AIR POLLUTION CONFERENCE BRAZIL
CMAS SOUTH AMERICA
COMMUNITY MODELING AND ANALYSIS SYSTEM

Atmospheric Aerosol Behavior Study in Natal City through LIDAR Backscatter Profiles and Random Errors Propagation Analysis by Monte Carlo Method

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Abstract: The physical and optical interaction of aerosols in atmospheric processes are complex and have high temporal and spatial variability, representing uncertainties as, for example, the aerosol particles influence on the atmosphere energetic balance. The Duster is a LIDAR system (Light Detection and Ranging) located in Natal / RN, capable of working with four detection channels (355 nm, 532 nm p, 532 nm s and 1064 nm). Duster sends pulses of laser light to the atmosphere and detects the return signal that results from the interaction of light with aerosol particles in the atmosphere. The signal detected by the system is represented by the LIDAR equation, which describes the optical properties and the system geometric parameters. The solution for this equation is obtained by the Klett-Fernald-Sasano Inversion Method (KFS), which extracts the inverted optical properties as backscattering (β) and extinction (α) profiles. The present work brings the result of analysis in backscatter profiles of the LIDAR signal in channel 532 nm during the aerosol Monitoring Campaign Long-Range Transportation Over Natal II (MOLOTOV II) that occurred from November 2017 to February 2018. We applied the Monte Carlo method for the analysis of the error in DUSTER measurements, which employs random numbers sequences. Two days of signal measurements were selected, to deal with four groups files, within approximately 30 min each group (frequency acquisition every 10 seconds). N synthetic profiles, as height function, with a random number generator, were created. Algorithms were performed, which removed the measurements clouds, the dark profiles, the background noise and generated the Range Corrected Signal (RCS). The KFS was applied to the synthetic profiles to obtain a set of N solutions (backscatter and extinction coefficient profiles). The results show that the N optical property profiles presented a considerable variability, characterized by their standard deviation. This variability, calculated as the height function, is the random error estimate of the LIDAR signal associated with the inversion procedure. The observed aerosols, according to information from the Hysplit trajectory model, were originated from the Sahara desert.

Keywords: LIDAR, Backscattering, Error Propagation
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INTRODUCTION

As propriedades físicas e ópticas dos aerossóis nos processos atmosféricos são complexas e tem uma alta variabilidade temporal e espacial, representando incertezas quanto à influência das partículas de aerossóis nos processos na atmosfera, como, por exemplo, no balanço radioativo da Terra (RUIZ-ARIAS, et al., 2013; ORZA; PERRONE, 2015), de forma direta, espalhando e absorvendo a radiação solar que chega à atmosfera, e de forma indireta, modificando as propriedades das nuvens (KAUFMAN et al., 2002; CORTÉS-HERNÁNDEZ et al., 2014; TOMASI et al., 2015), que pode alterar o perfil de temperatura na camada da atmosfera, uma vez que o aerossol é variável no tempo e no espaço. Os aerossóis podem prejudicar a saúde humana, a qualidade do ar, a visibilidade, o balanço da radiação do planeta, causando efeitos danosos à sociedade, o que implica em um assunto de grande importante a ser estudado.

O Brasil é um país de escala continental onde existem, atualmente, apenas três sistemas Lidar realizando o monitoramento das propriedades ópticas de aerossóis na troposfera do território brasileiro: um instalado em São Paulo-SP, outro em Manaus-AM e o mais recente em Natal-RN.

No Brasil, o monitoramento das propriedades ópticas dos aerossóis na atmosfera é aplicado nas seguintes áreas:

The physical and optical properties of the aerosols in the atmospheric processes are complex and have a high temporal and spatial variability, representing uncertainties as to the influence of the aerosol particles in the processes in the atmosphere, such as in the Earth's radioactive balance (RUIZ-ARIAS, (1998), directly by spreading and absorbing the incoming solar radiation to the atmosphere, and indirectly modifying the properties of the clouds

(KAUFMAN et al., 2002; CORTÉS-HERNANDEZ et al., 2014; TOMASI et al., 2015), which can alter the temperature profile in the atmosphere layer, since the aerosol is variable in time and space. Aerosols can harm human health, air quality, visibility, and the planet's radiation balance, causing harmful effects to society, which implies a major issue to be studied.
Brazil is a continent-wide country where there are currently only three Lidar systems monitoring the optical properties of aerosols: one installed in São Paulo-SP, another in Manaus-AM and the most recent in Natal -RN.
In Brazil, the aerosols optical properties monitoring in the atmosphere is applied in the following areas:

(a) transportation of dust from the Sahara desert and from burning emissions from the sub-Sahelian region to the South American continent;

(b) study of optical and physical properties and formation of Cirrus clouds, which are formed at the international flights altitude;

(c) validation and comparison of measurements of satellite and solar photometer of the AERONET Network data, which measure the vertical distribution of aerosols in the atmosphere; d) calibration, alignment and optimization of the atmosphere optical properties measurements, for application in the validation of the EARTHCare satellite.

These applications are being developed with national and international cooperation, such as the Institute of Energy and Nuclear Research - IPEN / Brazil, University of Granada / Spain, LangleyResearch Center-NASA / USA, National Institute for R & D for Optoelectronics in Romania, Ludwig Maximilians University , in Germany, Spain and the European Space Agency under the project Assessment of atmospheric optical properties during biomass burning eventsand Long-range transport of desert dust - APEL and the project ADM-Aeolus CAL / VAL of the ESA, for the validation of the satellite EARTHCare.

In order to monitor the transportation of dust from the Sahara desert and the emission of fires from the sub-Sahelian region to the South American continent, and to study the properties of the aerosols in the atmosphere, a Duster Light Detection and Ranging (Duster / LIDAR) remote sensing system and a CIMEL solar photometer from the AERONET network were installed in the Brazilian northeast (city of Natal / RN), which is located in a strategic geographic position for this study (5th S).

