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CALIPSO

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Validation of CALIPSO space-borne-derived aerosol vertical structures using a ground-based lidar in Athens, Greece

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Abstract

We present initial aerosol validation results of the space-borne lidar CALIOP retrievals -onboard the CALIPSO satellite-, using coincident observations performed with a ground-based lidar in Athens, Greece (37.9° N, 23.6° E). A multi-wavelength ground-based backscatter/Raman lidar system is operating since 2000 at the National Technical University of Athens (NTUA) in the framework of the European Aerosol Research Lidar NETwork (EARLINET), the first lidar network for tropospheric aerosol studies on a continental scale. Since July 2006, a total of 40 coincidental aerosol ground-based lidar measurements were performed over Athens during CALIPSO overpasses. The duration of the ground-based lidar measurements was approximately two hours, centred on the satellite overpass time. From the statistical analysis of the ground-based/satellite correlative lidar measurements, a mean bias of the order of 22% for daytime measurements and of 8% for nighttime measurements with respect to the CALIPSO profiles was found for altitudes between 3 and 10 km. The mean bias becomes much larger for altitudes lower than 3 km (of the order of 60%) which is attributed to the decrease of the CALIOP signal-to-noise ratio, as well as to the incomplete overlap height region of the ground based lidar and finally to the distance between the two instruments, resulting to the observation of possibly different air masses. In cases of aerosols layers underlying cirrus clouds, comparison results for aerosol tropospheric profiles become worst, illustrating the limitations of space-borne downward-looking lidar measurements due to strong signal attenuations.

1 Introduction

Lidar techniques play an increasing role in future Earth observation strategies. CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization), onboard the NASA/CNRS CALIPSO satellite, provides a first opportunity to study in detail the performance and the scientific value of a space-borne aerosol lidar during a long-term mission.

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CALIPSO observations provide global, but snapshot-like view of aerosol vertical distributions. However, combined studies with ground-based lidars together with transport modeling techniques will allow full exploitation of this data for a detailed description of the temporal and spatial aerosol distribution and evolution on a global scale (Ansmann, 2006).

Space-borne active remote sensing (e.g. LITE (Lidar Inspace Technology Experiment; McCormick et al., 1993), GLAS (Geoscience Laser Altimeter System; Spinhirne et al., 2005) and CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations; Winker et al., 2004, 2006, 2007)) of atmospheric aerosols and clouds is the key for providing global vertically resolved observations that are needed to better understand a variety of aerosol-cloud radiation-climate feedback processes (e.g. Spinhirne et al., 2005; Berthier et al., 2006).

Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) onboard CALIPSO, provides information on the vertical distribution of aerosols and clouds as well as on their optical properties over the globe with unprecedented spatial resolution (Winker et al., 2006, 2007). Validation of CALIOP products via intercomparison with independent ground-based or airborne lidar measurements is essential to the production of a high quality dataset (Liu et al., 2006; Winker et al., 2006). To our knowledge, a very small number of studies concerning CALIPSO validation exist currently in the literature, especially using ground-based coincident lidar measurements. McGill et al. (2007) have presented initial airborne validation results where cloud layer top determinations from CALIPSO are found to be in good agreement with those from the Cloud Physics Lidar (CPL) onboard the NASA ER-2 research aircraft. On the other hand Kim et al. (2008), have presented initial validation results of the space-borne lidar CALIOP data using coincidental observations from a ground-based lidar in Seoul located at the National University (SNU), Seoul, Korea (37.46° N, 126.95° E). Their study was based in a small number of coincident measurements (six selected cases between September 2006 and February 2007, including 3 daytime and 3 night-time observations). The authors found good agreement for the night-time CALIOP data, but relative large discrepancies were

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found at the height range above PBL for the daytime data, even if absolute difference values are not mentioned. They attributed the discrepancies found to the small signal-to-noise ratio of the CALIOP measurements due to contamination by solar background (McGill et al., 2007).

5 Finally, the EARLINET lidar teams have presented some initial validation results referring to the first year of operation of the CALIOP (Mattis et al., 2007; Mona et al., 2007).

10 Since June 2006, when CALIOP was launched, the ground-based stations of the European Aerosol Research Lidar Network perform coincident correlative measurements for CALIPSO validation studies. EARLINET was established in 2000 to derive a comprehensive, quantitative, and statistically significant data base for the aerosol distribution on the European scale (Bösenberg et al., 2003). At present, EARLINET consists of 25 partners, including backscatter lidar stations, 16 combined backscatter/Raman lidar stations and 8 multi-wavelength Raman lidar stations which are used to retrieve the aerosol microphysical properties (Mattis et al., 2007). EARLINET follows a specific measurement strategy for CALIPSO validation, according to which, each station performs measurements each time CALIPSO overpasses the station location within a maximum distance of 100 km and 2 h (so-called “case 1” measurements). Additional measurements are performed at the lidar station which is closest to the actually overpass site (“case 2”). If a multi-wavelength Raman lidar station is overpassed, then also the next closest multiwavelength station performs measurements as well (“case 3”) (Mattis et al., 2007). In this study we present initial validation results of the space-borne lidar CALIOP aerosol retrievals, using 40 coincident “case 1” measurements performed in Athens, Greece, with NTUA’s multi-wavelength ground-based Raman lidar. For this study, Level 1 CALIPSO data are used referring to attenuated aerosol backscatter profiles. In the Sect. 2 we describe the ground-based and the space-borne instrumentation used along with the validation approach followed. Results and conclusions are presented in Sects. 3 and 4 respectively.

