CHARACTERISATION OF BIOMASS BURNING AEROSOLS IN THE SOUTHERN HEMISPHERIC MIDLATITUDES BY MULTIWAVELENGTH RAMAN LIDAR

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ABSTRACT

Vertically resolved multiwavelength aerosol Raman lidar observations were conducted in the pristine environment of the Southern-hemisphere midlatitudes at Punta Arenas, Chile (53.1346°S, 70.8834°W). In contrast to the usually prevailing clean and pristine conditions at this site, two pronounced lofted aerosol layers were observed up to 4.2 and 4.4 km height on 4 and 5 February 2019, respectively. The layers mainly consisted of biomass burning aerosols originating from the region of Central Chile, where wildfires were also observed. Based on spectrally resolved backscatter and extinction coefficients, lidar ratios and depolarization ratio a detailed characterization of the aerosol optical properties is presented.

1. INTRODUCTION

Vertically resolved measurements of aerosol optical and microphysical properties are of high importance for climate research and the Light Detection And Ranging technique (lidar) is commonly used within the atmospheric research community for the retrieval of vertical aerosol profiles. On global scale, monitoring of the aerosol characteristics has been achieved through spaceborne missions, e.g. with the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations mission (CALIPSO, [1]) and the upcoming EarthCARE satellite [2], and by ground-based networks e.g. the European Aerosol Research Lidar Network (EARLINET [3]), the ceilometer network of the German Meteorological Service (DWD, [4]) and the portable Raman lidar systems network Polly^{NET} ([5], [6], [7]). More specifically, in the framework of worldwide field campaigns, Polly^{XT} systems have acquired unique lidar data sets in the Amazonian basin, India, China, South Africa, Finland, Korea, Chile and over the Atlantic and Arctic on board the research vessels Polarstern and Meteor. Since November 2018, the Leipzig Aerosol and Cloud Remote Observations System (LACROS) operates 24/7 in Punta Arenas, Chile (53.1346°S and 70.8834°W, 9 m a.s.l.) aiming to provide further information on aerosol, clouds and their interaction processes in the Southern Ocean environment.

2. METHODOLOGY

The lidar observations were conducted in the framework of the Dynamics, Aerosol, Cloud and Precipitation Observations in the Pristine Environment of the Southern Ocean (DACAPO-PESO). The Raman lidar Polly^{XT} [7] deployed on site allows the determination of vertically resolved profiles of volume extinction and backscatter coefficient (at 355, 532 and 355, 532, 1064 nm respectively), lidar ratio (at 355 and 532 nm), and depolarization ratio (at 355 and 532 nm). The extinction and backscatter coefficients were determined as described by Ansmann and Müller (2005) [8], while for the depolarization ratio the methodology as described in Freudenthaler et al. (2009) [9] was applied. The influence of noise to the lidar signals was reduced by means of a moving average filter with a window length of 742.5 m.

