Measurement of tropospheric aerosol in São Paulo area using a new upgraded Raman LIDAR system

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ABSTRACT

Elastic backscatter LIDAR systems have been used to determine aerosol profile concentration in several areas such as weather, pollution and air quality monitoring. In order to determine the aerosol extinction and backscattering profiles, the Klett inversion method is largely used, but this method suffers from lack of information since there are two unknown variables to be determined using only one measured LIDAR signal, and assumption of the LIDAR ratio (the relation between the extinction and backscattering coefficients) is needed.When a Raman LIDAR system is used, the inelastic backscattering signal is affected by aerosol extinction but not by aerosol backscatter, which allows this LIDAR to uniquely determine extinction and backscattering coefficients without any assumptions or any collocated instruments. The MSP-LIDAR system, set-up in a highly dense suburban area in the city of São Paulo, has been upgraded to a Raman LIDAR, and in its actual 6-channel configuration allows it to monitor elastic backscatter at 355 and 532 nm together with nitrogen and water vapor Raman backscatters at 387nm and 608 nm and 408nm and 660 nm, respectively. Thus, the measurements of aerosol backscattering, extinction coefficients and water vapor mixing ratio in the Planetary Boundary Layer (PBL) are becoming available. The system will provide the important meteorological parameters such as Aerosol Optical Depth (AOD) and will be used for the study of aerosol variations in lower troposphere over the city of São Paulo, air quality monitoring and for estimation of humidity impact on the aerosol optical properties, without any a priori assumption. This study will present the first results obtained with this upgraded LIDAR system, demonstrating the high quality of obtained aerosol and water vapor data. For that purpose, we compared the data obtained with the new MSP-Raman LIDAR with a mobile Raman LIDAR collocated at the Center for Lasers and Applications, Nuclear and Energy Research Institute in São Paulo and radiosonde data from Campo de Marte Airport, in São Paulo.

Keywords: LIDAR, Aerosols, Optical Properties, Water Vapor

1. INTRODUCTION

In recent decades, great progress has been made toward understanding exactly how aerosol particles affect the climate system. In polluted, populated regions, aerosol particles not only affect the climate but can also impair air quality and consequently endanger the health of population. Such is the case in the Metropolitan Area of São Paulo (MASP), one of the largest mega-cities in the world. It is recognized that megacities have regional and global effects on climate, and that aerosols constitute the principal tracer of those effects. Also, when studying the atmosphere of mega cities, it is of big interest to study the water vapor concentration, especially below the Planetary Boundary Layer (PBL), where the water vapor can largely interact with aerosols, depending on their chemical nature. The size increase of aerosol due the water uptake has important effects on direct radiation scattering (direct effect), but it has also influences on indirect effects, related to the capacity of this aerosol population to work as CCN (cloud condensation nuclei) - i.e. the ability of an aerosol particle to grow its liquid water content and form cloud droplets. As clouds contribute for the enhancement of the albedo from earth, the indirect effect leads to a radiative cooling of the global system.[1] To monitor physical and hygrocopic properties

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of aerosols in the MASP is then an important subject. For that purpose, the use of a Raman LIDAR as a remote sensing technic is a powerful tool to derive many of these properties, like Aerosol Optical Depth, extinction, backscattering and hygroscopic behavior. Raman LIDAR has many advantages over a backscatter LIDAR, since there are two unknown variables and only one equation for the backscatter LIDAR, so an assumption of the LIDAR ratio (the relation between the extinction and backscattering coefficients) is needed.[2] When a Raman LIDAR system is used, the inelastic backscattering signal is affected by aerosol extinction but not by aerosol backscatter, which allows this LIDAR to uniquely determine extinction and backscattering coefficients without any assumptions or any collocated instruments.[3] That is the reason we started an upgrade of our MSP-LIDAR in Brazil from a backscatter LIDAR to a Raman LIDAR. The first changes started in 2011 and in 2012 during a winter campaign part of the NUANCE project (http://nuance-lapat.iag.usp.br/) we could get our first data set of optical parameters and water vapor concentration using this new Raman LIDAR. Preliminary results will be shown in this work.