METHODS

The signal detected by the system is represented by the LIDAR equation, which describes the optical properties of the aerosol particles in the atmosphere, generating information from the backscatter profiles, according to (Weitkamp, 2005):

$$P(R,\lambda) = P_0 \frac{c\tau}{2} A\eta \frac{O(R)}{R^2} \beta(R,\lambda) \left[-2\int_0^R \propto (r,\lambda)\,dr\right]$$

Where:
P (R, l) is the Laser energy flux backscattered at wavelength l, at distance R; Po is the mean power of the laser unit pulse; c is the speed of light; t is the pulse duration; A is the area of the primary receiver, which receives the light backscattered back; h is the overall efficiency of the system; The (R) is the overlap function; ß (R, l) is the backscatter coefficient at wavelength l, at distance R, and is given in m-1sr-1; l is the backscattered light wavelength; a (r, l) is the extinction coefficient [m-1].
According to theoretical and observational studies, the extinction and backscattering coefficients may be related to the LIDAR ratio:

$$RL_{aer}(R) = \beta_{aer}(R)/\alpha_{aer}(R).$$

The solution of the Lidar Equation is obtained through the Klett-Fernald-Sasano Inversion Method (KFS), which extracts the coefficients ß (R, l) and a (R, l) from the measurements performed with the Lidar system.

We applied the Monte Carlo method for the error analysis of in DUSTER measurements, which employs random numbers sequences (Rascado, 2008). Two days of signal measurements were selected, to deal with four groups files, within approximately 30 min each group (frequency acquisition every 10 seconds). N synthetic profiles, as height function, with a random number generator, were created. Algorithms were performed, which removed the measurements clouds, the dark profiles, the background noise and generated the Range Corrected Signal (RCS). The KFS was applied to the synthetic profiles to obtain a set of N solutions (backscatter and extinction coefficient profiles).

RESULTS AND DISCUSSION

In this section we show results using two days of signal measurements: 19 and 27 December 2019.

For 19 December, we present Figure 1 with the particulate backscatter profile in wave length, as below.

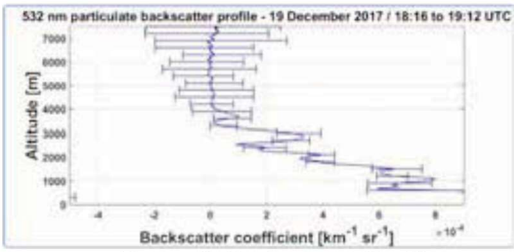

Figure 1. Backscatter Profile

Figure 2 shows the Quicklooks figures, where we can observe aerosols as light blue stripes.

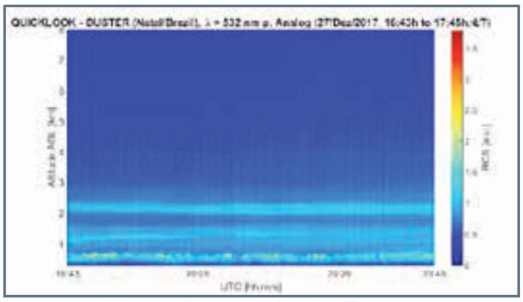

Figure 2. Quicklooks figures

And Figure 3 shows aerosols originated from the Sahara desert.

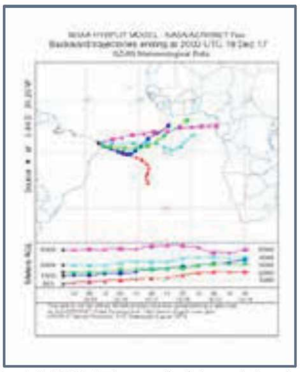

Figure 3. HYSPLIT model backtrajectories

For 27 December, we present sim19 December day.

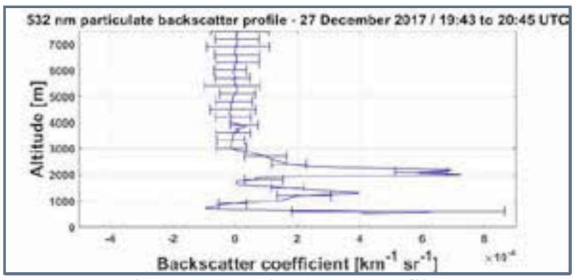

Figure 3. Backscatter Profile

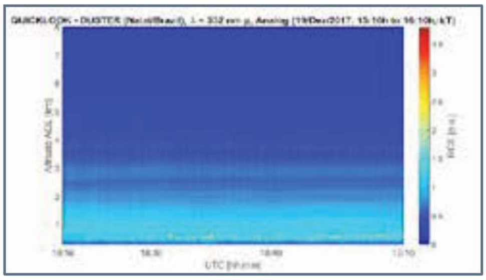

Figure 5. Quicklooks figures

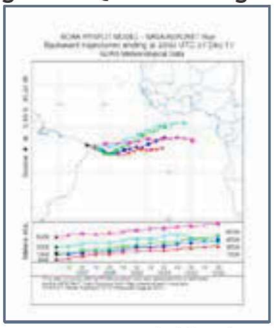

Figure 6. HYSPLIT model backtrajectories

The error bars considering both days characterize the random error estimate of the LIDAR signal associated with the inversion procedure.

CONCLUSIONS

This preliminary study shows that the N optical property profiles presented a certain variability that is characterized by their standard deviation (Particular Backscatter Profile figure). This variability, calculated as the height function, is the random error estimate of the LIDAR signal associated with the inversion procedure. According to the HYSPLIT model backtrajectories, the observed aerosols, as shown by the Quicklooks figures, were originated from the Sahara desert.

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