3. RESULTS

3.1 Aerosol optical properties

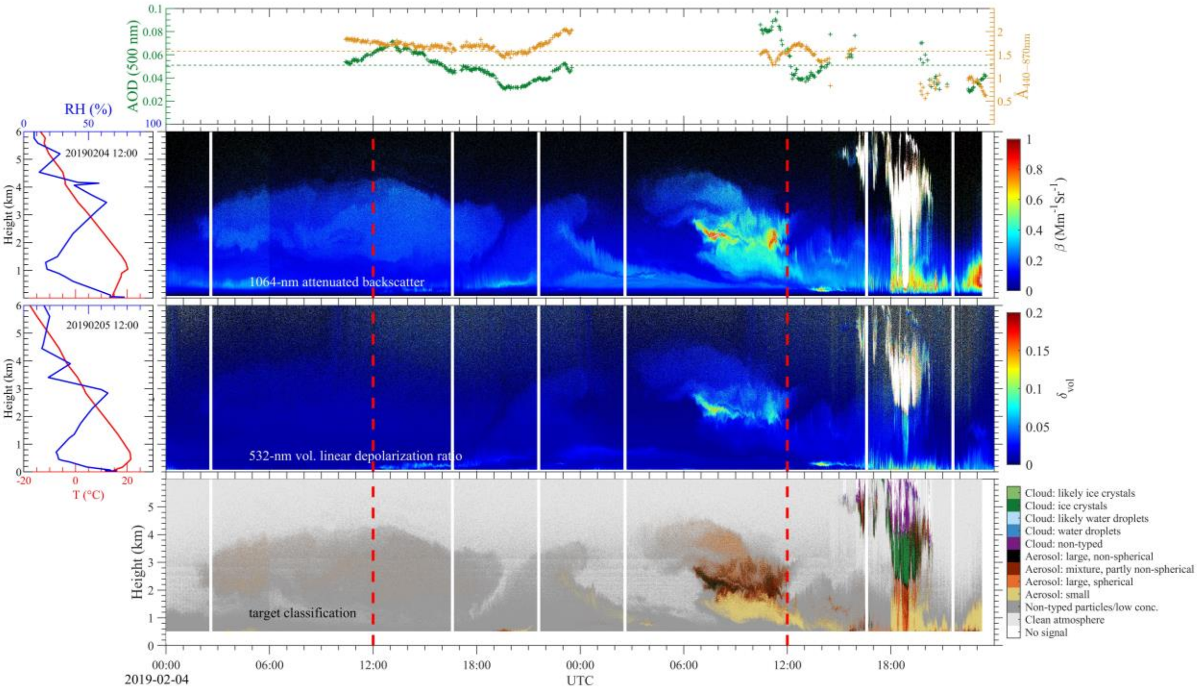

Figure 1. From the upper to the lower panel: AOD (500 nm) and Ångström exponent (440/870 nm), attenuated backscatter coefficient at 1064 nm ($sr^{-1}m^{-1}$), volume depolarization ratio (%), and target classification reflecting the atmospheric conditions over Punta Arenas from 04.02.2019 to 05.02.2019. Within the study period, two radiosonde launches took place (depicted with red dashed lines). The corresponding temperature and relative humidity profiles can be seen on the left panels.

During the DACAPO-PESO campaign, from 4 February to 5 February 2019, several lofted aerosol layers were observed between 1 and 5 km height. Figure 1 shows the two-day overview of the AOD (500 nm), attenuated backscatter coefficient (1064 nm), volume depolarization ratio (%), temperature (°C) and relative humidity (%) over Punta Arenas. As Figure 1 indicates, on 4 February 2019 between 02:00 and 19:30 UTC an extensive aerosol plume was present, characterized by low backscatter and extremely low depolarization values. Data from radiosondes (Fig. 1, left top) revealed a temperature inversion at 1 km height, while the relative humidity decreased rapidly up to 1 km and then increased with height up to 65% and up to the top of the layer at 4 km height. On 5 February 2019 between 06:00 and 12:00 UTC, the aerosol plume was characterized by higher backscatter values and, at some parts, higher depolarization ratios. A temperature inversion was present at 0.5 km height and up to the same altitude, the relative humidity decreased rapidly to values of 30%. Above that level the relative humidity increased up to 70% at 3 km above which it decreased strongly towards 20% throughout the clean middle troposphere (Fig. 1, left bottom).

According to the Aerosol Robotic Network (AERONET, [10]), the aerosol optical depth (AOD, which is a measure of the integrated extinction of solar radiation by atmospheric particles) reached values up to 0.07 and 0.09 at 500 nm on 4 and 5 February respectively. The AOD is relatively high (despite the values smaller than 0.1 observed) for the typical average AOD values observed over Punta Arenas of approx. 0.04 at 500 nm. The daily variability of AOD at 500 nm and Ångström exponent at the wavelength pair of 440/870 nm are shown in Fig. 1 (top panel).

The Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT, [11]) model was used in order to identify the origins of the air masses observed. As shown in the 5-day backward trajectories (Fig. 2), the air masses arriving on 5 February 2019 at 08:00 UTC at 3, 2 and 1 km originate from the Southeastern Pacific Ocean, and on their descending route to Punta Arenas they pass over Central Chile (on 4 February 2019). Data from FIRMS (Fire Information for Resource Management System, [12]) show that above the aforementioned regions, where the air masses passed by on 3 and 4 February 2019, active fires and wildfires occurred (shown in Fig. 2 with red and yellow colors). Therefore, our observations are most likely biomass burning aerosols (4 February 2019) and biomass burning aerosols possibly mixed with some volcanic ash from the eruptions of Planchón-Peteroa and Nevados de Chillán volcanoes (5 February 2019).

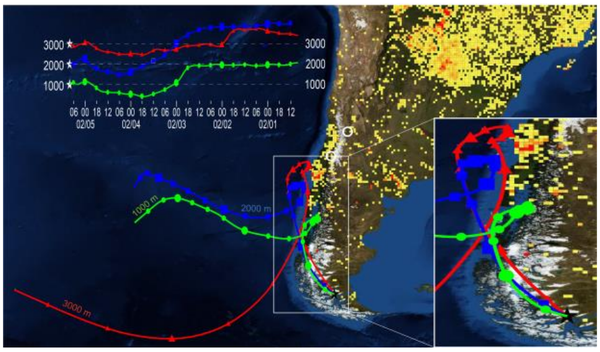

Figure 2. 5-day HYSPLIT backward trajectories arriving over Punta Arenas at 2 km (red line) and 3 km (blue line) on 05 February 2019, at 08:00 UTC. The underlying fire map derived from FIRMS shows all fires (yellow and red spots) detected during January 2019 and the locations of the two active volcanoes (white circles).

