LIDAR OBSERVATION CAMPAIGN OF SUGAR CANE FIRES AND INDUSTRIAL EMISSIONS IN THE STATE OF SÃO PAULO, BRAZIL.

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ABSTRACT

Brazil has an important role in the biomass burning, with the detection of approximately 100,000 burning spots in a single year (2007). Most of these spots occur in the southern part of the Amazon basin during the dry season (from August to november) and these emissions reach the southeast of the country, a highly populated region and with serious urban air pollution problems. With the growing demand on biofuels, sugarcane is considerably expanding in the state of São Paulo, being a strong contributor to the bad air quality in this region. In the state of São Paulo, the main land use are pasture and sugarcane crop, that covers around 50% and 10% of the total area, respectively. Despite the aerosol from sugarcane burning having reduced atmospheric residence time, from a few days to some weeks, they might get together with those aerosol which spread over long distances (hundreds to thousands of kilometers). In the period of June through February 2010 a LIDAR observation campaign was carried in the state of São Paulo, Brazil, in order to observe and characterize optically the aerosols from two distinct sources, namely, sugar cane biomass burning and industrial emissions. For this purpose 2 LIDAR systems were available, one mobile and the other placed in a laboratory, both working in the visible (532 nm) and additionally the mobile system had a Raman channel available (607 nm). Also this campaign counted with a SODAR, a meteorological RADAR specially set up to detect aerosol "echoes" and gas-particle analyzers. To guarantee a good regional coverage 4 distinct sites were available to deploy the instruments, 2 in the near field of biomass burning activities (Rio Claro and Bauru), one for industrial emissions (Cubatão) and others from urban sources (São Paulo). The whole campaign provide the equivalent of 30 days of measurements which allowed us to get aerosol optical properties such as backscattering/extinction coefficients, scatter and LIDAR ratios, those were used to correlate with air quality and meteorological indicators and quantities. In this paper we should focus on the preliminary results of the Raman LIDAR system and its derived aerosol optical quantities.

Keywords: LIDAR, aerosols, scatter ratio, lidar ratio, biomass burning

1. INTRODUCTION

The direct radiative forcing estimated for biomass-burning aerosols was revised due to their strong influence over the clouds.[1] Brazil has an important role in the biomass burning, with the detection of approximately 100,000 active fires in 2007, according to CPTEC/INPE (www.cptec.inpe.br\queimadas). The biomass burning includes the burning of forests, savannas, and agricultural land. In Brazil, the Northeast and Southeast regions are of great importance to the emission of aerosols due to the burning of sugarcane crops made in a programmed way.

In the last decades a great number of studies about biomass burning was carried out mainly on the physical (direct[2–4] and indirect effects[5,6]) and chemical properties.[7,8] In terms of air quality biomass burning is a major

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Figure 1. Map displaying the sites used in the measuring campaign as part of the CONSOLIDAR network.

source of air pollution and the second largest source of anthropogenic aerosols,[2] specifically in Brazil, it is possible to highlight several studies referring to: gases,[9,10] trace gases transport[11] particulate matter composition,[10] effects on diffuse and photossinthetically active radiation,[12] cloud physics,[13] satellite measurements[14] and air masses trajectories.[15,16]

In Brazil, up to date, few studies using lidar were made concerning biomass burning. Landulfo*et al.*[17] using an elastic lidar showed the presence of highly absorbent particles, characteristic of biomass burning aerosol. In this study four-day air mass backtrajectories analysis and satellite data showed that the aerosol originated from Amazon regions. The optical depth measured by the Sunphotometer also indicated the presence of biomass burning coming from these distant regions. Despite the average value for LR around 45 sr (typical of urban environment), studies indicate that the presence of dust and biomass burning aerosol transported from great distances[18] away from São Paulo city increases the suspended atmospheric aerosol variability where normally the layer between 1-3 km is responsible for 20-25% of all the tropospheric aerosol amount.[19] The purpose of this paper was to study the influence of aerosol from biomass burning on the aerosol loading over the city of São Paulo, Brazil during the Brazilian dry season of 2007.

