Multi-instrumental study of aerosol optical properties over the city of Sao Paulo: Lidar, sunphotometer and CALIPSO satellite

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ABSTRACT:

The objective of this project is the study of aerosols optical properties in the São Paulo atmosphere using an elastic backscattering LIDAR (Light Detection and Ranging) system set-up in the Center for Lasers and Applications (CLA) at the Instituto de Pesquisas Energéticas e Nucleares (IPEN) located at University of Sao Paulo, Brazil. Besides, our system is in the list of the correlative validation of CALIPSO Satellite mission effort. We show here a methodology to be followed and first preliminary results of the correlative measurements between the ground-base system at IPEN and the satellite mission.

Keywords: Lidar, CALIPSO, CALIPSO Validation.

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1. Introduction

The backscatter Lidar system MSP Lidar, operating since 2001, has been set-up in a suburban area in the city of São Paulo (23°33' S, 46° 44' W) in the Center of Lasers and Applications at the Instituto de Pesquisas Energéticas e Nuclear. This system provides aerosol optical properties such as backscatter and extinction coefficients, extinction-to-backscatter ratio (Lidar ratio) and the aerosol optical thickness (AOT). The Lidar data are analyzed in synergy with the AOT values obtained from the AERONET network sun-tracking photometer in visible spectral region [1]. In face of the challenge to apply these new techniques in our lab and to participate in the understanding processes of the influence of the anthropogenic aerosol on Earth's radiation balance and climate, we are part of a cooperative effort in data validation of the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO), a satellite mission designed to measure the vertical profile structure and optical properties of aerosol and clouds over the globe [2,3]. In this work we present the statistics data from correlative measures between CALIPSO Satellite and the MSP Lidar System, vertical profiles from two retrieved from both systems and a methodology approach to validate the measurements carried during the first semester of 2007 following the minimum requirements related to the time and spatial frame in which the CALIPSO overpasses takes place [4,5].

2. MSP lidar system setup

The lidar system utilized in this work is a coaxial mode single-wavelength backscatter system pointed vertically to the zenith. The light source is a commercial pulsed Nd:YAG laser with fundamental frequency at 1064 nm, which operates at the second and third harmonic frequencies, 532 nm and 355 nm, respectively. The principal functional characteristics of the system are:

- Repetition rate: 20 Hz.
- Pulse energy @ 532 nm: 100 mJ.
- Pulse duration @ 532 nm: 4 ns.
- Laser beam diameter: 7 mm.
- Divergence: 0.5 mrad.

The lidar receiver system consists of a Newtonian telescope of 30 cm de diameter, a PMT and narrow band interferences filters (~1 nm FWHM). The optics set-up is such that the maximum overlap is reached at about 300 m above the lidar system. The PMT output signal is digitized and stored by a lidar Transient Recorder LR 20-80/160 (LICEL-GmBh) which has a dual acquisition in analog and photoncounting modes.

3. CALIPSO system setup

The CALIPSO payload consists of three instruments designed to operate autonomously and continuously; a two-polarization Lidar system referred as Cloud and Aerosol Lidar with Orthogonal Polarization - CALIOP, a three-wavelength Imaging Infrared Radiometer - IIR, and a Wide Field Camera - WFC. The CALIOP laser transmitter subsystem consists of two lasers, each with a beam expander to reduce the divergence of the laser beam at the Earth's surface. These Nd:YAG lasers are diode-pumped and operate at 1064 nm and 532 nm with a pulse repetition rate of 20.25 Hz. The receiver subsystem consists of a telescope of 1 m of diameter, relay optics, detectors, preamps, dielectric interference filter and narrowband etalon to reduce the solar background for the 1064 nm and 532 nm channel, respectively. These receiver subsystems measure the backscattering signal intensity at 1064 nm and the two orthogonal polarization components at 532 nm [4].

4. CALIPSO correlative measurements

The CALIPSO mission will provide profiles of aerosol backscatter and the extinction coefficients over the globe. This validation is important because the retrieval of these products from backscatter lidar measurements requires a priori knowledge of a backscatter-to-extinction coefficient (Lidar Ratio). Such comparison will be the basis to guarantee the accuracy for the derived products data. For the CALIPSO mission, validation is defined as an assessment of the accuracy and precision of the derived science products by independent ways [6]. Aerosols and clouds require a different validation once they vary with different form not only spatially but also temporally. The aerosols have a longer spatial and temporal correlation than clouds, their height and optical thickness tend to remain fairly consistent about 50-100 km except near local sources, which guarantee a great opportunity to comparative measurements between different instruments [6]. For this reason it is important that the correlative measurements between ground-based instruments and CALIPSO ground-track should be made in coincident distances.

