Characterization of Recent Aerosol Events Occurring in the Subtropical North Atlantic Region Using a CIMEL CE376 GPN Micro-LiDAR

Y. González Ramos[1][0000-0001-5153-3972], I. Popovici[2], A. Barreto[3][0000-0001-5806-585X], M. F. Sanchez-Barrero[4], L. Pronieswki[5], S. Victori[6][0000-0003-3045-2377], F. A. Almansa[7], R. Ramos[8], E. Cuevas[9][0000-0003-1843-8302]

[1] CIMEL Electronique, Paris, 75011, France; Izaña Atmospheric Research Centre, S/C de Tenerife, 38001, Spain, y-gonzalez@cimel.fr
[2] CIMEL Electronique, Paris, 75011, France, i-popovici@cimel.fr
[3] Izaña Atmospheric Research Centre, S/C de Tenerife, 38001, Spain, abarretov@aemet.es
[4] CIMEL Electronique, Paris, 75011, France, m-sanchez@cimel.fr
[5] CIMEL Electronique, Paris, 75011, France, l-pronieswki@cimel.fr
[6] CIMEL Electronique, Paris, 75011, France, s-victori@cimel.fr
[7] CIMEL Electronique, Paris, 75011, France; Izaña Atmospheric Research Centre, S/C de Tenerife, 38001, Spain, f-almansa@cimel.fr
[8] Izaña Atmospheric Research Centre, S/C de Tenerife, 38001, Spain, rramos@aemet.es
[9] Izaña Atmospheric Research Centre, S/C de Tenerife, 38001, Spain, ecuevas@aemet.es

Abstract. A CIMEL CE376 GPN micro-LiDAR was installed at the facilities of the Izaña Atmospheric Research Center (2368 m a.s.l., Tenerife, Canary Islands) in August 2021, and it operates in continuous mode since then. During this period, the pristine dust-free clean conditions that characterize this mountain-top site have been mainly disrupted by two-type aerosol events: the Saharan dust outbreaks that passes over the site on their way towards the Atlantic, and the eruption of Cumbre Vieja Volcano (La Palma, Canary Islands) last fall. We show two study cases that provide a brief overview of aerosol properties under Saharan dust conditions and volcanic emissions using volume depolarization ratio (VDR), particle linear depolarization ratio (PLDR) at 532 nm and lidar extinction coefficients products from the CE376 at 532 and 808 nm, as well as aerosol optical depth from AERONET photometers. We also performed a 20-day intercomparison between the CE376 and MPL-4B LiDAR from the Nasa Micro-Pulse Lidar Network (MPLNET). The retrieved aerosol products show the good performance of the CE376 micro-LiDAR as a tool for the characterization of the vertical distribution of atmospheric aerosols.

Keywords: volume depolarization ratio, extinction, dust, volcanic aerosols.

1 Introduction

Understanding the distribution and properties of aerosol particles at regional and global scales will contribute reducing the uncertainties of models predicting future climate scenarios. Low-cost polarization LiDAR instruments are opening a new path for extending the aerosol measurements around the world. Here we present the performance of a low-cost and compact CE376 micro-pulse LiDAR for aerosol characterization at the remote site of the Izaña Atmospheric Research Centre.

The Izaña Observatory (Tenerife, Canary Islands), located at 2372 m a.s.l., is representative of the well-stratified subtropical North Atlantic lower troposphere. The pristine clean conditions that characterize the site are disrupted by the regional dust production and exportation from North Africa within the Saharan Air Layer (SAL), especially in summertime [1, 2]. Some sporadic events of long-range transport of pollutants from North America and Europe are also observed. This site also witnessed the eruption of the Cumbre Vieja volcano (La Palma, Canary Islands) last fall. The variety of aerosol events occurring during last summer and fall made Izaña a perfect laboratory to test the performance of new instruments for aerosol characterization.

2 Specifications of the CE376 and ancillary information

2.1 Specifications of the CE376

The CE376 micro-pulse LiDAR is an eye-safe compact elastic backscatter LiDAR, emitting and measuring at two wavelengths with a pulsed diode pumped solid state laser in the visible (532 nm) and a pulsed laser diode emitting in the near infrared (808 nm), at a repetition rate of 4.6 kHz. The CE376 is a biaxial system with a small field of view for emission (50 µrad) and reception (120 µrad) at 532 nm. At 808 nm, the emission field of view is 230 µrad and 260 µrad in reception. With a range resolution of 15 m and 1 minute integration time, the CE376 can detect the backscattered signal at distances from 8 km during daylight up to more than 20 km by night at 532 and 808 nm and provides depolarization at 532 nm for enhanced aerosol characterization.