2.1 EQUIPMENTS

2.1.1 The New MSP-Raman LIDAR features

The MSP-RAMAN LIDAR is a Raman system operating at the Center for Lasers and Applications, Nuclear and Energy Research Institute in São Paulo. It is a monostatic coaxial system, operating at two wavelengths (532nm and 355nm) and vertically pointed to the zenith. The Nd:YAG laser has a fundamental wavelength at 1064nm and second and third harmonics generators, 532nm and 355nm respectively, working with a repetition rate of 10Hz. The energy per pulse is 240mJ for 532nm and 160mJ for 355nm. The laser beam diameter is 8mm and it is directed by a mirror set to a beam expander (BMX), which expands around 4 times the beam diameter. This expanded beam is then directed to the atmosphere by a second mirror set. The receiver system comprises a Newtonian telescope with 30cm diameter and 1 to 2mrad of FOV (Field of View). In the detection box are used spectral filters with 1nm FWHM. With this geometric configurations, the total overlap is around 300m.[4] Hamamatsu R7400 PMT tubes are used for the detection system, which is composed by six channels: 532nm and the corresponding Raman signals for nitrogen (607nm) and water vapor (660nm) and 355nm and the corresponding Raman signals for nitrogen (387nm) and water vapor (408nm). The received signal is then digitalized by a transient recorder LR 20-80/160-LICEL, containing an analogic and a photocounting channel for each wavelength. The spatial resolution ranges from 3.75m to 15m. Each collected profile is composed by 2000 to 4000 pulses. To analyse data, we use local developed softwares, calculating the aerosol backscattering, extinction, LIDAR Ratio and water vapor mixing ratio.

2.1.2 The Raman LIDAR Mobile System

The mobile Raman system belongs to the research group in São Paulo and is used for field campaigns in collaboration with other groups in Brazil. Its laser is a CFR 200 Nd:YAG, operating at 532nm. The repetition rate is 20Hz. The emitted laser pulses have a divergence of less than 0.5 mrad after expansion (4x). The telescope is cassegranian, with 1mrad of Field of View (FOV). With this geometrical configuration, the full overlap is around 180m. The detection system has two channels, the 532nm and the corresponding Raman for nitrogen, 608nm, with two photomultiplier tubes coupled to narrowband (1nm FWHM) interference filters. The transient record is a Licel GmbH in both analog and photoncouting mode. The vertical resolution is 7.5 meters

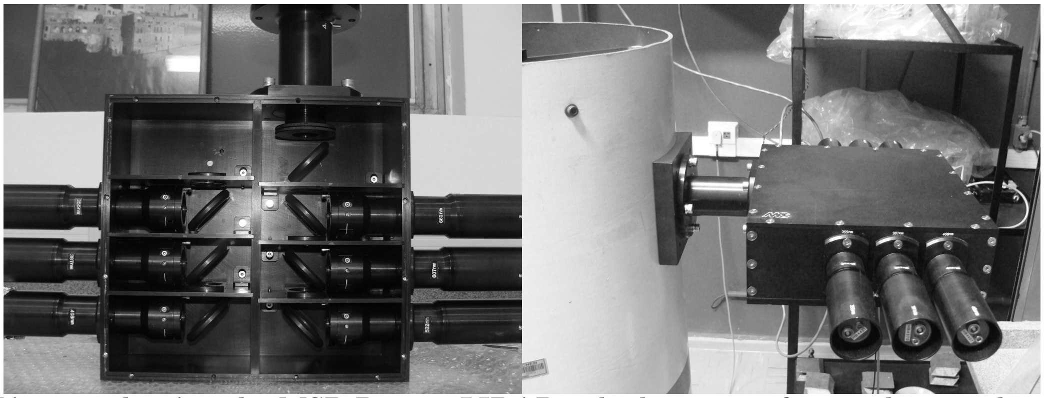

Figure 1: **Pictures showing the MSP-Raman LIDAR. The last one refers to the new detection box with six cannels**