Herein a multi-sited approach was employed, using active a lidar system in 5 different sites, namely, São Paulo, Cubatão, Rio Claro and Bauru. These sites belong to the so-called CONSOLIDAR network and their locations are given in Figure 1 The entire campaign spanned from June 2009 through November 2009, in order to observe and characterize optically the aerosols from two distinct sources, that is, sugar cane biomass burning and industrial emissions. For this purpose a mobile LIDAR system was available, working in the visible (532 nm) and additionally the mobile system had a Raman channel available (607 nm). Also in this campaign we counted with a SODAR, a meteorological RADAR specially set up to detect aerosol “echoes” and gas-particle analyzers their correlated data should be covered in the near future in a more detailed paper. The good regional coverage displayed 4 distinct sites where the instruments were deployed, 2 in the near field of biomass burning activities (Rio Claro and Bauru), one for industrial emissions (Cubatão) and others from urban sources (São Paulo). The whole campaign provided the equivalent of 30 days of measurements which allowed us to get aerosol optical properties such as backscattering\extinction coefficients, scatter and LIDAR ratios, those were used to correlate with air quality and meteorological indicators and quantities. Thus we could try to extract a regional signature among different aerosol typed sites and from the obtained aerosol optical data and try to correlate them with specific sites in terms of these data.

2. EQUIPMENT DESCRIPTION

2.1 LIDAR SET-UP

The lidar system employed in the campaign is a single-wavelength backscatter system pointing vertically to the zenith and operating in the biaxial mode. The light source is based on a commercial Nd:YAG laser (CFR 200 by Quantel SA) operating at the second harmonic frequency (SHF), at 532 nm, with a fixed repetition rate of 20 Hz. The emitted laser pulses have a divergence of less than 0.5 mrad after expansion (4×). A 20 cm diameter telescope (F# = 4.5) is used to collect the backscattered laser light. The telescope's field of view (FOV) is variable (1-2 mrad) by using a small diaphragm. The lidar is currently used with a fixed FOV, which permits a full overlap between the telescope FOV and the laser beam at heights around 180 m above the lidar system. This FOV value, in accordance with the detection electronics, permits the probing of the atmosphere up to the free troposphere (12-15 km asl.).

The backscattered laser radiation is then sent to 2 photomultiplier tubes (PMT) coupled to a narrowband (1 nm FWHM) interference filters to assure the reduction of the solar background during daytime operation and to improve the signal-to-noise ratio (SNR) at altitudes greater than 3 km. The PMT output signal is recorded by a Transient Recorder in both analog and photoncounting mode. Data are averaged between 2 and 5 min and then summed up over a period of about 30 min -1 h, with a typical spatial resolution of 7.5 m, which corresponds to a 100 ns temporal resolution. For the Raman channel at 607 nm longer integration times are applied.

The LIDAR systems, LR101-V-D200, summarized features are shown in the table 1below:

Table 1. LIDAR SYSTEM FEATURES

SYSTEM FEATURES	LR101-V-D200
LASER Energy/pulse	up to 130 mJ
TELESCOPE Config.	Cassegranian
TELESCOPE Diam.	200 mm
TELESCOPE F #	4.5
DETECTION Channels	532 nm and 607 nm

3. METHODOLOGY

The mobile lidar system was deployed in 4 different sites during the period of June 2009 through November 2009. The sites and period of each sub-campaign is given in Table 2.

Table 2. LIDAR CAMPAIGN PERIODS

SITE	PERIOD	TOTAL DAYS OF MEAS.
São Paulo	April - June 2009	12
Cubatão	November 2009	22
Rio Claro	June - October 2009	41
Bauru	February 2010	5

3.1 Elastic Channel

From the elastic channel, namely the 532 nm, one could retrieve the Aerosol Scattering Ratio SR and the aerosol backscattering coefficient profile, $\beta(r)$.

$$ASR = \frac{\beta^a(\lambda, r) + \beta^m(\lambda, r)}{\beta^m(\lambda, r)} \tag{1}$$

Where $\beta^a(\lambda, r)$ is the aerosol backscattering coefficient at a given wavelength and height, λ, r, and $\beta^m(\lambda, r)$ is the molecular backscattering coefficient, which could be parametrized form a standard atmosphere or when available from a sounding retrieval.