The CALIPSO satellite overpasses São Paulo about 5 or 6 times per month and the closest distance between the ground-track of the CALIPSO and MSP-Lidar system vary in a range of 44 to 80 km. In order to participate in the process of validation products data from CALIPSO mission, we present some first preliminary results from correlatives measurements from CALIPSO ground-track and our MSP-Lidar system. The histogram in the figure 1 shows the partial correlative measurements days for the both systems in 2007. In January measurements have not been carried out because all overpasses happened to be when there was heavy precipitation over the lidar site at São Paulo, which is very common in this period of the year since this is the so-called Brazilian wet season that comprehends the interval for November to May. In the months of February and March the CALIPSO Satellite passed over São Paulo 6 and 5 times, respectively, and the measurements have been carried out for 3 times each month. During April and May the CALIPSO passed 6 times each month but only 2 days of measurements have been made. In June we were able to measure all the five CALIPSO overpasses. It is important to mention that after the overpass it takes about 1-2 weeks to have the Level-1 aerosol data published by the CALIPSO data-analysis team. This paper is intended to cover only a few measurements and a broader view paper is planned to be submitted by the end of 2007 when we are supposed to have a larger dataset in order to carry a more detailed statistical analysis.

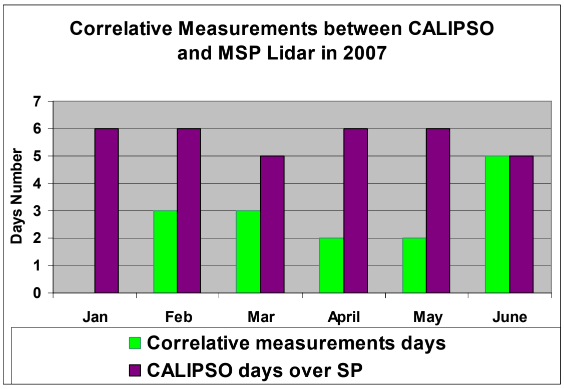

Fig. 1. Correlative measurements day between CALIPSO Satellite and MSP-Lidar system in the first semester in 2007.

4.1. Comparison between correlatives measurements

As stated before, direct comparison between correlative measurements implies that the later must be made in the same atmospheric features, but this is a difficult task for ground-based systems because the brief window of opportunity during the satellite overpass. However, aerosol air masses can have correlation scales of 50-100 km and several hours or more [6]. In this case, knowledge about trajectories is important to trace a strategy to follow and to improve matching conditions. Some correlative measurements between CALIPSO and MSP Lidar system are showed in following figures in order to present our preliminary correlation work.

Figure 2 shows the CALIPSO trajectory over São Paulo in the smaller box and the vertical profile of the 532 nm total attenuated backscattering for CALIPSO system in 02/03/2007 that begins at 16:57:56 and stops at 17:11:15 (UTC) in a coordinates range (-60.53, -33.69) to (-12.98, –49.86). The CALIPSO ground-track coordinates over São Paulo for this case is (-24.753, -47.146) and the closest distance is 69.45 km. The red box enclosures the measured region over São Paulo. The figure 3 shows the Lidar range corrected signal obtained by the MSP-Lidar system at 532 nm within 1 hour window before and after the satellite overpass.

In the same way, Fig. 4 shows the CALIPSO trajectory over São Paulo and the vertical profile by 532 nm total attenuated backscattering for CALIPSO system for night conditions in 02/23/2007 beginning at 04:30:25 and stopped at 04:43:53 (UTC) for coordinates range (-6.56, -42.46) to (-54.91, -56.69). The red box comprehends the CALIPSO ground-track region over São Paulo with coordinates values of (-23.135, -46.182) and closest distance of 46.04 km. The figure 5 shows the Lidar range corrected signal from MSP-Lidar system within 1 hour before and after the CALIPSO overpass.

