Characterization of atmospheric aerosols for a long range transport of biomass burning particles from Canadian forest fires over the southern Iberian Peninsula in July 2013

Caracterización del aerosol atmosférico en un evento de transporte a gran distancia de partículas de combustión de biomasa procedente de incendios de Canadá en julio de 2013 sobre el sur de la Península Ibérica

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ABSTRACT:

This work presents the characterization of aerosols during a special episode of long-range transported biomass burning particles from Canadian forest fires. This event was detected at the EARLINET Granada station (37.16° N, 3.61° W, 680 m asl) from 11th to 17th July 2013, and also over other EARLINET stations. Different techniques, covering active/passive and ground based/satellite ones, have been used. In particular, the study has involved processing of both Raman and elastic lidar signals and sun-photometer AERONET data. Furthermore, modeling tools as HYSPLIT, NAAPS and BSC-DREAM8b have been used to understand the synoptic behavior of the aerosol plumes. The results highlight the presence of a multilayered structure showing large backscatter-related Angstrom Exponent (around 2) and very low particle linear depolarization (less than 0.04) at layers around 5-6 km (asl) which means considerably small and spherical particles. During the strongest period, on 14th July, aerosol backscatter values up to 2.9×10^{-6} (m sr)⁻¹ at 532 nm were detected in this layer.

Key words: AERONET, Canadian Biomass Burning Particles, EARLINET, Lidar, Long-Range Transport, Sun-Photometer.

RESUMEN:

Este trabajo presenta la caracterización, durante un evento especial de transporte a gran distancia, de partículas de combustión de biomasa, procedentes de incendios forestales en Canadá. El evento se detectó entre el 11 y el 17 de julio de 2013 en la estación de EARLINET en Granada (37.16° N, 3.61° W, 680 snm), así como en otras estaciones de EARLINET. Para su caracterización se han usado diferentes técnicas, incluyendo activas/pasivas y terrestres/por satélite. En particular, el estudio implicó el procesamiento de señales lidar tanto elásticas como Raman, y datos de fotómetro solar de la red AERONET. Además se han usado modelos como HYSPLIT, NAAPS y BSC-DREAM8b para investigar el comportamiento de las plumas de aerosol a escala sinóptica. Los resultados destacan la presencia de una estructura con múltiples capas que muestran un exponente de Angstrom de coeficiente de retrodispersión alto (aproximadamente 2) y una despolarización lineal de partículas muy baja (menos de 0.04) en las capas a 5-6 km (snm) de altura, lo que indica que son partículas considerablemente pequeñas y esféricas. Durante el período más intenso, el 14 de julio, se detectaron valores del coeficiente de retrodispersión de hasta 2.9×10^{-6} (m sr)⁻¹ para 532 nm.

Palabras clave: AERONET, EARLINET, Fotómetro Solar, Lidar, Partículas de Combustión de Biomasa Canadienses, Transporte a Larga Distancia.

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1. Introduction

In recent years, the important role of atmospheric aerosols on climate has been studied in several works that focus both on direct and indirect effects. Particularly, it has been demonstrated that biomass burning particles produce a considerable impact on local radiative properties of the atmosphere [1], both by absorbing and scattering shortwave radiation. For this reason, all studies made in order to typify and characterize such aerosols are relevant for a better understanding of the complex system of atmospheric radiative transfer and the Earth's radiation budget. Likewise, comparable studies have been made for the same aerosol type (biomass burning particles) and both for medium- and long-range transport [2, 3]. Studying the same kind of particles at a different transport time is crucial to figure out the ageing processes involved.

This work presents a general optical characterization of a strong plume of long-range transported biomass burning particles from Canadian forest fires, registered over Southern Iberian Peninsula in July 2013. The aim is to identify the layers in terms of aerosol backscatter coefficient vertical profiles, and then characterize the changes in variables like Angstrom Exponent and particle linear depolarization ratio, compared to days after and before the arrival of the plume.

2. Experimental site, instrumentation and methodology

The instrumentation used to acquire the data used in this study is located at the Andalusian Institute for Earth System Research (IISTA-CEAMA) in Granada (37.16° N, 3.61°W, 680 m above sea level). This city is located in Southern

Spain. The station is included in several research networks like EARLINET (European Aerosol Research Lidar Network) [4], SPALINET (Spanish and Portuguese Lidar Network) [5], AERONET (Aerosol Robotic Network) [6] and MWRNET [7].