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2 Instrumentation and methods

2.1 Description of the ground-based lidar system of NTUA

The NTUA compact 6-wavelength Raman lidar system is based on a pulsed Nd:YAG laser emitting simultaneously at 355 nm, 532 nm and 1064 nm. The respective emitted output energies per pulse are 75 mJ, 130 mJ and 140 mJ, with a 10 Hz repetition rate. The optical receiver is a Cassegrainian reflecting telescope with a primary mirror of 300 mm diameter and of focal length $f=600$ mm, directly coupled through an optical fiber to the lidar signal multi-channel detection box.

The elastically backscattered lidar signals (at 355, 532 and 1064 nm), as well as those generated by stimulated Raman scattering by atmospheric N_2 and H_2O (at 387, 607 and 407 nm, respectively) are simultaneously recorded by photomultipliers (PMTs) and an avalanche photodiode system (APD), after the spectral separation of the returned lidar signals (Mamouri et al., 2007; Papayannis et al., 2007). The PMT detectors used are operated both in the analog and photon-counting mode and the spatial raw resolution of the detected signals is 15 m.

NTUA's lidar is used to perform continuous measurements for the retrieval of the aerosol optical properties over Athens inside the Planetary Boundary Layer (PBL) and the lower free troposphere. The lidar signals detected at 355, 387, 532, 607 and 1064 nm are used to derive the aerosol backscatter (at 355, 532 and 1064 nm) and the extinction (at 355 and 532 nm) coefficient profiles (Ansmann et al., 1992), while the 407 nm channel is used to derived the water vapor mixing ratio profiles (Whitman et al., 1992). In the frame of the EARLINET and EARLINET-ASOS projects, the NTUA lidar system was quality assured by performing direct intercomparisons, both at hardware (Matthias et al., 2004) and software (Böckmann et al., 2004; Pappalardo et al., 2004) level.

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2.2 Description of the space-borne CALIOP lidar system

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) mission (<http://www-calipso.larc.nasa.gov/>) is a collaborative effort between the NASA Langley Research Center (LaRC), the Centre National d'Etudes Spatiales (CNES), Hampton University (HU), the Institut Pierre Simon Laplace (IPSL), and Ball Aerospace and Technologies Corporation (BATC). It aims to study the global radiative effects of aerosols and clouds on climate. CALIPSO is an Earth Science observation mission that was launched on 28 April 2006. It flies at a nominal orbital altitude of 705 km and an inclination of 98 degrees as part of a constellation of Earth-observing satellites including Aqua, PARASOL, and Aura – collectively known as the “A-train” (Hostetler et al., 2001). The CALIPSO mission includes active lidar and passive sensors to obtain unique data on aerosol and cloud vertical structure, cloud particle phase and classification of the aerosol size.

The CALIPSO payload consists of three co-aligned, near-nadir viewing instruments: a 2-wavelength polarization-sensitive lidar, an imaging infrared radiometer (IIR), and a high-resolution wide field camera (WFC). CALIOP is an elastically backscattered lidar operating at 532 and 1064 nm, equipped with a depolarization channel at 532 nm that provides high-resolution vertical profiles of aerosols and clouds (Winker et al., 2007). It includes two Q-switched lasers operating at 20.16 Hz with a pulse length of about 20 ns. Each laser generates nominally 220 mJ per pulse at 1064 nm, which is frequency-doubled to produce about 110 mJ of pulse energy at 532 and 1064 nm. Beam expanders reduce the angular divergence of the transmitted laser beam to produce a beam diameter of 70 m at the Earth's surface (corresponding to a nominal laser beam divergence of 100 μ rad) (Hostetler et al., 2006).

CALIPSO produces Level 1 and Level 2 science data products (http://www-calipso.larc.nasa.gov/products/CALIPSO_DPC_Rev2x4.pdf).

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The Level 1 data include:

- lidar calibrated and geolocated profiles with associated browse imagery
- IIR geolocated, calibrated radiances registered to a 1 km grid centered on the lidar track
- WFC geolocated radiances at 125 m and 1 km resolution.

Level 2 products include:

- a cloud layer product with horizontal resolutions of 1/3 km, 1 km and 5 km (cloud height, thickness, backscatter, extinction, ice/water phase, emissivity, and ice particle size)
- an aerosol layer product at 5 km resolution (height, thickness, optical depth, and integrated attenuated backscatter)
- an aerosol profile product with a horizontal resolution of 40 km and vertical resolution of 120 m (backscatter, extinction, and depolarization ratio)
- IIR Level 2 cloud emissivity and particle size in 1 km pixels, with a 70 km swath width co-located to the lidar track.

The Level 1 V2 (Version 2.01) attenuated backscatter profile products are used for the validation presented in this paper. Level 2 aerosol products relative to aerosol extinction profiles are not discussed here, since the lidar ratio assumption of CALIPSO algorithm for the calculation of backscatter and extinction profiles introduces an additional uncertainty that complicates the validation. Additionally, the backscatter and extinction coefficients reported in the Level 2, (version 2.01) release of the CALIPSO profile products are still unvalidated, thus are beta-quality data products. As such, they still contain a number of errors and/or inconsistencies. According to CALIPSO team, these products contain no data quality information, and hence cannot be used as stand-alone products.

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2.3 Description of the validation approach

For the calculation of the attenuated backscatter coefficient from the ground-based lidar measurements in this study, the procedure suggested by Mona et al. (2007) to convert backscatter coefficients into CALIPSO-like attenuated backscatter is followed.

