Identification and monitoring of atmospheric particles by multiwavelength Radar Laser in South America

E. Montilla-Rosero[1,4,5], A. Silva[1,2], C. Jimenez[3], A.Guedes[5], J. Hoelzeman[5], F. Lopes[4], E. Landulfo[4], C. Saavedra[1]

[1]*Centro de Óptica y Fotónica CEFOP, Universidad de Concepción, Casilla 4016, Concepción (Chile)*
[2] *Departamento de Ciencias Físicas, Universidad de La Frontera, Av. Francisco Salazar 01145, Temuco, Chile.*
[3]*Leibniz-Institut für Troposphärenforschung, Leipzig (Germany)*
[4] *Instituto de Pesquisas Energéticas e Nucleares (IPEN), Avd. Prof. Lineu Prestes 2242, 05508-000, São Paulo (Brazil)*
[5] *Federal University of Rio Grande do Norte - Center for Natural and Earth Sciences - UFRN/CCET, Natal/RN (Brazil)*
emontill@gmail.com

Abstract: First monitoring LIDAR measurements of tropospheric aerosols in two different places of South America are reported. Characteristics optical parameters were retrieved using inversion algorithms for two coastal cities in the Pacific and Atlantic Oceans.

OCIS codes: 010.0280 Remote sensing and sensors; 010.1110 Aerosols

1. Introduction

A complete study of Earth's atmosphere needs to combine information from satellite, in situ and ground instrumentation. To complement and improve this information the LIDAR (Light Detection and Ranging) technique, or radar laser due to similarity on fundamental operation principles, has been developed to provide atmospheric vertical profiles with high spatial and temporal resolution about aerosol extinction and backscattering coefficients [1], aerosol distribution [2], water vapor content [3], planetary boundary layer [4], or cloud studies [5].

In the Center for optics and photonics (CEFOP) of University of Concepcion (Chile), a multiwavelength 2 elastic + 2 inelastic Lidar has been developed to study the urban air pollution and the aerosol events originated in natural sources like biomass burning and volcanoes eruptions, the system has been operated routinely from January 2012 in Concepción (36° S, 73° W, 170m asl) a coastal city in Southern Pacific Ocean [6]. Additionally, the Laser Environmental Application Laboratory (LEAL) at the Nuclear and Energy Research Institute (IPEN, São Paulo, Brazil) has developed a depolarization lidar system which has been installed at the end of January 2016, at the Department of Atmospheric and Climate Sciences of the Federal University of Rio Grande do Norte (UFRN) in the city of Natal in the Brazilian Northeast (5°50'29 S, 35°11'57 W, sea level) for study the Saharian dust aerosol layers coming from Africa.

Basic methodology for retrieving the aerosol backscattering coefficient profiles and the effect of air humidity in LIDAR measurements is described below. Selected days of aerosol monitoring in both LIDAR stations are presented in the section 3.

2. Methodology

In a LIDAR system, a pulsed laser emits radiation into the atmosphere, a portion of this laser radiation is backscattered by particles and molecules as the pulse propagates away from the system. The backscattered photons are collected and selected in an optical system (telescope, beam splitters, and optical filters) for separating inelastically from elastically backscattered photons before entering to the photodetectors. The time from pulse emission to detection is a measure of the distance from the system at which the backscattering occurred.

For deriving the aerosol backscattering coefficient profiles, the LIDAR data is range-corrected and processed using inversion algorithms based on Klett-Fernald Method [7,8]. In this method, we solved the Lidar equation given by:

$$P^*(R) = P_L \frac{\eta_L}{R^2} O(R) \beta^*(R) exp\left[-2\int_0^R \alpha^*(R) dR\right] \tag{1}$$

where, $P(R)$ is the collected lidar signal from distance R, P_L is the emitted power, η_L contains lidar parameters describing the efficiencies of the optical and detection units, O(R) is the overlap factor. β(R) [km^{-1}sr^{-1}] and α(R) [km^{-1}] are the total coefficients for backscattering and extinction, caused by particles and molecules. The symbol * could be one for Mie-elastic single case, or $||$ and $\perp$ indicating parallel- and perpendicular- polarized components, respectively, of the lidar signal.

