Sección Especial / Special Section: V Workshop on Lidar Measurements in Latin America

Capability of atmospheric air monitoring in the urban area of Cubatão using Lidar technique

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Recibido / Received: 16/11/2010. Versión revisada / revised versión: 14/01/2011. Aceptado / Accepted: 17/01/2011

ABSTRACT:

This paper presents results of air quality monitoring campaigns carried out in the industrial city of Cubatão, based on the Lidar methodology. The interest in these monitoring campaigns is related to the specific situation of Cubatão as one of the largest petrochemical and industrial sites in Brazil, as well as its geographic location, in the seaside and surrounded by a mountain barrier with 600 to 1000 m height. The tests were carried using a vertically pointing mobile Lidar to derive vertical profiles of aerosols based on backscattered radiation. The results consist of vertical profiles of aerosol concentration over time, and represent a set of illustrative patterns that can be correlated with meteorological and air quality information, thus providing valuable instantaneous information on local atmospheric conditions.

Key words: Lidar Technique, Atmospheric Air Monitoring, Atmospheric Aerosols.

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1. Introduction

The city of Cubatão, located at the Atlantic cost, 50 km from São Paulo, southeast of Brazil, is one of the largest industrial sites in the country. In a region with 40 km2 there are 23 large industries, including a steel plant, an oil refinery, 7 fertilizer plants, a cement plant, and 11 chemical/petrochemical plants, adding up to 260 pollutant emission sources, besides the urban area, with ca 130 thousand inhabitants. A number of initiatives adopted since the 80´s have led to significant reductions in industrial emissions. However, the region deserves much concern by authorities.

The environmental problems caused by the industrial activities are aggravated by the climate and topography of the site, unfavorable to pollutant dispersion. Cubatão is located in a narrow coastal plain surrounded by a steep mountain range to the north, west, and east and by the sea to the south. At ca. 1 km west and northwest a 600-1000 m high mountain shell retains air circulation. Depending on meteorological conditions the atmospheric emissions by industries and local road traffic can accumulate, resulting in events of peak air pollution levels. During the day, the winds blow from the sea to the continent, carrying pollutants to the mountains, where they are channeled into narrow valleys. Thermal inversions often occur in winter months [1].

In a partnership with the University of São Paulo (USP) the Brazilian oil company PETROBRAS has supported the installation of an Environmental Research Center - CEPEMA- located in the industrial site, where a Lidar system was used to characterize the vertical profile of the aerosol backscatter at 532 nm wavelength.

Lidar (light detection and ranging) is an active optical technique in which a beam of light is used in remote range resolved measurements. A Lidar emits a light beam that interacts with the medium or object under study. Some of this light is scattered back and detected by the optical detection system. Analysis of the backscattered light allows some property of the medium or object to be determined [2]. Three-dimensional measurements can be performed with the Lidar technique, by using pulsed lasers and detecting the backscattered light from molecules and aerosols in the atmosphere in a radar-like mode [3]. Besides their detection, these species have to be tracked along neighboring areas by the use of dispersion models. This text presents results of a series of campaigns aimed at monitoring the vertical profile of backscattered laser light in Cubatão under different atmospheric conditions. The results serve to describe the characteristic patterns of aerosol concentration in the region, as a complementary information relative to other air monitoring techniques.

2. Lidar technique

Lidar is widely used in laser remote sensing for detection of pollutants in the atmosphere. In this technique, short wavelength laser radiation is transmitted through the atmosphere where gas molecules and particles along the beam path cause absorption and scattering of the laser beam. The absorption and/or scattering is detected.

The Lidar system used in this work consists of a biaxial mode single-wavelength backscatter commercial Raymetrics LR101-V-D200 system. The light source is a commercial Nd:Yag laser with fundamental frequency at 1064 nm, which emits pulses of 120 mJ output energy at 532 nm with repetition rate of 20 Hz and pulse duration of 6.7 ns. The laser beam is vertically directed to the atmosphere through a Cassegrain telescope with 100 mm diameter, 800 mm focal length and 1 mrad field of view. The signal acquisition unit consists of Hamamatsu R7400 PMTs and narrow band interference filters for the elastic backscatter and Raman channel, at 532 and 608 nm, respectively. The PMT output signal is digitized and stored in a Lidar Transient Recorder TR-20-160 (LICEL) with an acquisition analog channel with 12 bits resolution at 20 MHz. The data are averaged with a typical spatial resolution of 7.5 m. Figure 1 shows a scheme of the Lidar operation. Figure 2 shows the mobile system used in the campaigns in Cubatão. The backscattered light intensity data were compared with measurements of wind velocity (by sonic anemometer LSI-Lastem DNB 005) and under-10 μm particulate matter (PM_{10}), measured by tape-filtering and beta attenuation (Thermo FH62C14-0). Hourly average values of these measurements were provided by an air quality data monitoring station operated by the environmental agency CETESB [4].