The vertical profiles used in this work were acquired using a multiwavelength Raman lidar system (LR331D400), configured in a monostatic biaxial alignment pointing vertically to the zenith. The light source is a pulsed Nd:YAG laser with fundamental wavelength at 1064 nm, and additional emissions at 532 and 355 nm, which are obtained by using second and third harmonic generators. The radiation is collected by a 40 cm-diameter receiving Cassegrainian telescope, and then the radiation is split into seven channels allowing the detection of elastic signals at 1064, 355 and 532 nm (in parallel and perpendicular polarizations) and three Raman channels at 387 and 607 nm (nitrogen Raman-shifted signal from 355 and 532 nm, respectively) and 408 nm (water vapour Raman-shifted signal from 355 nm). The spatial resolution is 7.5 m and the temporal resolution is 1 min. This instrument has an overlap limitation due to its intrinsic setup, but it will not be taken into account in this work, since our study focuses in heights above 1.7 km asl [8,9]. The vertical profiles from the lidar signal were retrieved using the Klett-Fernald algorithm [10–13] for daytime signal and Raman algorithm [14] for night time signals.

The atmospheric column over Granada was analyzed in terms of certain aerosol optical properties: aerosol backscatter coefficient (β), particle linear depolarization ratio (δ_p) and backscatter-related Angstrom Exponent (β -AE), defined as follows:

$$\delta_p = \frac{R\delta(\delta_m + 1) - \delta_m(\delta + 1)}{R(\delta_m + 1) - (\delta + 1)}, \quad (1)$$

$$AE = -\frac{\ln \left[\frac{\beta(\lambda_1)}{\beta(\lambda_2)} \right]}{\ln \left[\frac{\lambda_1}{\lambda_2} \right]}, \quad (2)$$

In δ_p equation, R is the backscattering ratio defined as the ratio of total (particle plus molecule) to molecular backscatter coefficients, δ is the volume linear depolarization ratio calibrated following [15] and δ_m is the molecular linear depolarization ratio. The δ_p values provide information on the predominance of spherical versus non-spherical particles. The β -related AE describes the spectral dependence of aerosol backscatter coefficient. It is believed to be dominated by particle size and shape.

In our analyses some data retrieved from the CIMEL CE-138 sun-photometer are also used. This instrument measures solar transmissions, aureole and sky radiances through a large range of scattering angles. The automatic tracking Sun and sky scanning radiometers made direct Sun measurements with a 1.2° full field of view every 15 min at 340, 380, 440, 500, 675, 870, 940 and 1020 nm (nominal wavelengths). These solar extinction measurements are then used to compute aerosol optical depth at each wavelength except for the 940 nm channel, which is used to retrieve total column water vapour. A more complete description can be found in [6].

In order to know about the synoptic movement of the aerosol plumes before arriving to our station, some modelling tools were employed. With HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) [16] one can calculate back-trajectories and dispersion, particle concentration and deposition processes using a Lagrangian model and meteorological data from GDAS database. NAAPS (Navy Aerosol Analysis and Prediction System) model of Marine Meteorology Division, Naval Research Laboratory (NRL) [17] provides predictions of aerosol optical depth and surface particle density of sulphate, mineral dust and smoke. Finally, BSC-DREAM8b (Dust Regional Atmospheric Model) [18] gives maps showing the dust load –dust mass per unit section of

atmospheric column- and thus allows us to identify desert emitting sources.

3. Results and discussion

In the period from 11th to 17th July 2013, a strong aerosol load in the free troposphere –in terms of aerosol backscatter and extinction coefficients- was detected over our station. Back-trajectories at altitudes of 1000, 2000, 3000, 4000, 5000 and 6000 m asl were analysed with HYSPLIT model (v4.9) for every day in this period. Figure (1) shows these back-trajectories for the day which best describes the episode, the 14th July (trajectories starting 10 days before). It is seen that the air masses of interest came from the North of Canada, where several wildfires had started the week before and were still burning, as detected by MODIS sensor [19]. The same conclusion can be inferred from the back-trajectories for day 15th July. In contrast, 11th and 12th July trajectories (both calculated starting a week before) show wind coming mainly from Sahara desert and from the North of Spain. Back-trajectories corresponding to the rest of the days in the period (also starting a week before each day) reflect a mix of air masses from Sahara desert and from central Europe.