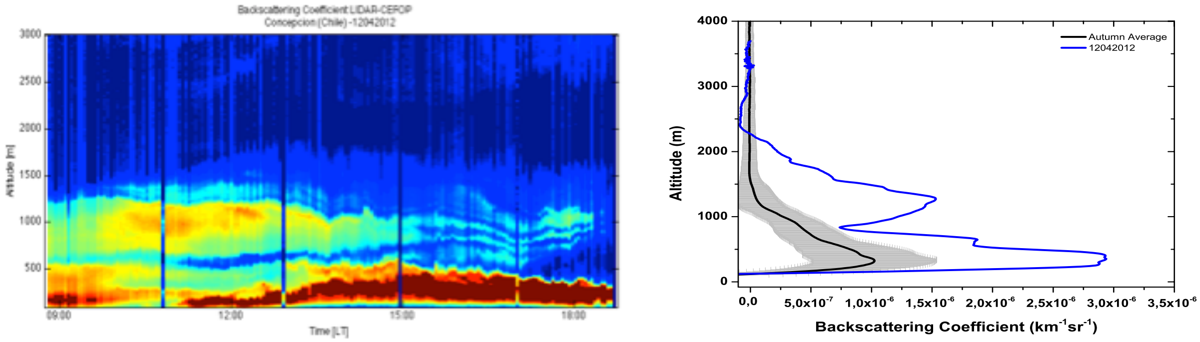
After Aerosol Backscattering Coefficient β_{aer} (R) is retrieved, the effect of environmental relative humidity is calculated by enhancement hygroscopic factor f (λ, R, RH):

$$f(\lambda, R, RH) = \frac{\beta_{aer}(\lambda, R, RH)}{\beta_{aer}(\lambda, R, RH_{ref})} \quad (2)$$

where λ is the LIDAR wavelength and RH_{ref} is the value of relative humidity from which the atmospheric aerosol starts to absorb water.

3. Results and Discussion

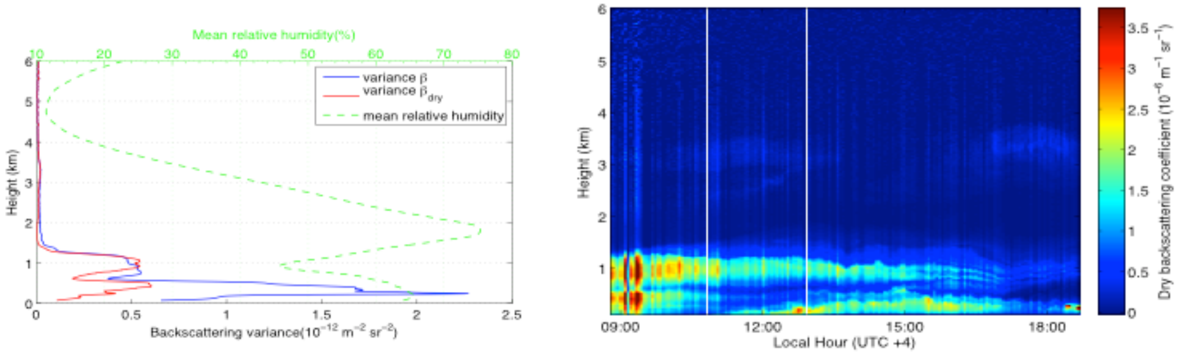
The LIDAR-CEFOP station was characterized like "air clean station" from routinely measurements [1], the Figure 1a shows an exceptional day (April 04, 2012) with air pollution background below 500m and a wide aerosol layer between 500 m and 1500m from early morning until 18 UTC as function of backscattering coefficient βaer (R). This day was compared with the average backscattering profile of 2012 autumn (Figure 1b) showing until three times the average values of βaer (R) and reaching until 1,8 km of altitude.



a. b.

Figure 1. a. Time series of backscattering coefficient profiles at Concepción (Chile) b. Comparison of average backscattering profiles for April 12, 2012 and autumn season 2012.

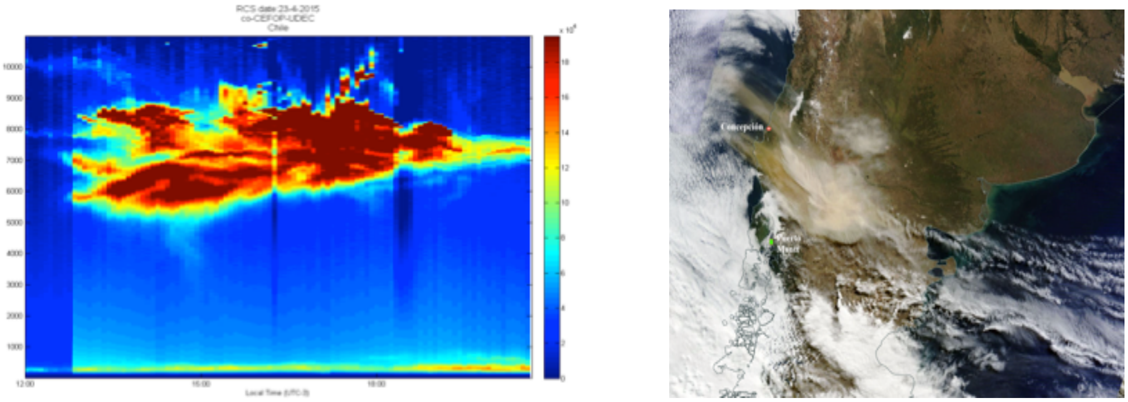
Regarding high relative humidity profile, the enhancement hygroscopic factor f (λ, R, RH) was calculated to retrieve the βaer (R) without air humidity effect (Figure 2).



a. b.