5 A summary of the methodology is given in the following:

The total backscatter coefficient $\beta_{\text{tot}}(z)$ is calculated from the molecular backscatter coefficient $\beta_{\text{mol}}(z)$ and the particle backscatter coefficient $\beta_{\text{par}}(z)$ as:

$$\beta_{\text{tot}}(z) = \beta_{\text{par}}(z) + \beta_{\text{mol}}(z) \quad (1)$$

10 The particle transmission term $T_{\text{par}}^2(z)$ of the lidar equation (Ansmann et al., 1992) can be obtained from the profile of the particle extinction coefficient $\alpha_{\text{par}}(z)$:

$$T_{\text{par}}^2(z) = \exp\left(-2 \int_z^{z_s} \alpha_{\text{par}}(z) dz\right) \quad (2)$$

Finally, the attenuated backscatter coefficient, $\beta'_{\text{tot}}(z)$ is defined as:

$$\beta'_{\text{tot}} = \beta_{\text{tot}}(z) T_{\text{par}}^2(z) T_{\text{mol}}^2(z) T_{\text{O}_3}^2(z) \quad (3)$$

15 For a downward-looking lidar as CALIOP, the attenuated backscatter coefficient is the lidar range-corrected signal normalized by a system dependent constant. To retrieve attenuated backscatter profile from NTUA's ground-based measurements, it has to be taken into account that NTUA and CALIOP transmission terms are different, because the first system is upward-looking while the second is a downward-looking lidar. However, following the above described procedure of Mona et al. (2007), the differences
20 between the final calculated parameters due to upward and downward field of views are removed, since the aerosol transmission term is calculated as a function of the aerosol extinction profile. Therefore, starting from the ground-based measurements

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and following this approach, the downward and upward derived attenuated backscatter coefficients are comparable without any assumptions.

Since the extinction coefficient profile has to be known, the proposed methodology by Mona et al. (2007), can be applied only for Raman ground-based lidars. Thus, for the validation purposes of this paper, only the attenuated backscatter coefficients at 532 nm (where a Raman channel is in operation) are used, since no Raman channel is operating at 1064 nm. Additionally, the extinction information needed for the transmission calculation, limits the correlative dataset only to nighttime measurements, when a Raman measurement can be performed. To overcome this limitation and since the daytime ground-based measurements of NTUA are always following nighttime measurements of the previous CALIPSO coincidental measurement (with approx. 11 h of difference), the mean lidar ratio measured for nighttime is used to convert daytime backscatter to extinction values. Finally, to remove molecular backscatter differences for the comparison needs the calculation of the atmospheric density was based in temperature and pressure values used by the CALIPSO algorithm.

3 Results and discussion

In this paper a total of 40 coincident ground-based lidar measurements for CALIPSO overpasses over Athens for the time period between July 2006 to December 2007 are analysed. During this period, a total of 87 “case 1” correlative measurements were performed. From this dataset, 47 cases were excluded for the purposes of our aerosol concentrated analysis, due the presence of low clouds (e.g. 2–4 km a.s.l.). The procedure followed for the analysis of the final 40 coincidental ground-based and CALIPSO profiles is first demonstrated for a specific case study in the following.

In Fig. 1, the CALIPSO overpasses (nighttime on 00:34 UT and daytime on 11:34 UT) are presented for the case study of 22 August 2007, selected for analysis demonstration purposes. The location of the ground-based station is presented on the map of Fig. 1 with a red square highlighted with an arrow. For the daytime overpass the dis-

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tance between the CALIPSO's and NTUA's lidar is of the order of 80 km, while for the nighttime overpass is 16 km. Synchronous daytime and nighttime measurements were performed by NTUA's lidar within two hours centred on CALIPSO overpass time. In Fig. 2, timeseries of the ground-based range-corrected lidar signal at 532 nm are shown for 22 August 2007, along with the overpass times of CALIPSO highlighted with black lines. This figure shows that one hour around the CALIPSO overpass time the dust atmospheric structure is quite stable for both daytime and nighttime measurements. The attenuated ground-based backscatter profiles used for the validation purposes were calculated from range-corrected lidar signals averaged around CALIPSO overpass time for a time period of approximately 1 h. This approach was followed for the total of 40 coincidental datasets to minimize the atmospheric aerosol structure variability mainly due to evolution of the boundary layer during daytime measurements.

The CALIPSO's total attenuated backscatter at 532 nm is presented in Fig. 3 for the case study of 22 August 2007. The CALIPSO location nearest to ground-based station is superimposed (black lines). Additional vertical rectangles are plotted to indicate the distance covered by CALIPSO that corresponds to the two different horizontal resolutions that were adapted in this validation study, namely at 5 km (grey rectangle) and 20 km (black rectangle). The homogeneity of the aerosol load during these distances is confirmed by CALIPSO overpass image (Fig. 3). On 22 August 2007 a Saharan dust outbreak was occurred and elevated dust layers were observed by CALIPSO over European mid-latitudes, in height ranges between 2.5 and 4.5 km. The ground-based range-corrected backscatter lidar signal (Fig. 2) confirms that an aerosol load located in the height range between 2.5 and 4.0 km was also present over Athens for both the nighttime and daytime measurements above the NTUA lidar station.