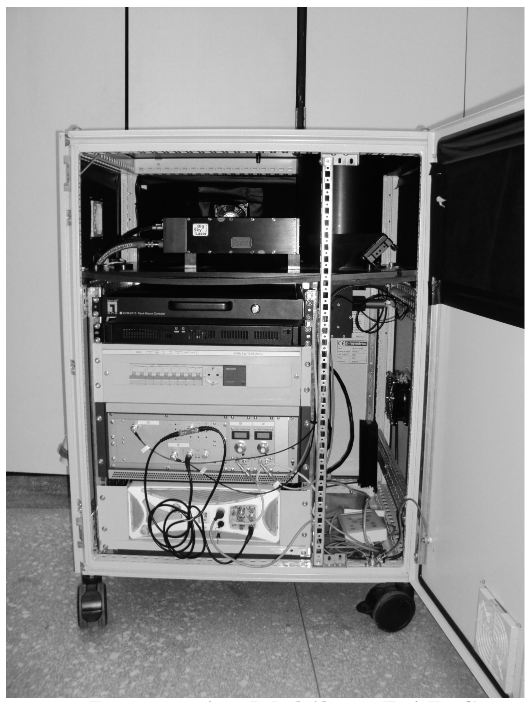

Figure 2: **Raymetrics Mobile LIDAR System**

2.1.3 RH profiles from radiosondes

To obtain information about the relative humidity profile for the chosen day, we used data from radiosondes. The sondes are launched twice a day, at 1200 UTC and 0000 UTC and are distant about 12km from the place where the LIDAR is located. It is possible to calculate relative humidity profiles from radiosondes using the temperature, the dew point temperature and Clausius-Clapeyron equation (the values of RH obtained this way are provided as product of these mesurements). After that, we compared the water vapor profile obtained with the LIDAR and that obtained with the radiosonde for the same period of time, and tried to determinate the average calibration constant between both systems.

2.2 The field campaign

We developed a field campaign in São Paulo during the winter (July, August and September 2012) as part of the big project NUANCE (http://nuance-lapat.iag.usp.br/), which aims to evaluate the impact of climate change on air quality in mega-cities. For this campaign, we collocated the Mobile Raman LIDAR and the MSP-Raman LIDAR. The measurements were made during the day (from 13 UTC to 23 UTC) to evaluate aerosol optical properties and during the night (from 21 UTC to 01:30 UTC) to evaluate the water vapor concentration, using only the MSP-Raman LIDAR. We had 16 days and nights of measurements, during which we performed comparisons between the measurements made with the Mobile LIDAR and the MSP-Raman LIDAR, objecting to check the performance of the new upgraded Raman system. During the night we performed measurements aiming to calculate the water vapor concentration especially below the PBL and with a special resolution of 15m, objecting to evaluate the hygroscopic behavior of this aerosol population. To perform the analysis, we used local developed softwares. In this work we present the results for two days of measurements, namely, 12 September 2012 for the aerosol optical properties evaluation and 22 September 2012 for water vapor concentration (mixing ratio) evaluation.

3. RESULTS

The results obtained for the first data for water vapor mixing ratio show good agreement with the radiosondes. The differences observed may be due to the variations of the water vapor concentration in the atmosphere, especially if it is a non well mixed boundary layer. The differences observed in the Lidar Ratio and Backscatter patterns can be possibly caused by corrections that we still have two improve in our softwares for analyses. Those are only preliminary data.