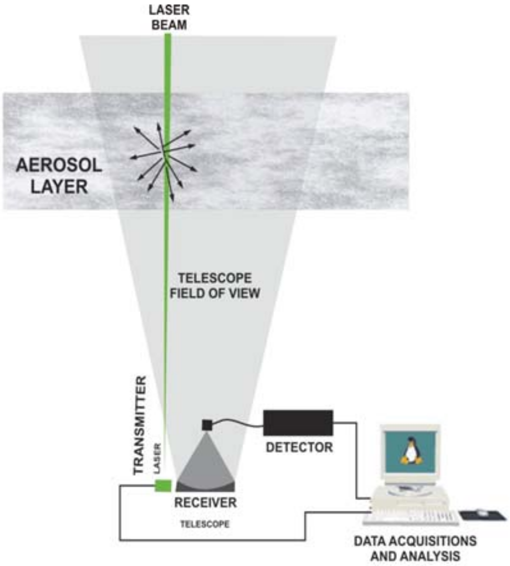

Fig. 1. Illustrative Lidar scheme.

Fig. 2. Lidar mobile system.

3. Description of the Cubatão region

The city of Cubatão is located at 23°45′–23°55′S and 46°21′–46°30′W, southeast of Brazil. Figure 3 shows a map of the region with its peculiar topography. Because of its location, the wind and thus the conditions for the dispersion of pollutants within the Cubatão area are strongly influenced by local topography. The climate is tropical and cloudy with no dry season and shows high annual averages for temperature (23°C) and precipitation (2600 mm). The large variation in rainfall in the region is controlled by the movements of sea-land and mountain-valley winds, with large influence of the convergence of sea breezes on mesoscale diurnal variation of precipitation over Cubatão.

Wind behavior in the area is characterized by drainage wind, which begins at dusk or before and is favored by the slopes to the northwest, which are heated during the day. This is particularly important for anticyclones with clear skies, when the air changes in the area are practically dominated by meso and micrometeorological phenomena [5]. Strong drainage winds from the northeast transport industrial emissions in the direction of the urban area. Observations show that the stable air mass, with most emissions from fertilizer industries, moves from the base of the mountains to the urban area of Cubatão. Solar heating of the slopes results in the development of anabatic winds and sea breezes, which are easily viewed by the trajectory of the plumes from chimneys. These winds are generally associated the high aerosol concentration. During winter mornings, layers of surface temperature inversions of different thicknesses and different intensities are observed.

The Lidar system operated in the CEPEMA site, close to the urban area. The PM_{10} and wind velocity data measuring place was located in the urban area, about 1 km far from CEPEMA, as indicated in Figure 3.

4. Results and discussions

Although a large number of data were collected in the campaigns, only selected results are presented in this study, since these correspond to days with different characteristics. . Figure 4 shows the backscattered light amplitude at different vertical distances from the ground over time for a representative situation observed in Cubatão, corresponding to the period from 18h30 on November 1 to 14h on November 2, 2009. During that period low velocity wind (0.2 to 1 m/s) was observed. A cloud layer due to condensation is observed at ca. 1.2 km altitude during the day (Nov. 1) until the beginning of the night. Below this layer, relatively high backscattering amplitude is observed, indicating high aerosol concentration.