In Fig. 4, the CALIPSO attenuated backscatter coefficient is plotted against the coincidental ground-based profile calculated following the approach described by Mona et al. (2007) for the measurements performed on 22 August 2007 during nighttime (left panel, up) and daytime (left panel, down). On the right panels of Fig. 4, the percent biases of CALIPSO to ground-truth lidar measurements with respect to CALIPSO pro-

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file for nighttime (right panel, up) and daytime (right panel, down) are presented. For the calculation of the percent bias, satellite and ground based lidar data were vertical averaged to 250 m bins, so the profiles would be correlative. Regarding the CALIPSO data, the attenuated backscatter profile is rather noisy and requires significant time averaging for a proper identification of the aerosol layers. For time averaging purposes, CALIPSO attenuated backscatter profiles are averaged for two selected horizontal resolutions, one for 5 km (thin grey line) and one for 20 km (thin black line). Averaging daytime CALIPSO data for 20 km distance, resulted in an improved comparison with the ground-based profile, decreasing mean bias from -16% (5 km horizontal averaging) to -8% (20 km horizontal averaging). For nighttime measurements, 5 km horizontal averaging resolution resulted in a satisfactory noise removal, showing no significant improvement when the averaging was performed for 20 km resolution.

The approach described for the case study of 22 August 2007 was followed for the analysis of the total of 40 coincidental “case 1” datasets for both 5 km and 20 km horizontal averaging of CALIPSO data. Figure 5 presents the mean percent differences between the CALIPSO and NTUA attenuated backscatter profiles for the total of our cases, grouped in 27 cases when no cirrus were present above the aerosol layer in CALIPSO’s field of view (left panel) and in 13 cases where cirrus clouds attenuated the CALIOP’s signal (right panel). Different horizontal resolutions are plotted with gray filled squares (5 km) and black open squares (20 km). It is evident that the two systems are in better agreement when no cirrus clouds are present. For the total of 27 cases of no cirrus presence, the calculated mean biases are $-30.7\pm 30.1\%$ for 5 km horizontal resolution and $-16.6\pm 19.6\%$ for 20 km, respectively. Our results indicate that CALIPSO lidar underestimates the aerosol attenuated backscatter coefficient. The underestimation becomes much larger below cirrus clouds, where from the total of 13 cirrus cases the calculated mean biases are $-118.7\pm 143.3\%$ for 5 km horizontal resolution and $-95.5\pm 106.3\%$ for 20 km. These results indicate the limitations of space-borne downward-looking lidar measurements and imply that satellite-based CALIOP aerosol observations are not reliable under the presence of thick clouds. Similarly, Kim et

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al. (2008), found that the only reliable information in such cases is the retrieval of the cloud top height.

From the 27 cases of no cirrus presence, the mean percent biases of attenuated backscatter coefficient, binned into 250 m layers are presented in Fig. 6, grouped in daytime (left panel) and nighttime (right panel) measurements. The mean difference between the two instruments is larger for the daytime data. Averaging the CALIPSO data for 20 km distance, showed an improvement in the comparison, in contrary to 5 km distance. For the total of 12 daytime cases with no cirrus presence, the calculated mean biases were found to be $-33.7 \pm 34.4\%$ for 5 km horizontal resolution and $-22.6 \pm 25.8\%$ for 20 km respectively. For the total of 15 nighttime cases with no cirrus presence, the calculated mean biases are $-18.0 \pm 21.7\%$ for 5 km horizontal resolution and $-11.9 \pm 18.6\%$ for 20 km. The results indicate that CALIPSO measurements have a larger diversity from ground-truth during daytime. The reason might be a possible disability of the CALIPSO sensor to reconstruct well the atmospheric layers during the daytime due to the increased atmospheric background noise due to sunlight. Furthermore a possible source of discrepancies between the correlative measurements could be the different free tropospheric height regions for the calibration of the two instruments. As the aerosol backscatter in stratosphere is insignificant with respect to molecular backscatter and the molecular density, exhibiting very small variations, CALIPSO's algorithm uses the height range between 30 and 34 km for signal calibration. For NTUA ground based lidar data, the calibration is performed at the height region between 7 to 9 km. Additional differences between daytime and night-time calibration procedures applied by CALIPSO algorithm could also be an explanation for the daytime discrepancies. Calibration constants are calculated over the dark side of each orbit and then interpolated on the day side (Winker, 2006). The calibration can be performed on both the dark and daylight side of the orbit, only when cirrus of sufficient backscatter strength exists (Winker, 2006).

From Figs. 5 and 6, it is evidenced that the comparison differences become larger for the height ranges between 0 and 3 km. This can be attributed to the fact that free