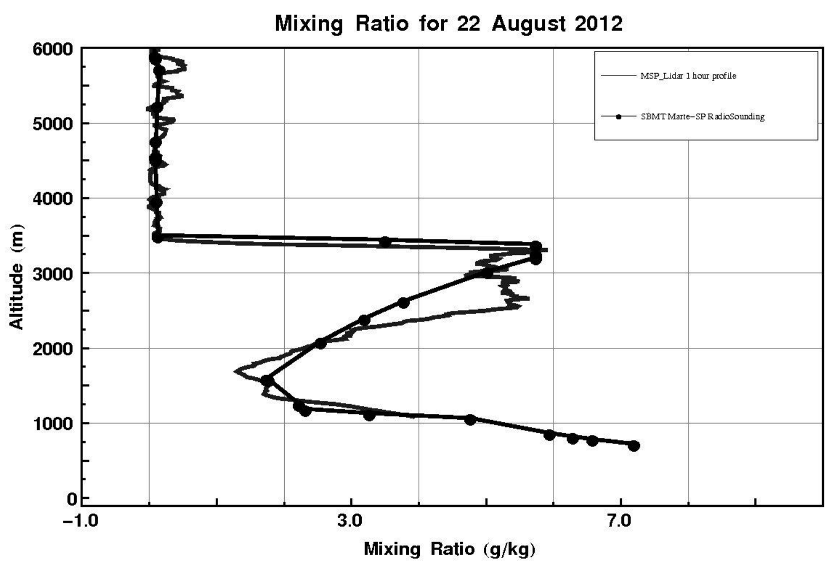

Figure 3: **Plot of the water vapor mixing ratio showing the comparison between data obtained with the LIDAR and the radiosonde. The radiosonde was launched at 00z (9:00 pm local time) and data from the LIDAR were averaged in a one hour profile from 8:30 pm to 9:30 pm local time). The highs are over the sea level (757m over the ground level).**

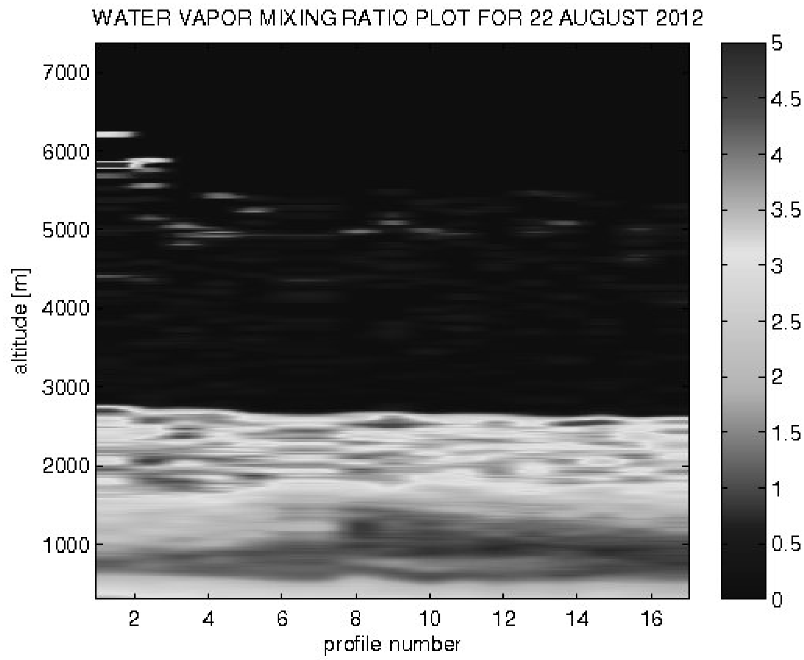

Figure 4: **Curtain plot for 17 profiles averaged each 6 minutes for the same day, for the night period. The altitude is above the ground level. It is possible to see the dry air capping layer around 1km, in agreement with radiosonde data.**