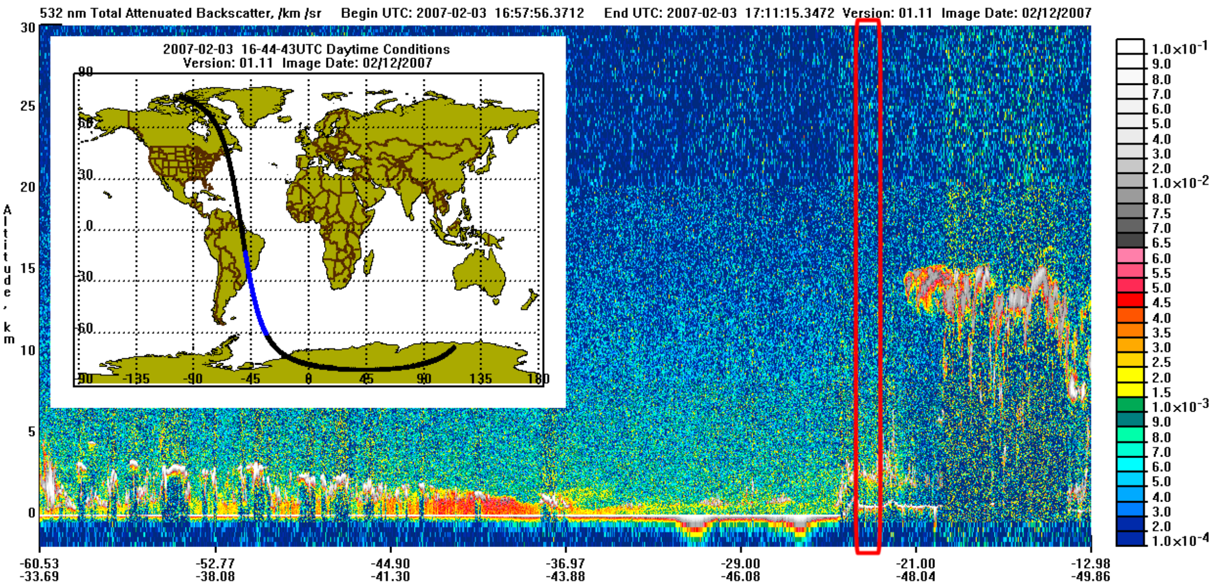

Fig. 2. The CALIPSO satellite trajectory over São Paulo and the 532 nm total attenuated backscattering from the CALIPSO system in day conditions for 02/03/2007 from NASA Langley website [2].

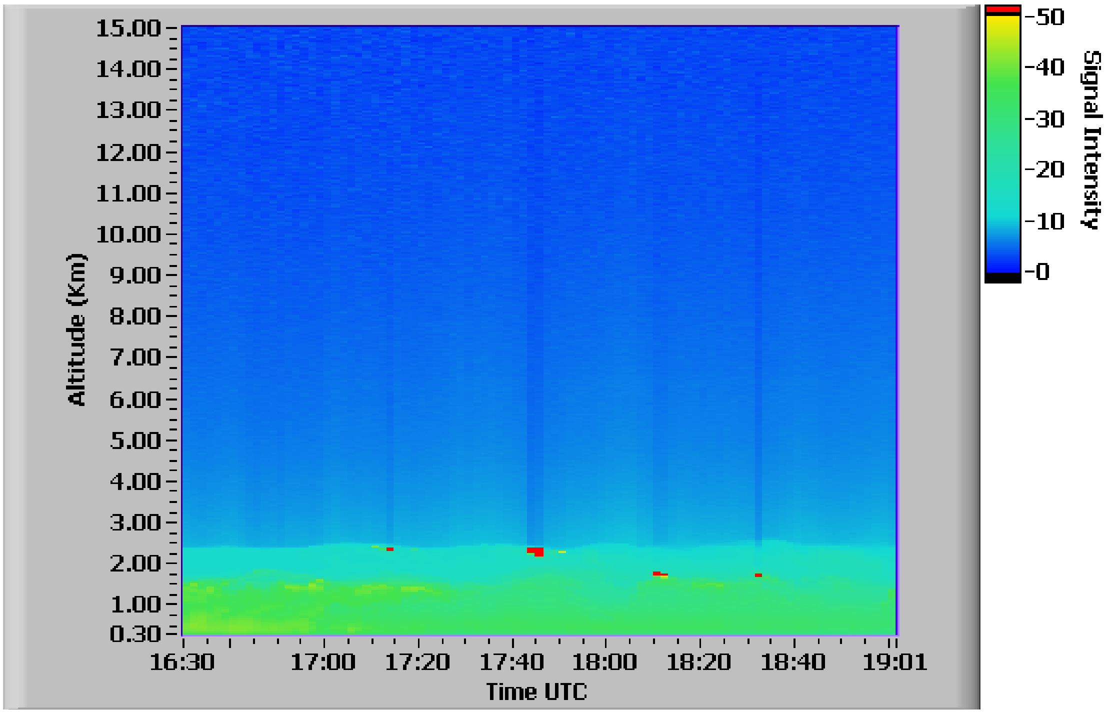

Fig. 3. The Lidar range corrected signal from MSP-Lidar system for 02/03/2007.