Figure 3 shows the aerosol optical properties observed over Punta Arenas on 4 (top panel) and 5 February (lower panel) 2019, respectively. As the backscatter coefficient profiles (Fig. 3a) indicate, the main aerosol load is located between 1.5 and 4 km height. For the same altitudes, the lidar ratio (Fig. 3c) at 355 nm is almost constant with height and it is roughly 50-60 sr, a value that indicates the presence of a biomass-burning dominated aerosol mixture. The backscatter-related Ångström exponents above 1 for both wavelength pairs (Fig. 3d), indicate the predominance of relatively small particles which are also spherical (low particle depolarization ratio, Fig. 3e). For the same period, the automated target classification (Fig. 1, [6]) was not able to assign a specific aerosol type due to the low aerosol scattering. The profiles of backscatter coefficient (Fig. 3f) along with the very low particle linear depolarization ratio (Fig. 3j) indicate that on 5 February 2019 the aerosol load, located between 1 and 4 km height, consisted mainly of smoke particles and a possible mix with

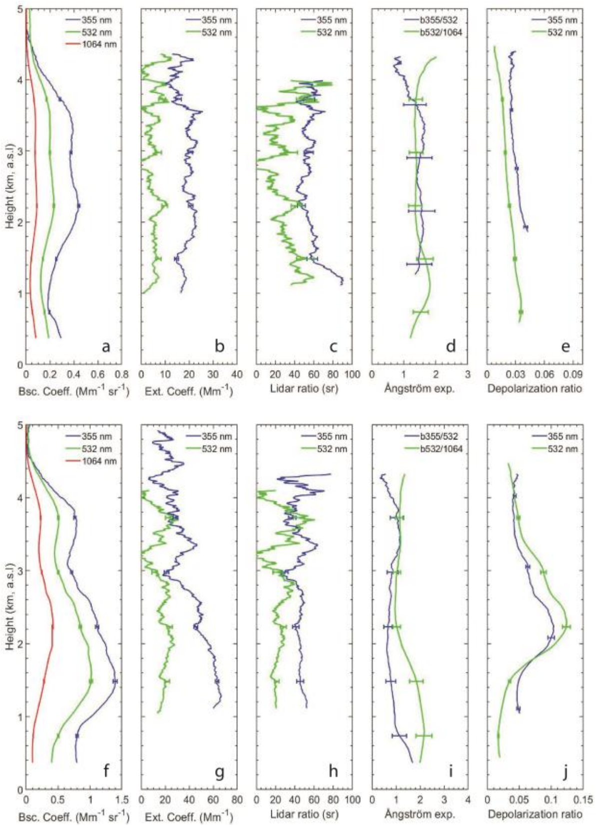

Figure 3. (a) and (f) mean particle backscatter coefficients (at three wavelengths), (b) and (g) extinction coefficients (at two wavelengths), (c) and (h) the corresponding extinction-to-backscatter ratios, (d) and (i) backscatter-related Ångström exponents, and (e) and (j) particle depolarization ratios measured at Punta Arenas (top) on 4 February 2019, 06:00-09:00 UTC and (bottom) on 5 February 2019, 08:00-09:00 UTC. Error bars (standard deviation) include systematic uncertainties and signal noise.

volcanic ash transported from the aforementioned erupting volcanoes. Below 2 km height, the lidar ratio is between 40 – 60 sr (at 355 nm, Fig. 3h) and the Ångström exponent values are higher than 1, indicating the predominance of small particles (Fig. 3i). At the same altitude, the particle linear depolarization ratio is smaller than 5% (for both wavelengths) indicating the presence of mainly spherical particles. Above 2 km height, the Ångström exponent values are decreasing, and the depolarization ratio increases up to 12 % (around 2.2 km) and then decreases with height again. From the aforementioned observations we can conclude the presence of relatively large, predominantly non-spherical particles above 2 km height. Our results are in agreement with the target classification (Fig. 1), which confirms the presence of small in size particles below 2 km height, whereas aerosols are classified as a mixture of partially spherical and non-spherical particles above that level.

4. SUMMARY AND OUTLOOK

Two lofted aerosol layers were observed by the Raman lidar Polly^{XT} in the pristine environment of the Southern Hemisphere Midlatitudes (Punta Arenas). Both the extensive and the intensive optical parameters of the layers were studied and it was found that the observed aerosol load was consisting of mainly biomass burning aerosols. In addition, this case study is intended to be used for validation purposes, as an input to a new aerosol typing algorithm that is currently under development at Leibniz Institute for Tropospheric Research (TROPOS). The algorithm will be applicable to both ground-based and spaceborne lidar and will exploit the multispectral information from sophisticated ground-based lidars (i.e., 3 backscatter, 2 extinction and 2 depolarization measurements at 355, 532 and 1064 nm), but will also be able to retrieve an aerosol typing from less information (e.g. EarthCARE). In brief, the aerosol mixing state (based on different aerosol types) will be estimated by means of optimal estimation by combining the lidar-measured quantities (lidar ratio, depolarization ratio and Ångström exponent) with the most representative microphysical description, in terms of size and shape distribution and spectral complex refractive index. Preliminary results from the algorithm show that separation between smoke, maritime, pollution and dust dominated aerosol mixtures and estimation of their mixing state are possible.

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