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5 tropospheric aerosol load (for heights greater than 3 km) over Athens is lower than the anthropogenic aerosol load of the boundary layer. However, it is well documented in the literature that over Greece (Balis et al., 2003; Balis et al., 2004; Amiridis et al. 2005; Gerasopoulos et. al., 2006; Kazadzis et al., 2007; Amiridis et al., 2008) and especially
10 over Athens (e.g. Papayannis et al., 2005; Papayannis et al., 2007), transboundary aerosol advection in the free troposphere is frequently observed due to the proximity of the region to the Sahara desert and regions with significant biomass burning activities. To compare the coincident CALIPSO-ground based dataset under different free tropospheric aerosol loads, we present in Fig. 7, the mean biases of attenuated
15 backscatter coefficient for the 27 cases of no cirrus presence, grouped in 12 (8 nighttime and 4 daytime) cases with low free tropospheric contribution (left panel) and 15 (5 nighttime and 10 daytime) cases of large free tropospheric contribution (right panel). For the total of 12 cases with low free tropospheric contribution, the calculated mean biases are $-28.7 \pm 58.3\%$ for 5 km horizontal resolution and $-19.0 \pm 31.4\%$ for 20 km. For the total of 15 cases with large free tropospheric contribution, the calculated mean biases are $-40.7 \pm 69.3\%$ for 5 km horizontal resolution and $-45.4 \pm 57.8\%$ for 20 km. For both cases presented in Fig. 7, the comparison differences become larger for the height ranges between 0 and 3 km, while the differences between the two lidars in the free troposphere over Athens are in good agreement. Specifically for the free troposphere over Athens, mean biases for the height range between 3 and 10 km, are $-14.9 \pm 55.7\%$ for low free tropospheric contribution and $-13.0 \pm 47.0\%$ for large free tropospheric contribution, for 5 km horizontal resolution for CALIPSO data, showing no significant difference. According to our findings, the mean biases for the height range between 0 and 3 km are of the order of -70% , indicating that the CALIPSO profiles are possibly unreliable for the representation of boundary layer vertical aerosol structures.
20 However, we have to mention that below 1.0 to 1.5 km height, the differences are attributed also to the incomplete overlap of the ground-based lidar. Finally, an additional source of discrepancy could be the distance between the two instruments, resulting to the observation of possibly different air masses.
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In Fig. 8, the mean biases between CALIOP and NTUA ground-based measurements for the total of 27 correlative measurements are presented against the minimum horizontal distance between the two instruments, grouped in mean biases for the height range between 0 to 3 km (up panel) and 3 to 10 km (down panel). Figure 8 indicates that the distance between the two instruments is not a criterion to classify difference levels, and small distances do not guarantee better agreement between ground-based and space-borne aerosol measurements due to the fact that aerosol horizontal distributions are not in the most cases homogeneous.

4 Summary and conclusions

In this paper, an initial CALIPSO validation study is presented using ground-based lidar measurements. CALIPSO level 1 Version 2 aerosol attenuated backscatter profiles are compared for 40 cases when coincident lidar measurements were performed by NTUA's 6-wavelength Raman lidar system. A detailed statistical analysis was presented for the total of 40 "case 1" correlative measurements performed at the NTUA station. The first categorization of the correlative dataset was based on the presence or not of cirrus clouds below the satellite track. The mean biases for the height range between 3–10 km was found equal to $-7.3 \pm 5.8\%$ under clear skies and $-53.3 \pm 77.6\%$ in case of cirrus presence. This result illustrates not only the limitations of space-borne downward-looking and ground-based upward-looking lidar measurements due to return signal attenuations, but also the complementarity between space-borne and ground-based lidar observations for providing complete vertical structures of aerosols and clouds.

Under no cirrus presence bellow the satellite track, a better agreement was found during nighttime measurements throughout the free troposphere. Specifically, an agreement of the order of $-10.2 \pm 11.6\%$ for daytime measurements and of $-3.9 \pm 6.4\%$ for nighttime measurements was found for altitudes between 3 and 10 km. The differences between 0 and 3 km were much larger ($-59.6 \pm 20.2\%$ for daytime and

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–35.9±23.2% for nighttime). An improvement on the agreement between CALIPSO and NTUA lidars for daytime measurements was demonstrated, when the horizontal resolution for CALIOP was increased from 5 to 20 km. The results indicated that both systems revealed similar structures above the 3 km, but the discrepancy became worst for altitudes lower than 3 km, especially during daytime. This was attributed to the decrease of the CALIOP signal-to-noise ratio in the boundary layer, as well as to the incomplete overlap height region of the ground based lidar. Additionally, a possible source of discrepancies is the distance between the two instruments, resulting to the probable observation of different air masses due to the horizontal inhomogeneity of the boundary layer aerosols. Furthermore, the correlative measurements could be deviate due to the different free tropospheric height regions used for the calibration of the signals.

Finally, the mean biases between CALIOP and NTUA ground-based measurements for the total of 27 correlative cloud-free measurements versus the minimum horizontal distance between the two instruments indicate that the distance between the instruments is not a criterion to classify difference levels, and small distances do not guarantee better agreement between ground-based and space-borne aerosol measurements due to the fact that aerosol horizontal distributions are not in the most cases homogeneous. The EARLINET network performed more than 1000 correlative observations during the first year of operation of the space lidar CALIOP and the three-stage measurement schedule continues. In the future, NTUA lidar data will be used in synergy with other EARLINET's stations data for CALIPSO data validation on continental scale.

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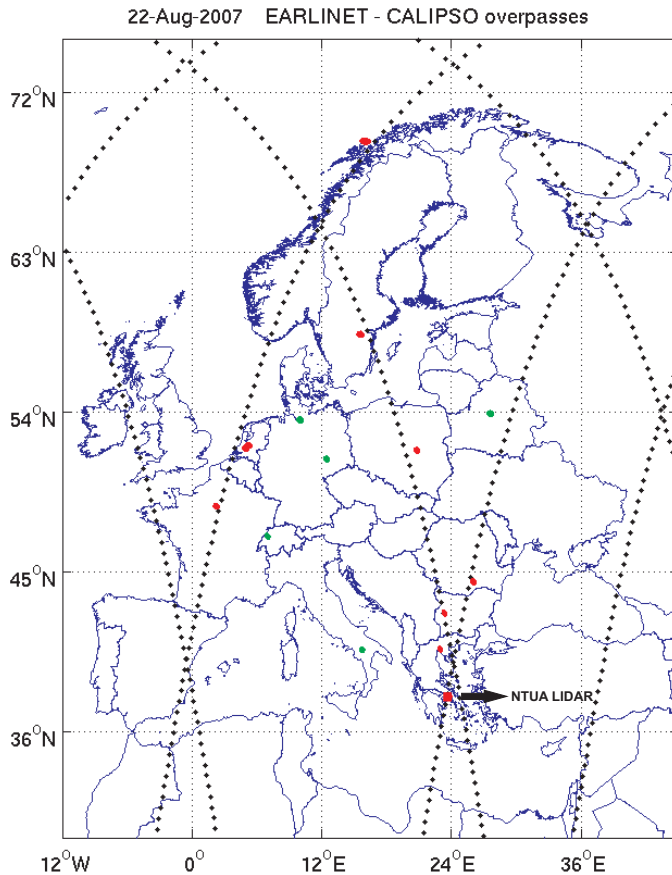