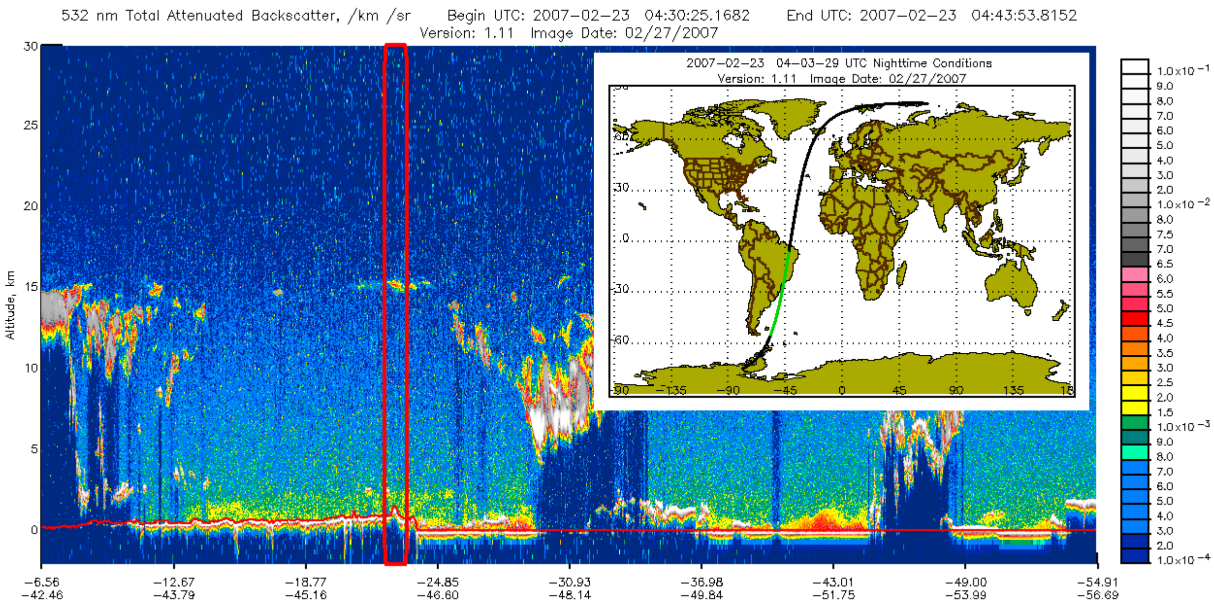

Fig .4. The CALIPSO satellite trajectory over São Paulo and the 532 nm total attenuated backscattering from the CALIPSO system in day conditions for 02/23/2007 from NASA Langley website [2].