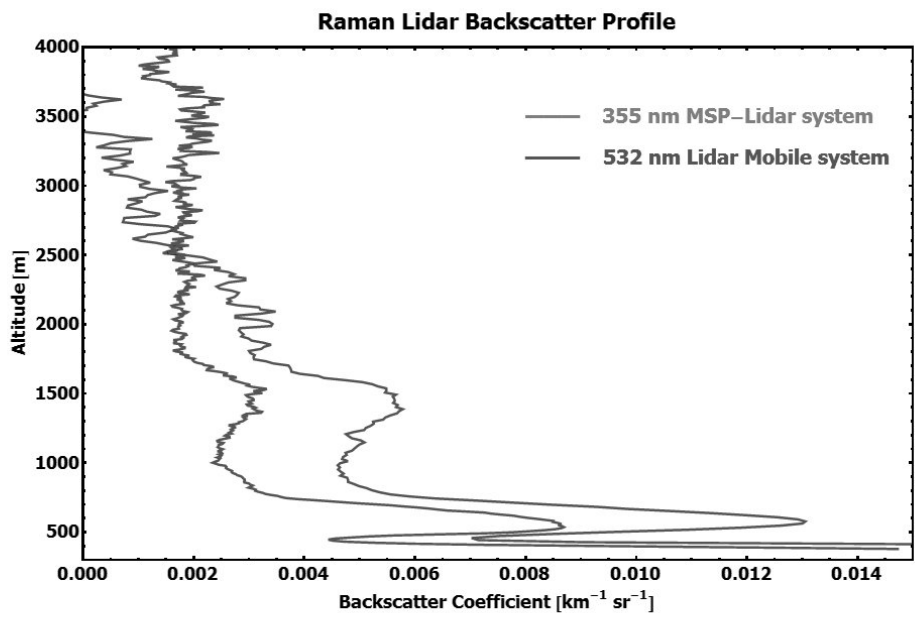

Figure 5: **Aerosol backscattering profile at 355 and 532 nm at 12 of September 2012 during the period of 19:50 and 20:30, measured using the MSP-Lidar system and the Raymetrics Mobile system, respectively.**

4. CONCLUSIONS AND FUTURE REMARKS

This field campaign, part of the big Project NUANCE, were realized in July, August and September 2012, and the data are still being processed and analysed. Some corrections have still to be applied. Differences

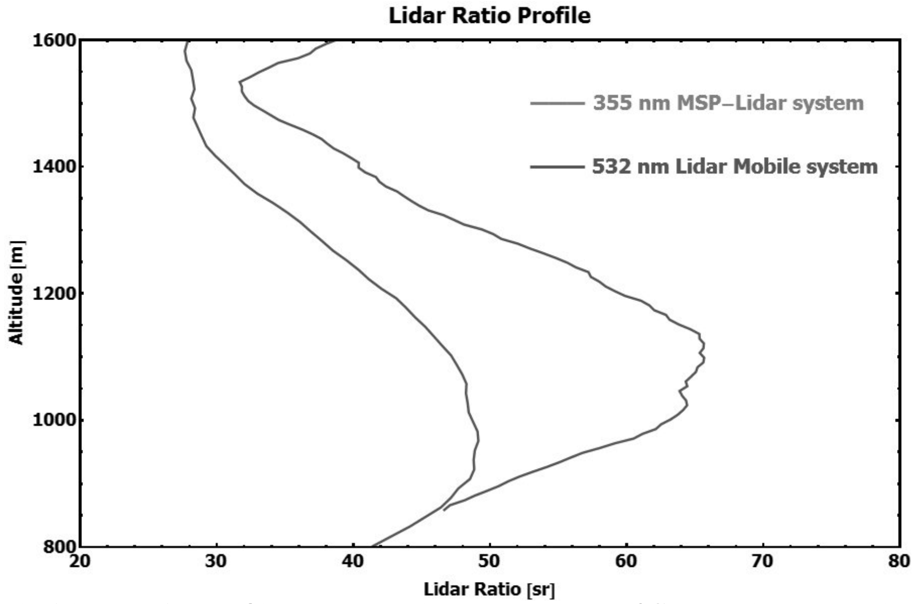

Figure 6: **Aerosol Lidar Ratio profile at 355 and 532 nm at 12 of September 2012 during the period of 19:50 and 20:30, measured using the MSP-Lidar system and the Raymetrics Mobile system, respectively.**

between the two collocated LIDARs show that the systems still need to be improved fot better agreement of the data. Also, we are constructing local softwares to improve the analyses. The differences between the water vapor mixing ratio pattern measured by the radiosonde and the LIDAR show that we still need to work with collocated sondes for betters understanding te behaviorof the new upgraded system. The differences may be due to natural differences in the atmosphere, as the sondes are located 12Km apart from the LIDAR site. But it was already possible to see the usefulness of the Raman LIDAR in the purpose of studying aerosols and water vapor in urban atmospheres, especially large urban areas. Future developments of this work include a summer campaign when we will have high levels of relative humidity and the hygroscopic behavior of aerosols over São Paulo can be better understood.

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