Fig. 1. NTUA's lidar station (red square) and CALIPSO ascending and descending orbits overpassing Athens (cross lines), on 22 August 2007. All the other EARLINET stations are reported as red dots for "case 1" and "case 2" and green dots for "case 3", according to CALIPSO correlative measurement strategy of EARLINET.

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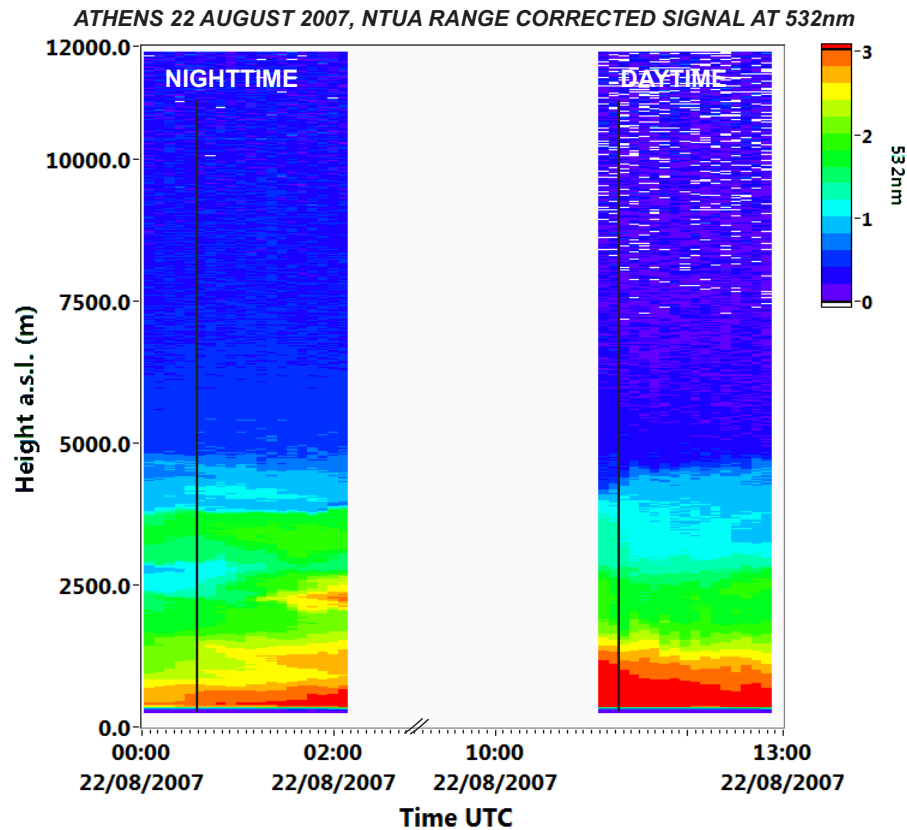


Fig. 2. NTUA's range corrected signal at 532 nm on 22 August 2007. Black lines correspond to the CALIPSO overpass time over NTUA lidar station for nighttime (00:34 UT) (left) and for daytime (11:39 UT) (right).

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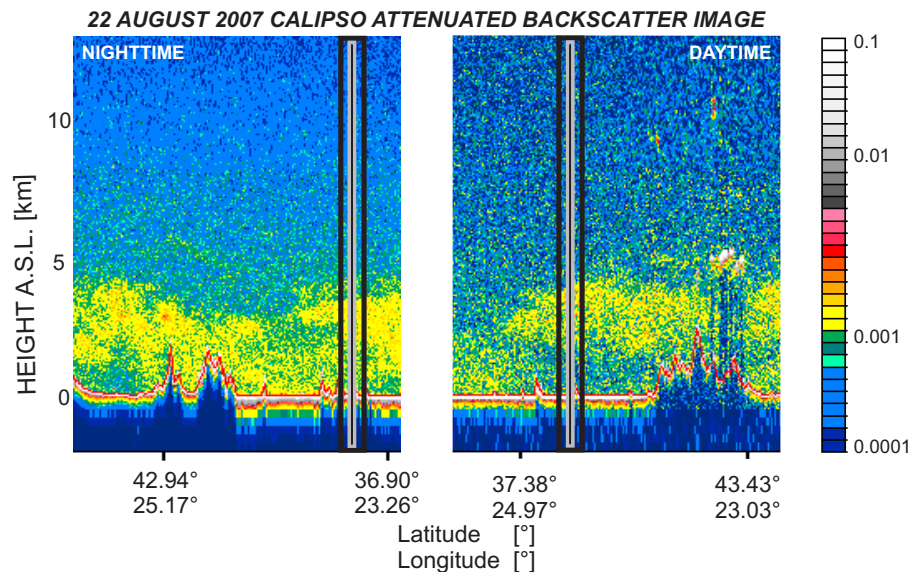


Fig. 3. CALIPSO total attenuated backscatter at 532 nm on 22 August 2007. Black lines correspond to the nearest overpass over NTUA lidar station for nighttime (00:34 UT) (left) and for daytime (11:39 UT) (right). Grey and black rectangles represent 5 km and 20 km horizontal resolution averaging period for the CALIPSO data respectively.