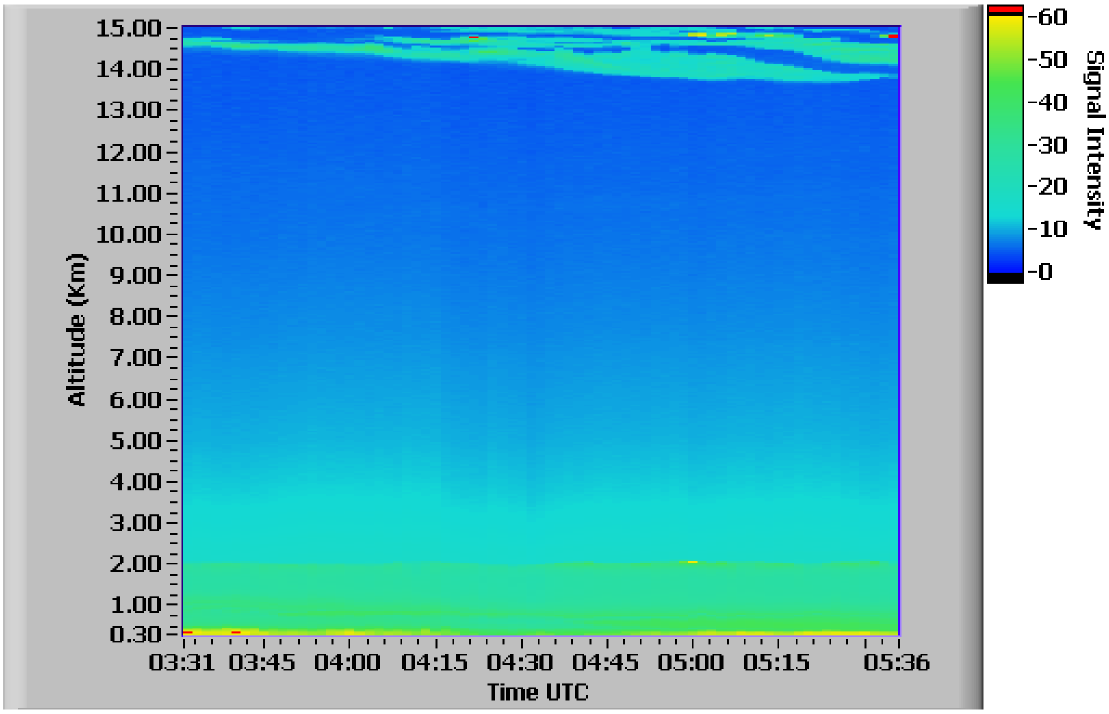

Fig. 5. The lidar range corrected signal from MSP-Lidar system in 02/23/2007.

A systematic analysis of some CALIPSO satellite products such as backscatter and extinction coefficients and AOT has not been made yet; however, the figures show that the correlative measurement agrees in some aspects such as the altitude of clouds. The figure 5 and 6 shows some cirrus clouds at altitude of 15 km, this is an evidence that both systems are detecting somehow the same atmospheric features.

The backscattering coefficient obtained by the lidar is corrected to an attenuated backscattered coefficient in order to compare with the CALIPSO data by the expression:

$$\beta_{att}(\lambda,z) = \beta(\lambda,z)\times T^2(\lambda,z)\,, \qquad (1)$$

where $\beta_{att}(\lambda,z)$ is the attenuated backscatter, in our case λ=532 nm, and $T^2(\lambda,z)$ is the two-way optical transmission from the lidar to the sample volume in question, this transmission is a sum of the molecular, ozone and aerosol contributions which were taken from external meteorological databases. In this first effort we took the molecular contribution from a radiosounding database, the ozone contribution we neglected since the heights were below 15 km, and aerosol contribution was taken from a collocated AERONET network sunphometer. The retrieval of the integrated backscatter is one of the objectives of the Level 2 algorithms from the CALIPSO Science Validation Plan and since we are not including those data here we performed the correction to our data instead.The backscattering coefficient obtained with MSP-Lidar system for the day 02/23/2007 at period of 04:19 to 04:50 (UTC) for altitude of the 1.1 km above the sea level (asl) is about 0.0022 km $^{-1}$ sr $^{-1}$ and the attenuated backscattering coefficient is about 0.002 km $^{-1}$ sr $^{-1}$ as showed in Fig. 6.

A “slice” of the total attenuated backscattering from the CALIPSO, corresponding to the red bracketed portion of figure 4 is also given in Fig. 7 in comparison with the attenuated backscattering coefficient obtained with MSP-Lidar system.

In Fig. 8 we present the percent difference of attenuated backscattering coefficients of CALIPSO and our system binned into 15 m layers. The large difference between both attenuated backscattering profiles may be attributed to strong vertical inhomogeneities in aerosol distribution along the CALIPSO overpasses.

We intend to analyze systematically the retrieves and compare the products from MSP-Lidar system and CALIPSO satellite such as Aerosol Optical Thickness (AOT), backscatter and extinction aerosol coefficients in a more detailed way in the near future. We plan also to follow the validation strategies described by Kovacs [7]. As stated before, there are difficulties in validation processes due the spatial or temporal inhomogeneities when comparing measurements which are separated in time or space, besides the matching errors. The correlative measures will continue being made within 100 km and at least 2 hour windows of observation. The idea is to perform measurements 1 hour before and 1 hour after the satellite overpass in order to guarantee the opportunity to make meaningful comparisons between the satellite sensor and the ground instrument as suggest by Kovacs [7].