This layer dissolved in the 2 hours that followed (19h30 to 21h30). On Nov. 1, high aerosol concentration is observed at low altitude from 21h30 until the morning hours of Nov. 2. The increase in temperature during morning hours caused a gradual move of the high aerosol concentration layer towards altitudes of 1 to 1.2 km again, as on the day before. During the whole monitoring period clear sky conditions are

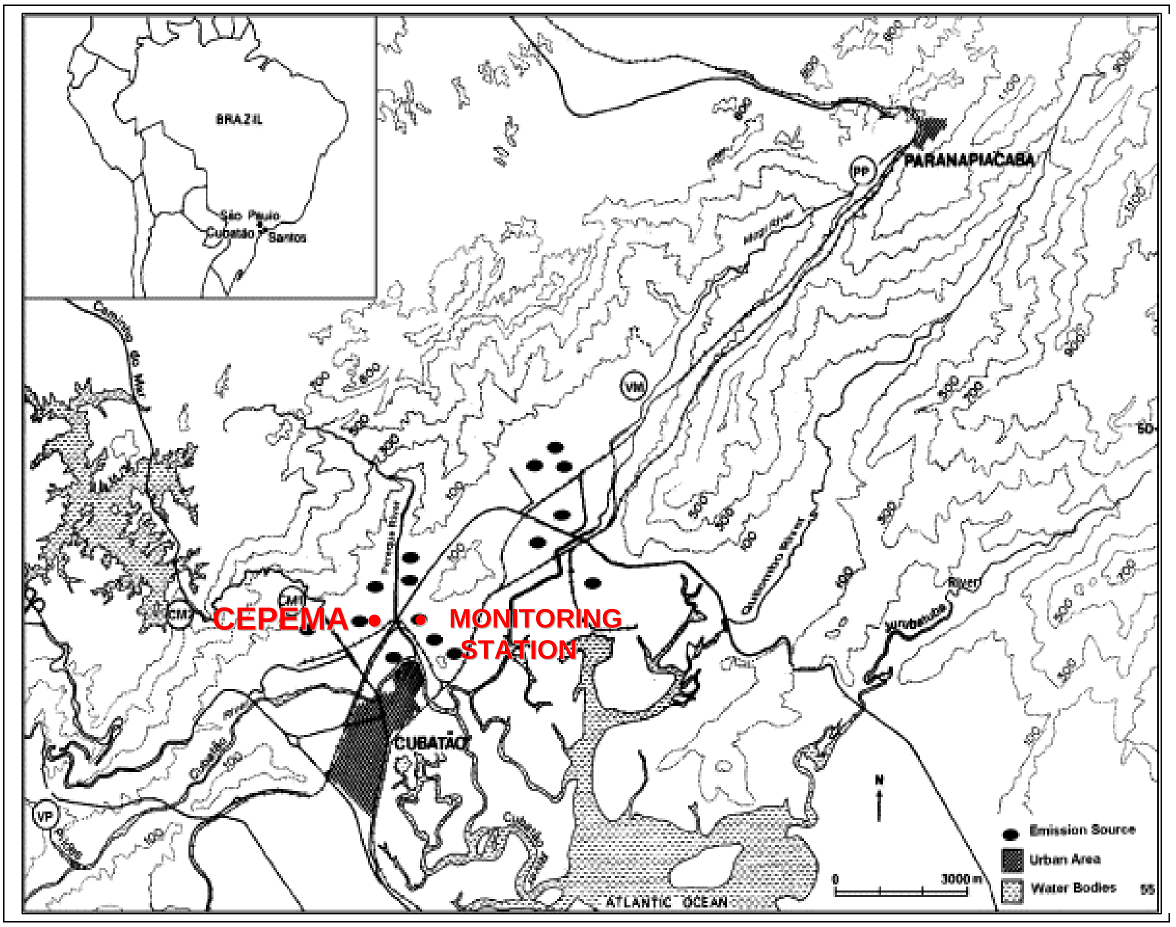

Fig. 3. Cubatão area with indication of the monitoring site at CEPEMA and main emission sources [6].