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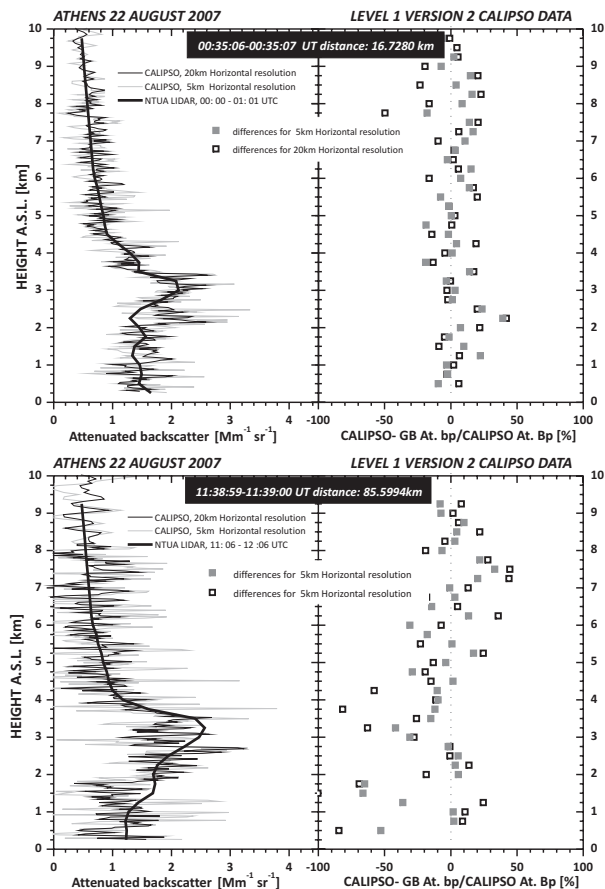


Fig. 4. CALIPSO level 1 total attenuated backscatter coefficient profiles at 532 nm for 5 km and 20 km horizontal averaging period coverage in comparison with NTUA's total attenuated backscatter coefficient (left). Percent bias binned in 0.25 km intervals (right). Daytime overpass (up), nighttime overpass (down).

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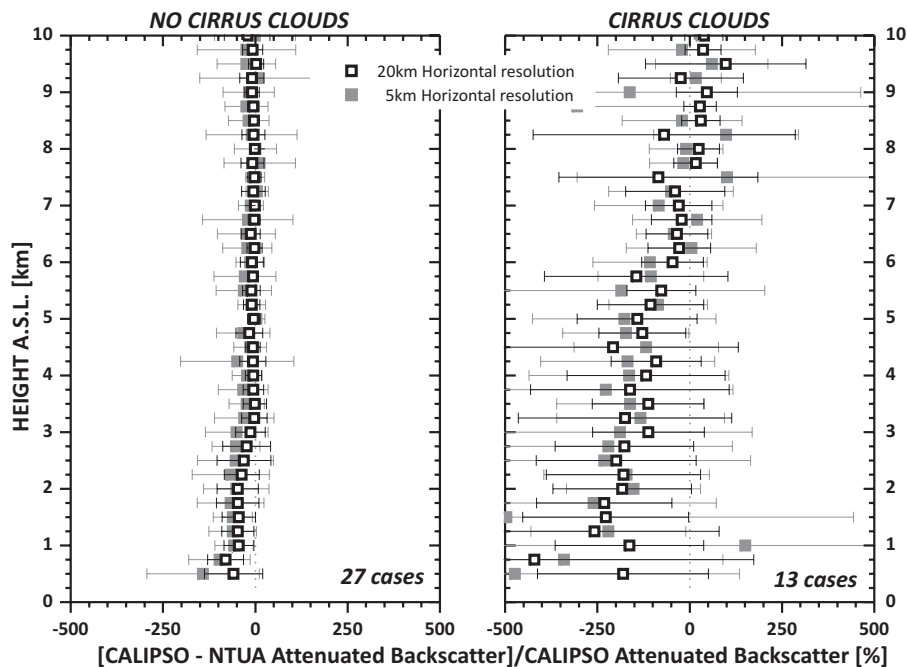


Fig. 5. Mean percent biases between CALIPSO and NTUA attenuated backscatter coefficient with respect to the CALIPSO profiles for daytime and nighttime measurements. The differences are calculated both for 5 and 20 km of the CALIPSO horizontal averaging period coverage.