The aerosol backscattering profile could be retrieved by solving the Lidar equation using a Klett like algorithm[20] .

$$P(\lambda, R) = P_L\left(\frac{c\tau}{2}\right)\frac{\beta(\lambda, R)\ A_0\ \xi(\lambda)\ \zeta(R)}{R^2}\ exp\left[-2\int_0^R \alpha(\lambda, r)r\right] \tag{2}$$

where, P(λ,R) is the lidar signal received from a distance R at the wavelength λ, P_L is the emitted laser power, A_0 is the telescope receiving area, $\xi(\lambda)$ is the receiver's spectral transmission factor, $\beta(\lambda, R)$ is the atmospheric volume backscatter coefficient, $\zeta(R)$ is the overlap factor between the FOV of the telescope and the laser beam, $\alpha(\lambda, R)$ is the extinction coefficient, c is the light speed and τ is the laser pulse length. In this calculation one has to assume the ratio $\frac{\alpha(\lambda,r)}{\beta(\lambda,r)}$ as known and this quantity could be retrieved form the Raman channel as shown below in the next section.

3.2 Raman Channel

For the calculation of aerosol backscattering and extinction profiles from elastic and Raman backscatters the traditional formulas from[21] we calculated the aerosol extinction and backscattering coefficient from the elastic 532 nm and 607 nm channels:

$$\alpha^{aer}_{\lambda_o}(r) = \frac{(d/dr)\left[ln\frac{N_R(r)}{r^2 P_{\lambda_R}(r)}\right] - \alpha^{mol}_{\lambda_o}(r) - \alpha^{mol}_{\lambda_R}(r)}{1 + (\frac{\lambda_o}{\lambda_R})} \tag{3}$$

where $\alpha^{aer}_{\lambda_o}(r)$ is the aerosol extinction coeffient at the laser wavelength, namely $532nm$, $N_R(r)$ is the nitrogen molecule number density, $P_{\lambda_R}(r)$ is the backscattered Raman signal, at 387 nm in the case of nitrogen, $\alpha^{mol}_{\lambda_o}(r)$ and $\alpha^{mol}_{\lambda_R}(r)$ are the molecular extinction coefficients at the two involved wavelengths, 532 nm and 607 nm. By the integration of the extinction coefficient at 532 nm one extracts the Aerosol Optical Depth, in the case of the Lidar data this is simply a summation over the atmospheric region where the aerosol presence is predominant:

$$\begin{aligned} AOD &= \int_{r_1}^{r_2} \alpha(r)dr \\ &= \sum_{r_1}^{r_2} \alpha(r)\Delta r \end{aligned} \tag{4}$$

4. RESULTS

Figures 4 shows the Aerosol Scattering Ratios (SR) for the for sites in specific days for the purpose of comparison. Since the value ranges are broad we decided for a Log scale. One can realize that the sites which show most of the larger aerosol load are Cubatão and São Paulo, both heavily industrialized or with a large urban environment, followed by Rio Claro and Bauru, respectively. Besides the larger loads do not go further than 2-3 km, which could be indicative of a near range aerosol transport.

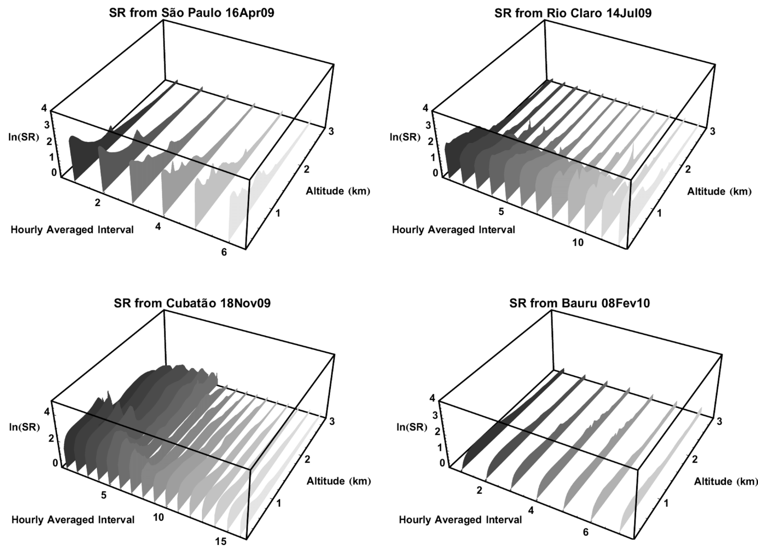

Figure 2. Aerosol Scattering Ratios for the 4 sites where the campaign took place. Their intensity are a signature of the aerosol load typical for industrialized (São Paulo and Cubatão site) and continental, rural sites (Rio Claro and Bauru).