The CE376 uses avalanche photodiode detectors (APD) in photon counting mode for all reception channels. The dead time of the channels varies between 23 and 28 ns. The range corrected signal (RCS) is obtained after applying a series of additional corrections, such as background, dead-time and overlap to the raw signal. The CE376 installed at Izaña achieves a full overlap at 2.6 km a.g.l. in the 532 nm channel and at 1.9 km a.g.l. in the 808 nm. The incomplete lidar signal is corrected using the overlap function [3] determined using clean atmospheric conditions (Izaña, AOD of 0.02-0.03). Due to the effect of the overlap uncertainty (~ 10 %) [4] and the saturation of the detector in the near range, the information below 600 m is disregarded in this initial evaluation.

The polarized channels were calibrated using the ±45° method [5] on site. Using a reference height of approximately at 6-7 km (depending on the aerosol content of the layer in each particular case) we determine the extinction coefficient from the Klett-Fernald inverse integration method [6, 7]. We check the performances of the CE376 lidar by following the standard EARLINET procedures [8], namely the Rayleigh fit (5-10% relative deviations from molecular) applied to a micro-LiDAR.

2.2 Ancillary information

AOD and AE from AERONET. We use cloud-screened and quality-assured AERONET level 2.0 [9] column-integrated aerosol optical depth (AOD) and Ångstrom Exponent (AE) from the CE-318 sun photometer at Izaña site. The synergy between the CE376 and the sun photometer at Izaña station, allow us to determine the extinction profile and the column-integrated extinction-to-backscatter ratio (or lidar ratio LR) [7].

VDR from MPL-4B. The micropulse lidar MPL-4B is an eye-safe elastic lidar operating at 532 nm with depolarization capability. It operates in continuous mode with a low pulse energy (5-6 μJ) laser and a repetition rate of 2.5 kHz. MPL is the standard lidar system with standardized data processing algorithms within the federated global NASA Micro-Pulse Lidar Network (MPLNET, https://mplnet.gsfc.nasa.gov) [4]. During August 2021, the CE376 and an MPL-4B were together measuring at Izaña site. The volume depolarization ratio (VDR) from MPL-4B level 1.5 (L15-NBR) was compared with the CE376 VDR product as part of the analysis of the performance of the CE376.

Meteorological profiles from radiosondes. Meteorological vertical profiles are provided by radiosondes launched by AEMET at the coastline of Güímar at 12:00 UTC (28.3° N, 16.4° W at 105 m a.s.l.), 11 km from Izaña.

Backtrajectories. The kinematic trajectory model FLEXTRA-ERA5 from the European Centre for Medium-Range Weather Forecasts (ECMWF) [11] is used to determine the origin of the different air masses arriving at Tenerife. FLEXTRA-ERA5 was run to provide 120 h back-trajectories arriving at 2400 m.

3 Characterization of dust and volcanic aerosols properties using the CE376

During August 2021, Izaña was frequently impacted by African dust transported westwards within the Saharan Air Layer (SAL). In this period, not only the CE376 micropulse LiDAR but also an MPL-4B LiDAR from the Nasa Micro-Pulse Lidar Network (MPLNET) was measuring at the site. The two systems were located in the same mountain plateau at 2368 m. a.s.l. and distancing 223 m from each other.

Figure 1 shows the VDR profiles at 532 nm from CE376 and MPL instruments as well as the AOD and AE at 532 and 808 nm computed from AERONET for 11th - 29th August 2021. Between the 14th to the 19th of August, Izaña received the impact of the SAL. The layer was observed up to 8 km height [10, 2]. In this event, the observed AOD at 532 nm was 0.27±0.06, 0.24±0.06 at 808 nm, AE for 532-808 was 0.3±0.1, and VDR ranged between 0.04 and 0.2 in agreement with previous publications [5]. To compare the aerosol products of both systems, the CE376 VDR profiles were averaged to the 75m vertical resolution of the MPL, and 1minute resolution was kept. A good general agreement is observed between the 2 instruments, with differences lower than 0.01. Only close to the ground and under relatively high VDR values (> 0.15), differences up to 0.05% in the 1min- VDR profiles of the two instruments are associated with the retrieval uncertainties in the region of incomplete overlap (< 1000 m above the ground, see Fig. 1).

The first row of Figure 2 (1a-1d) shows the retrieved profiles on 16th August 2021 at 20:00 PM (15 min average). The range corrected signal (RCS) at 532 and 808 nm follows the Rayleigh fit in the regions of the atmosphere where only molecular signal is expected. The profiles show the impact of the SAL up to 7.5 km height. The profiles of extinction coefficients for both channels ($\alpha \sim 0.04$- 0.05 km^{-1} within the SAL), lead to LR about 65 sr, and in the range of those previously observed in the free troposphere in this region [10]. The AE for 532-808 from the CE376 shows relatively large particles (~ 0.5 in agreement with the photometer), AOD at 532 nm of 0.23, and relative high depolarization (VDR ~ 0.1, PLDR ~ 0.2), in agreement with previous studies [5].