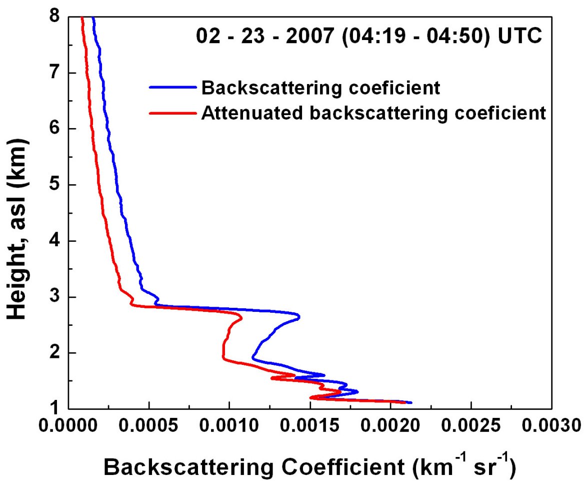

Fig. 6. Attenuated and Backscattering coefficient profiles for 02/23/2007 at period of 04:19 to 04:50 (UTC).

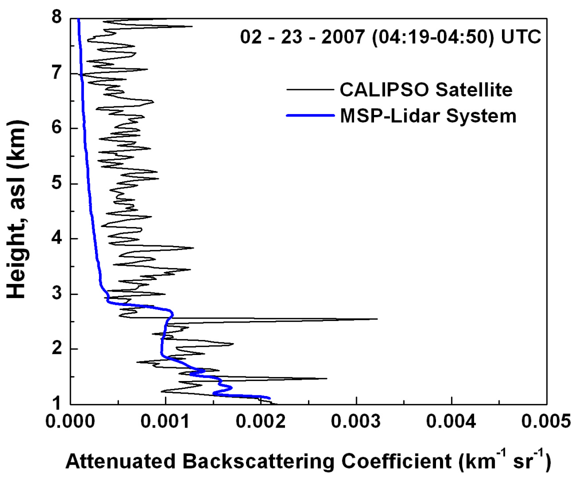

Fig. 7. Comparison between Attenuated backscattering coefficient profile from CALIPSO Satellite and MSP-Lidar System for 02/23/2007 at period of 04:19 to 04:50 (UTC).

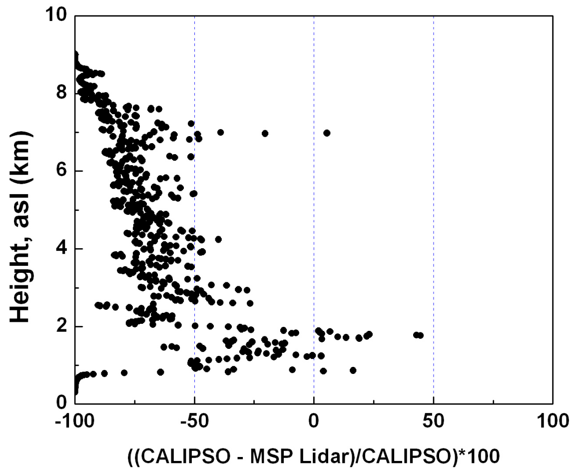

Fig. 8. Percent difference between CALIPSO and MSP-Lidar.

5. Conclusion

In this paper we presented the first preliminary results from correlatives measurements between the CALIPSO ground-track sensor and the MSP-Lidar system. It was showed the 532 nm total attenuated backscattering vertical profiles for CALIPSO system and the Lidar corrected backscattering coeficients obtained by the MSP-Lidar system. The backscattering coefficient obtained by the Lidar was corrected by the atmospheric transmission into attenuated backscattered coefficients. Both profiles presented the same features with more agreement around the range of 1 - 3 km since the CALIPSO data are normalized to a higher portion of the atmosphere. We have also to take into account the fact that the area illuminated by the CALIPSO sensor does not overlap with the zenith pointed Lidar beam from the São Paulo station besides the result shown here is just one of many to be compared along the over one year overpasses taken by CALIPSO (~ 60 overpasses altogether). We intend to carry a more detailed and systematic analysis in order to obtain and compare some CALIPSO products such as backscatter and extinction coefficients and AOT with our system as soon as the CALIPSO level 1 and 2 are corrected to have backscattering coefficients as the ground instruments provides.

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