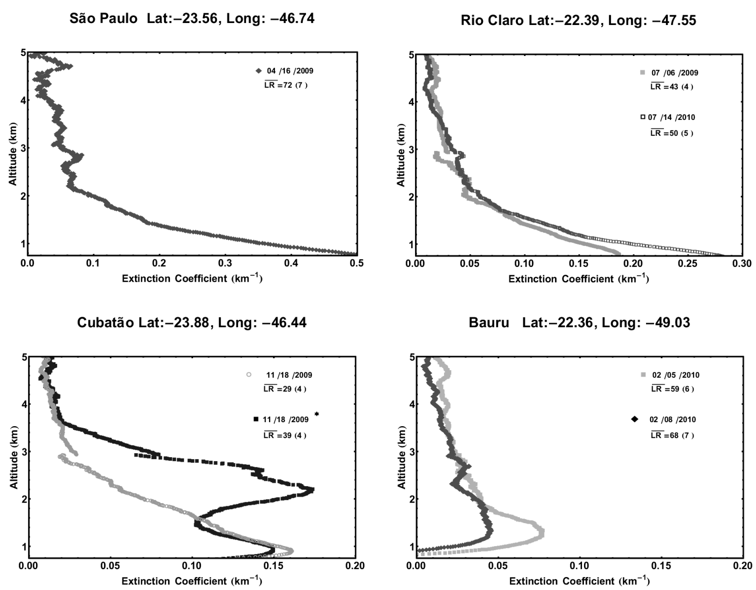

Figure 3. Some chosen days to illustrate the typical aerosol extinction profiles for each one of the sites. We also give the average Lidar Ratio (LR). In some of the examples we have for a same site more than one profile to illustrate the intrusion of industrial (Cubatão) or biomass burning plumes (Rio Claro). The LR values are summarized in Table below.

In Figure 4 we have some chosen aerosol extiction profiles taken from the elastic (532 nm) and Raman (607 nm) signals. In each of them we also show the average Lidar Ratio (LR). In some of the examples we have for a same site more than one profile to illustrate the intrusion of industrial (Cubatão) or biomass burning plumes (Rio Claro).

The LR's are given for each site and are in good agreement[22] with those values for urban, biomass buning and continental sites. It is intersting to observe that despite of Cubatão being an industrial site, its LR signature point to a maritime site. It is also given in this table the AOD values at 532 nm and the largest ones are for Rio Claro and São Paulo, in both cases the intrusion of plumes could well explain such high values for the days chosen.

Table 3. LR typical values for each site.

SITES	DATE	AOD	LR
Bauru	08/02/10	0.12(6)	59(12)
Bauru	08/02/10	0.09(9)	68(14)
Cubatão	01/11/09	0.26(6)	35(7)
Cubatão	01/11/09	0.33(6)	35(7)
Cubatão	18/11/09	0.24(4)	29(8)
Cubatão	18/11/09	0.34(5)	39(8)
Rio Claro	06/07/09	0.24(5)	43(9)
Rio Claro	14/07/09	0.32(6)	50(10)
São Paulo	16/04/09	0.63(4)	72(8)

5. CONCLUSIONS

In the period of June through February 2010 a LIDAR observation campaign was carried in the state of São Paulo, Brazil, in order to observe and characterize optically the aerosols from two distinct sources, namely, sugar cane biomass burning and industrial emissions. For this purpose 2 LIDAR systems were available, one mobile and the other placed in a laboratory, both working in the visible (532 nm) and additionally the mobile system had a Raman channel available (607 nm). In this paper we focused on the preliminary results of the Raman LIDAR system and its derived aerosol optical quantities and obtained the Aerosol Scattering and LIDAR ratios for the fours sites which charaterized them well enough and in good agreement with those values given in the literature.

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