During 25th-26th of August, backtrajectories (not shown for the sake of brevity), AE for 532-808 nm of 0.27±0.06, AOD at 532 nm of 0.05±0.03 and low depolarization (VDR of 0.03±0.01, see Fig. 1) indicate the arrival at Izaña of long-range transport of smaller particles associated to pollution from North America; followed by a new Saharan dust event on the 28th of August.

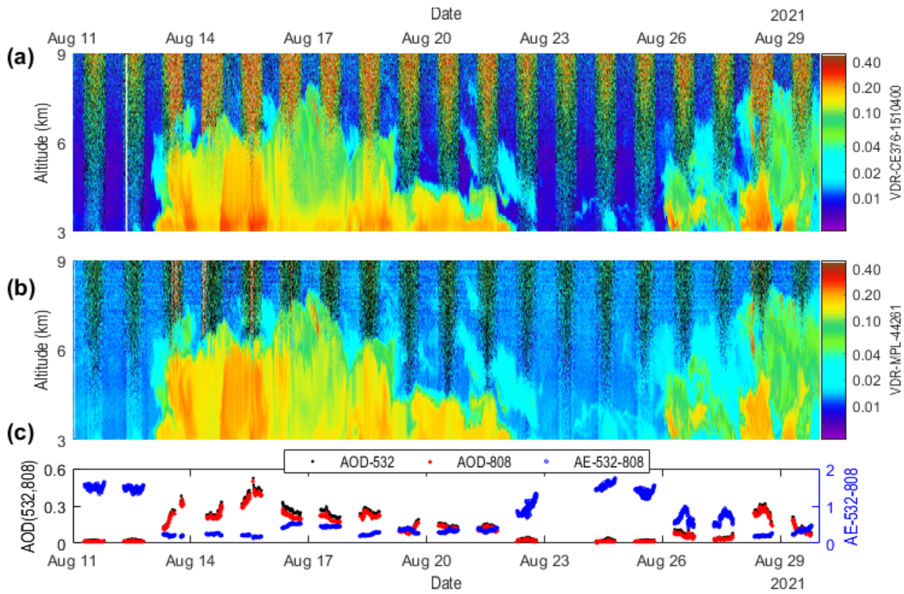

Fig. 1. Volume depolarization ratio (VDR) at 532 nm obtained with the a) CE376-1510400, b) the MPL-44261, c) AOD at 532nm and 808 nm and AE at 532-808 nm computed from AERONET.

During the first days of Cumbre Vieja eruption, clouds of SO_2 travelling to Izaña were observed in the RGB satellite and detected by the instrumentation at Izaña station (23-24th September, figure not shown for the sake of brevity). The second row of Figure 2 (2a-2d) shows the retrieved 1h-average profiles on 24th September 2021 (15:30 PM). The RCS in both channels shows follows the Rayleigh fit in the absence of aerosols (> 5 km). Small particles associated to SO_2 emissions from the Cumbre Vieja were observed around 4 km height, presenting extinction coefficients between 0.15- 0.2 km^{-1} for both channels, and LR around 30 sr, relatively high AE for 532-808 (~ 1.55), AOD at 532 nm of 0.16 and low depolarization (VDR ~ 0.04, PLDR ~ 0.08) in agreement with previous studies [12].