Figure 2. a. Comparison of the variance of βaer (R) average profiles as function of air humidity. b. Daily evolution of βaer (R) without humidity effect at April 12, 2012 in LIDAR-CEFOP station.

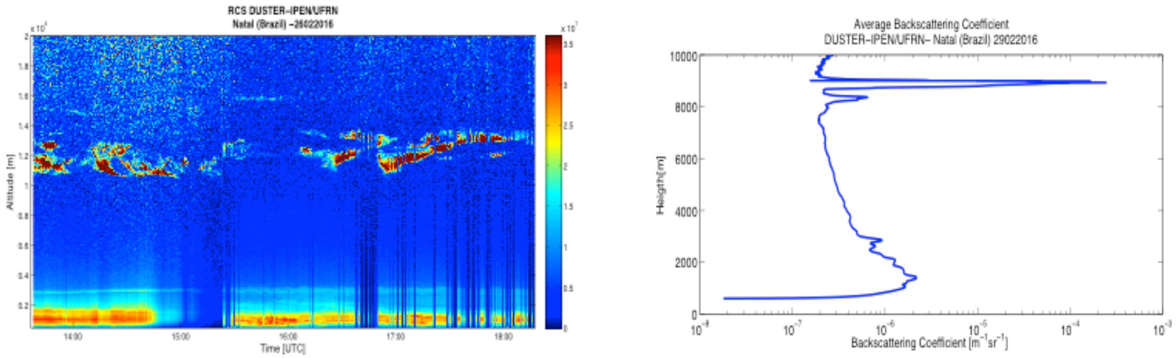
On April 22, 2015, Calbuco volcano in southern Chile erupted. At April 23, the LIDAR-CEFOP station measured and monitored the plume during its traveling over Concepción, as Figure 3 shows, the ash plume arrive to the city at 16 UTC and leaves at 21.30 UTC, the layer thickness was between 6,0 km and 9,0 km.



a. b.

Figure 3. a. LIDAR range corrected signal of ash plume from Calbuco volcano. b. MODIS satellite image of Calbuco ash plume traveling between Chile and Argentina.

In Natal (Brazil), the LIDAR system (named DUSTER) uses two polarized channels at 532nm for monitoring urban air pollution. Figure 4 shows the measurements of February 29, 2016 and the average backscattering profile for the same day, a high cirrus cloud at 9,8 km and high background aerosol layer until 2,8 km were identified.



a. b.

Figure 4. a. DUSTER range corrected signal at February 29, 2016. b. Average βaer (R) profile at 532|| nm

4. References

[1] E. Montilla-Rosero, A. Silva, C. Jimenez, R. Hernandez, C. Saavedra. "Optical characterization of lower tropospheric aerosols by the Southern East Pacific Lidar station (Concepcion, Chile)". Journal of Aerosol Science. Volume 92, Pages 16–26. 2016. doi:10.1016/j.jaerosci.2015.09.008.

[2] Boris B. Chen, Leonid G. Sverdlik, Sanjar A. Imashev, et al., "Lidar Measurements of the Vertical Distribution of Aerosol Optical and Physical Properties over Central Asia," International Journal of Atmospheric Sciences, vol. 2013, Article ID 261546, 17 pages, 2013. doi:10.1155/2013/261546.

[3] Whiteman D. N., "Examination of the traditional Raman lidar technique. II. Evaluating the ratios for water vapor and aerosols". Applied Optics, 42, 2593-2608. 2003.

[4] Sicard, M., Peèrez, C., Rocadenbosch, F., Baldasano, J. M., and Garciìa-Vizcaino, D.: "Mixed-layer Depth Determination in the Barcelona Coastal Area from Regular Lidar Measurements: Methods, Results and Limitations", Bound.-Lay. Meteorol., 119, 135–157, 2006.

[5] Del Guasta, M., "Simulation of LIDAR returns from pristine and deformed hexagonal ice prisms in cold cirrus clouds by means of face tracing". J. Geophys. Res., 106, 12 589–12 602. 2001

[6] Silva, A., Montilla-Rosero, E., Jiménez, C., Saavedra, C., & Hernández, R. "Tropospheric measurements of aerosol optical properties at Concepcion (36S, 73W)". Proceedings of 26th international laser radar conference (26th ILRC), (Vol. I, pp. 521–524). Porto Heli, Greece, 2012.

[7] Klett, J. D. "Lidar inversion with variable backscatter/extinction ratios", Appl. Optics, 24, 1638–1643, 1985.

[8] Fernald, F. G. "Analysis of atmospheric lidar observations: some comments", Appl. Optics, 23, 652–653, 1984.