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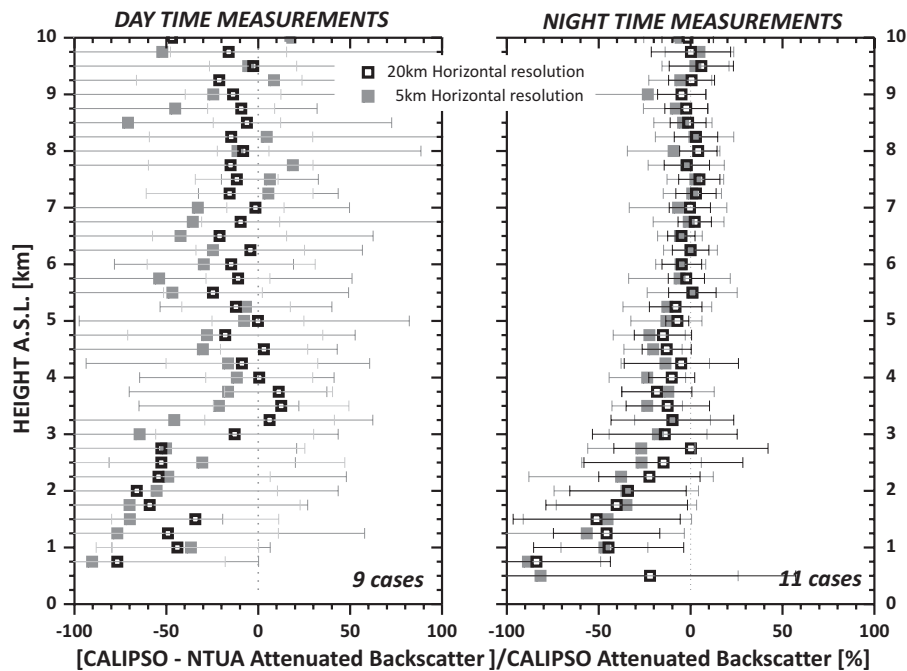


Fig. 6. Mean percent biases between CALIPSO and NTUA attenuated backscatter coefficient for cloud-free (left) and cirrus presence (right) cases.

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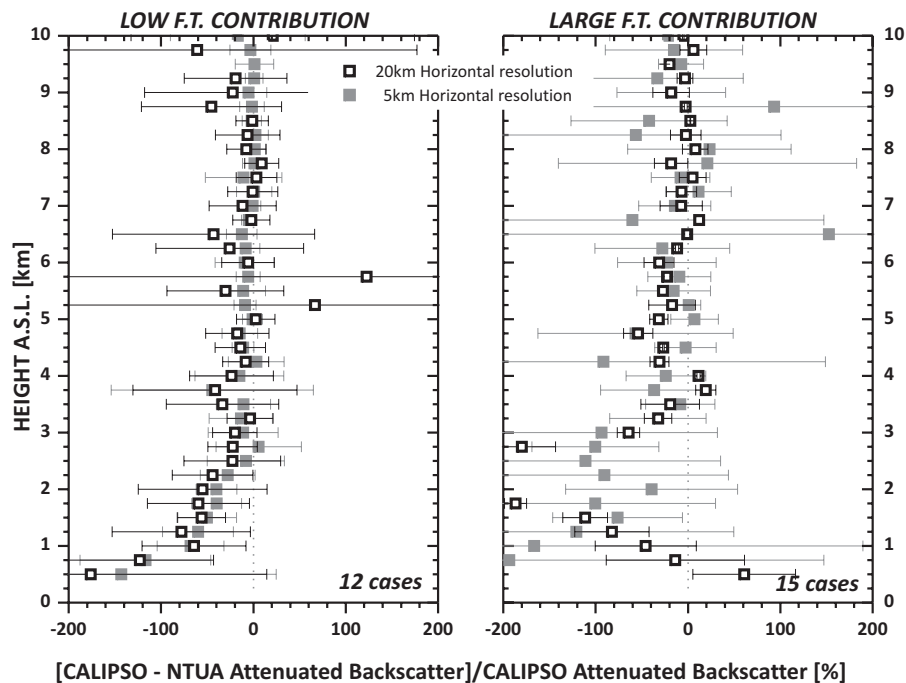


Fig. 7. Mean percent biases between CALIPSO and NTUA attenuated backscatter coefficient for low (left) and large (right) free tropospheric contribution.

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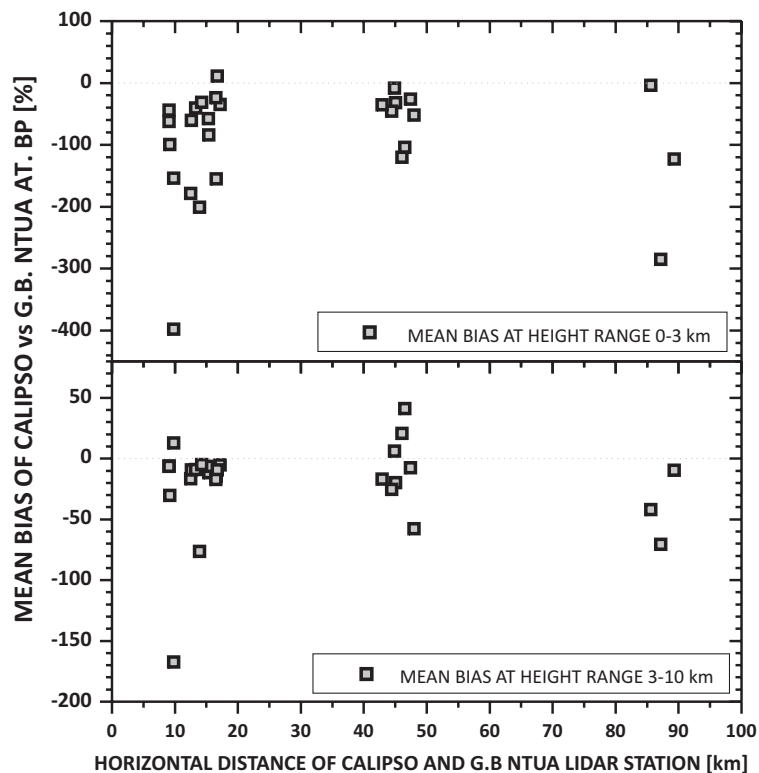


Fig. 8. Mean percent biases (0–3 km (up) and 3–10 km (down)) between the attenuated backscatter profiles of the two instruments, in relation with distance.

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