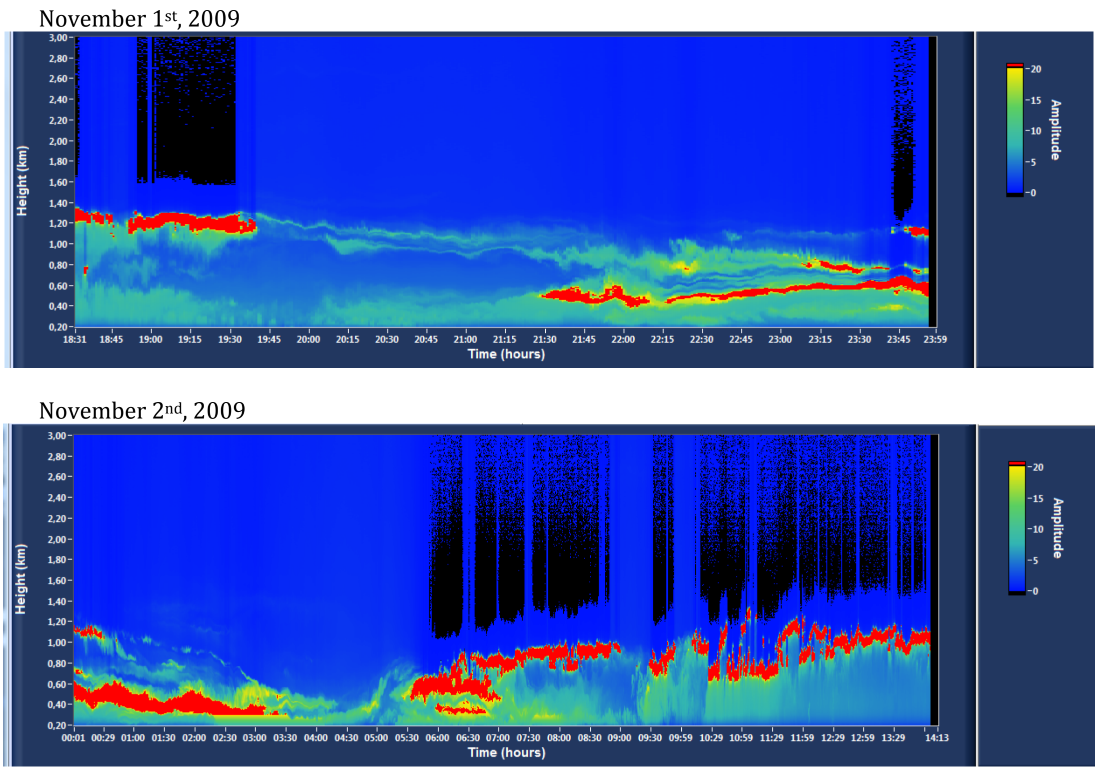

Fig. 4. Lidar monitoring results with presence of low altitude confined aerosols.

observed above ca. 1.3 km. This corresponds to the previous description of local atmospheric conditions in Cubatão. The presence of the condensation layer is indicative of temperature inversion, and causes the confinement of warmer air and pollutants by the mountains, as shown in the illustrative scheme in Figure 5. Therefore, even when no Lidar signal is observed at high altitudes (as on clear sky days) a characteristic pattern can be observed below 1.2 to 1.4 km from ground.

A different pattern of the Lidar data is observed on days with higher wind velocity and lower relative humidity. As shown in Figure 6 (Nov. 6, 2009), besides occasional clouds at 3.0 km altitude, no clear condensation layer is observed. However, even under such dispersion-favorable conditions, higher light backscattering amplitude is observed at altitudes below 1.0 km, indicating that the aerosol concentration remains significantly higher at low altitudes. During that time period the wind velocity varied from 1 to 2 m/s, and particulate matter (PM_{10}) concentration stayed at ca. 40 μg/m^3, which is about 1.5 times the mean value of PM_{10} concentration during the monitoring period.

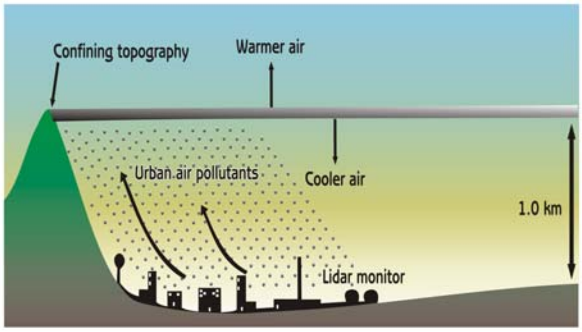

Fig. 5. Illustration of air confining in a temperature inversion [7].