NAAPS model for the days mentioned has also been analysed (not shown here). This model

Fig. 1. 10-day back-trajectories of the air masses at altitudes of 4000, 5000 and 5500 m asl on 14th July.

does not predict any significant surface concentrations of dust, smoke or sulphate. Predictions about dust concentrations, made with BSC-DREAM8b simulation model, show that only on 11th July a dust load, up to 0.25 g/m² was forecasted. Looking at these three models, we can understand the synoptic behaviour of the aerosol plumes: according to that, it can be inferred that it is potentially expected a small mineral dust load on 11th July originated in Africa, long-range transported biomass burning particles advected from Canadian forest fires to Granada on days 14th and 15th July, and some anthropogenic aerosol coming from Europe, maybe mixed with remaining smoke on 16th and 17th July. In Fig. (2), the evolution of the lidar range corrected signal (raw lidar signal multiplied by square distance) at 532 nm is displayed, with altitude above sea level in the

vertical axis and time UTC in the horizontal axis. They allow seeing the main aerosol layers at a glance, thus the day of the strongest load, 14th July, can be easily identified. They highlight the presence of a multilayered structure with aerosol particles at high altitudes (around 5-6 km).

Lidar calculations were performed, and the results combined with the models discussed above reveal that on days 14th and 15th July an important plume of biomass burning aerosol passed the free troposphere over Granada. Figure (3b) shows how in 4 km layers, the aerosol backscatter coefficient undergoes a sharp increase (from $5 \times 10^{-7} \text{ m}^{-1} \text{sr}^{-1}$ to $2 \times 10^{-6} \text{ m}^{-1} \text{sr}^{-1}$ at 532 nm) compared to the dust layers on 11th July, as seen in Fig. 3(a). This increase occurs parallel to a decrease in the particle

Fig. 2. Time series of lidar range corrected signal at 532 nm (arbitrary units).

Fig. 3. Vertical profiles retrieved for: (a) 11th July; (b) 15th July; (c) 17th July. Left: backscatter coefficient calculated at 355, 532 and 1064 nm. Right: δ_p and β -related Angstrom Exponents for the ranges 532-1064 nm and 355-532 nm.

linear depolarization ratio (which reaches values less than 0.05) and an increase in the backscatter-related Angstrom Exponent (from 0.3 to 2), what means that these biomass burning particles transported along the Atlantic ocean are much smaller and spherical than dust ones [20,21]. Coherent results are also obtained from sun-photometer: Fig. 4, representing sun-photometric data, shows that on 14th July, fine mode particles are the main responsible of the

Fig. 4. Aerosol Optical Depth at 500 nm for the period studied, retrieved from sun-photometer data.

total aerosol optical depth at 500 nm (around 83% of the total AOD). Finally, looking at Fig. 3(c), it can be guessed a certain mixture of layers with high β -AE and low δ_p , and others with the opposite features.

4. Conclusions

The location of Granada station is such that different types of aerosol are usually registered: dust particles coming from Sahara desert, anthropogenic aerosol from Europe or biomass burning particles. This study presents a preliminary characterization of particles arriving from Canadian wildfires, after a several-day transatlantic transport with the subsequent aging process. Despite having travelled for more than a week, these particles can produce a strong increase in aerosol backscatter and extinction coefficients in the free troposphere (above 5000 m asl), as the Raman lidar measurements revealed.

During the studied period, aerosol backscatter coefficient values up to $2.9 \times 10^{-6} \text{ (m} \cdot \text{sr)}^{-1}$ at 532 nm were detected in the layers corresponding to biomass burning aerosol. After having investigated the air masses origin, the vertical aerosol optical profiles were analyzed in order to establish an aerosol typing. The analysis of vertical profiles of particle linear depolarization ratio (showing values less than 0.04) and backscatter-related Angstrom Exponent (with values more than 2) reflects that such particles are significantly small and

spherical. High-quality vertical profiles were obtained for this special episode, what makes motivating to follow with the study in order to obtain accurate optical properties of the layer, such as layer-mean lidar ratio and layer-mean Angstrom Exponent, and microphysical properties derived by LIRIC [22].

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