents the level-2-40 km backscatter coefficient profile retrieved by CALIOP at 01:01 UTC and at a distance d_{C-U} = 12 km. A lidar ratio at 532 nm of 65 sr from 0.4 up to 1.7 km (Fig. 6, red dots) is assumed to retrieve the CALIOP β(z) profile. An aerosol layer from 0.9 up to 1.6 km is detected by CALIOP, in fair accordance with ground-based lidar measurements. The differences between the two β(z) profiles are on average of 39±27% from 0.3 up to 1.7 km. It is worth noting that the thin aerosol layer between 0.6 and 0.9 km detected by UNILE is not resolved by CALIOP that provides β(z) values larger than 60±15% at altitudes lower than 0.6 km. Differences on air mass properties sampled by CALIOP and UNILE are probably responsible for this last result. However, the poor ability of CALIOP to detect thin aerosol layers may also contribute to the differences revealed by Fig. 6 between the backscatter coefficient profile by CALIOP and the one by the UNILE-laser.

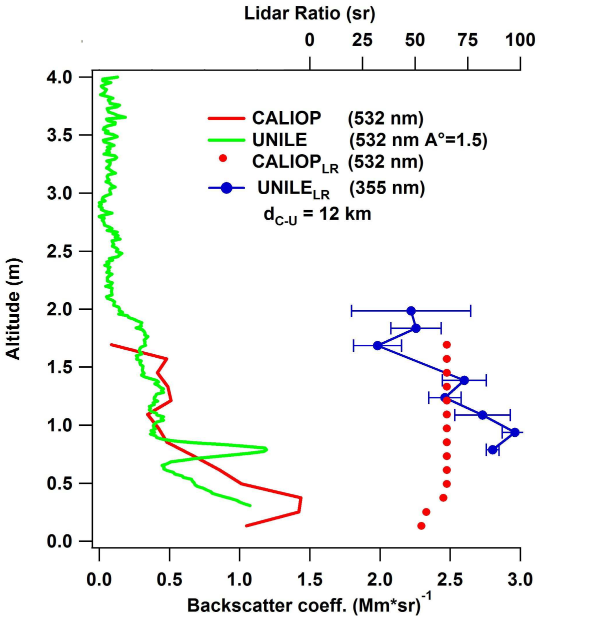

Figure 5. *Vertical profile of β(z) at 532 nm by CALIOP at 01:01 UTC (solid red line) and by the UNILE Raman lidar (green lines). Blue and red dots represent the vertical profile of the lidar ratio by UNILE at 355 nm and by CALIOP at 532 nm, respectively*.

4. Conclusion

Selected study-cases have been analyzed to contribute to the validation of CALIOP products. The analysis of CALIOP measurements performed on September 16, 2006 has lead assuming that CALIOP can provide a better estimate of the cloud-top. Whereas, ground-based lidars can provide a better estimate of the cloud-base, mainly in presence of thick cloud layers, in accordance to previous studies. The reduced sensitivity of CALIOP to detect low altitude aerosol layers below thick cloud layers has also been demonstrated. The profile-to-profile comparison has revealed that the accordance on top and base heights of level-2 detected cloud and aerosol thick layers (>1 km) is generally satisfactory. However, thin layers (< 1 km) may not be even detected and the accordance on β(z) profile modulations is generally rather poor. We believe that the high variability over space and time of cloud and aerosol properties significantly contribute to the differences revealed by profile-to-profile comparisons. Even if, the rather uniform profile of the CALIOP assumed lidar ratio can also contribute to the profile-to-profile differences.

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