November 6th, 2009

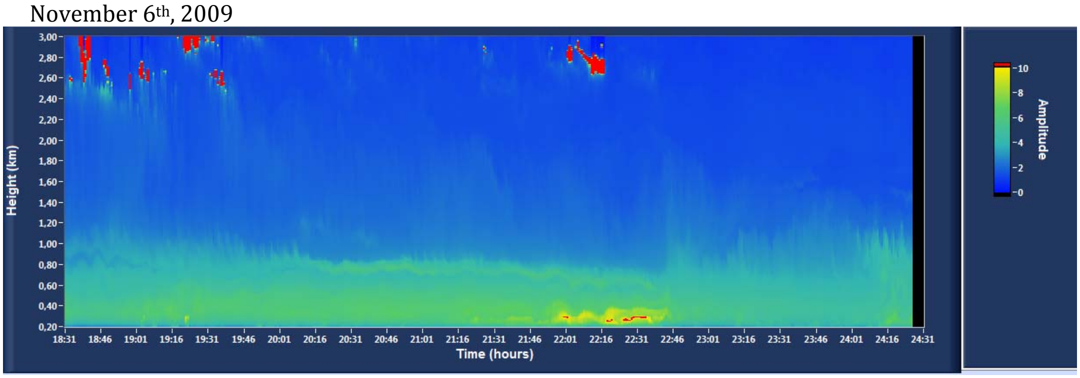

Fig. 6. Lidar monitoring results under lower relative humidity conditions.

November 18th, 2009

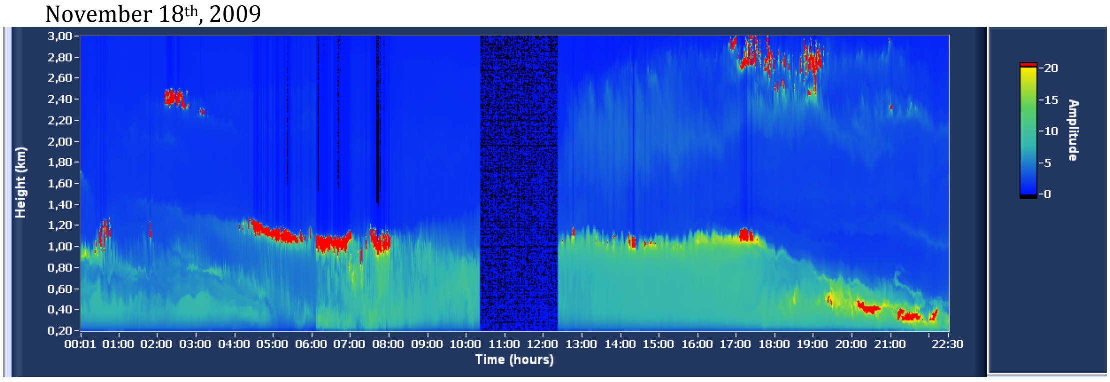

Fig. 7. Lidar monitoring results under transition conditions.

Thus, the lidar response pattern in Fig. 6 can be explained by the relatively high levels of PM_{10} near ground level.

A third lidar response pattern is shown in Fig. 7, corresponding to rain conditions and a transition. During the monitoring period on Nov. 18, clouds were present in the morning at 1.5 km from ground, and monitoring had to be interrupted due to rain. Wind velocity was about 2 m/s, and PM_{10} concentration stayed at relatively low levels, around 20 μg/m^3, which is ca. 0.7 times the average level during the monitoring period. Then a transition occurred, with the disappearance of clouds, and in the afternoon the Lidar response pattern became similar to Fig. 6.

5. Conclusions

The results shown in the previous section were selected among the many data obtained over the monitoring campaigns in Cubatão. Besides the fact that these are the first systematically collected Lidar backscattering data in that location, the selected results indicate that there is a possibility of associating the Lidar response pattern and air quality in the region, including not only the conventional meteorological information such as clouds characteristics, or inversion layer height, but also the levels of particulate matter in the air. Since in Cubatão this pollutant is essentially emitted by industries, the Lidar monitoring can be used to instantly detect changes in the response pattern and associate this to local atmospheric emissions.

Since this is a continuing development, in the next steps of the study specific quantitative criteria will be developed to associate these patterns with air quality, by using multivariate statistical techniques.

Acknowledgements

The authors would like to thank the Brazilian research support agencies CNPq and FAPESP, as well as Petrobras for the financial support, and CETESB for providing the data and the monitoring infrastructure.