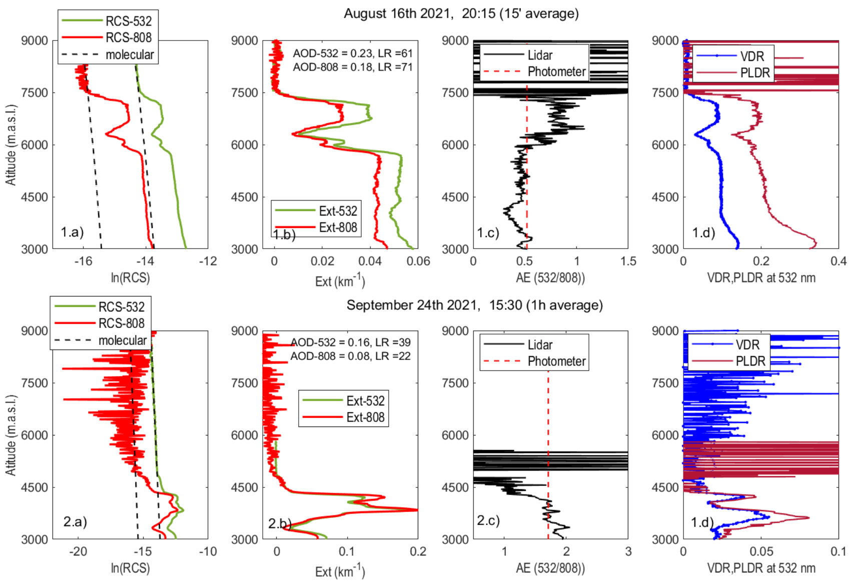

Fig. 2. Range corrected signals (RCS) and extinction coefficients (Ext) at 532 and 808nm, lidar AE at 532-808 nm, and volume depolarization ratio (VDR) and particle linear depolarization ratio (PLDR) for (1) August 16th 2021 at 20:15 UTC in the first row, and (2) September 24th 2021 at 15:30 UTC.

4 Conclusions

We present the first results on aerosol characterization provided by the CIMEL CE376 GPN micro-LiDAR installed at Izaña site, specifically for two case scenarios where the station was impacted by the arrival of Saharan dust particles and volcanic emissions from Cumbre Vieja volcano. The results on volume depolarization ratio at 532 nm, aerosol extinction at 532 and 808 nm, and AE for 532-808 nm retrieved profiles show the good performance of the micro-LiDAR CE376. These first aerosol products, together with future work focused on the 808 nm channel will provide a better insight of the possibilities of this instrument for atmospheric aerosol characterization in remote sites.

Acknowledgements

This work has been developed under the framework of the activities of the World Meteorological Organization (WMO) Commission for Instruments and Methods of Observations (CIMO) Izaña Testbed for Aerosols and Water Vapour Remote Sensing Instruments.

References

1. Cuevas, E., et al.: Izaña Atmospheric Research Center Activity Report 2015-2016, Tech. Rep. WMO/GAW No. 236, World Meteorological Organization & Izaña Atmospheric Research Center (AEMET), available at: https://library.wmo.int/doc_num.php?explnum_id=4139.
2. Rodríguez, S., et al.: Transport of desert dust mixed with North African industrial pollutants in the subtropical Saharan Air Layer, Atmos. Chem. Phys., 11, 6663–6685, https://doi.org/10.5194/acp- 11-6663-2011, (2011).
3. Kunz, G. J. and de Leeuw, G.: Inversion of the lidar signals with the slope method. Appl. Opt., 32(18), 3249–3256 (1993).
4. Welton, E. J. and Campbell, J. R.: Micropulse Lidar Signals: Uncertainty Analysis. J. Atmos. Oceanic Technol., 19 (12), 2089-2094, https://doi.org/10.1175/1520-0426(2002)019<2089:MLSUA>2.0.CO; 2, (2002).
5. Freudenthaler, V. et al.: Depolarization ratio profiling at several wavelengths in pure Saharan dust during SAMUM 2006. Tellus, Ser. B Chem. Phys. Meteorol., 61(1), 165–179, doi:10.1111/j.1600-0889.2008.00396.x (2009).
6. Fernald, F., Herman, B., and Reagan, J.: Determination of aerosol height distribution by lidar. J. Appl. Meteorol., 11, 482-489 (1972).
7. Klett, J.D.: Lidar Inversion with Variable Backscatter/Extinction Ratios. Applied Optics, 24, 1638-1643. https://doi.org/10.1364/AO.24.001638 (1985).
8. Freudenthaler, V., Linné, H., Chaikovski, A., Rabus, D., and Groß, S.: EARLINET lidar quality assurance tools. Atmos. Meas. Tech. Discuss. [preprint], https://doi.org/10.5194/amt-2017-395, in review (2018).
9. Giles, D. M., et al.: Advancements in the Aerosol Robotic Network (AERONET) Version 3 database – automated near-real-time quality control algorithm with improved cloud screening for Sun photometer aerosol optical depth (AOD) measurements. Atmos. Meas. Tech., 12, 169–209, https://doi.org/10.5194/amt-12-169-2019, (2019).
10. Barreto, A., et al.: Long-term characterisation of the vertical structure of the Saharan Air Layer over the Canary Islands using lidar and radiosonde profiles: implications for radiative and cloud processes over the subtropical Atlantic Ocean. Atmos. Chem. Phys., 22, 739–763, https://doi.org/10.5194/acp-22-739-2022 (2022).
11. Stohl, A. and Seibert, P.: Accuracy of trajectories as determined from the conservation of meteorological tracers. Q. J. Roy. Meteor. Soc.,125, 1465–1584, (1998).
12. Prata, A. T., Young, S. A., Siems, S. T., and Manton, M. J.: Lidar ratios of stratospheric volcanic ash and sulfate aerosols retrieved from CALIOP measurements. Atmos. Chem. Phys., 17, 8599–8618, https://doi.org/10.5194/acp-17-8599-2017, (2017).