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Lidar ratio discrimination retrieval in a two-layer aerosol system from elastic lidar measurements in synergy with sun-photometry data

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Abstract

The extinction-to-backscattering coefficient ratio (Lidar Ratio, LR) is an aerosol-type dependent parameter associated to the chemical composition, particle shape and size distribution of aerosols. Hence, the LR estimation from lidar measurements is a crucial task in aerosol research. However, the elastic approach for LR data inversion must be carefully applied to realistic aerosol conditions when a multiple contribution of different types of aerosols can coexist. This is the case for aerosols present in the Boundary Layer (BL), where a mixing of different particles can be expected. In this work, we present an experimental LR discrimination elastic inversion procedure focused on the LR estimation for both pure dust particles and BL mixed dust aerosols under Saharan dust intrusion occurrence. In addition, the importance of the selected aerosol scenario ("pure dust", PDS, vs. "mixed dust", MDS) applied together to the elastic dust LR retrieval in a two-layer (BL and Free Troposphere, FT) aerosol system is examined. Synergetic lidar and sun-photometry measurements carried out in two AEMET (Spanish Meteorological Agency) stations in the Tenerife Island, close to Saharan dust sources: the Sta. Cruz de Tenerife (SCO, 28.5ºN 16.2ºW, 52 m a.s.l.) and Izaña (IZO, 28.3ºN 16.5ºW, 2400 m a.sl.) observatories, and placed at a relatively close horizontal distance and distant altitudes, are used for that propose. Dusty cases observed during 2009 (55.4 % occurring in summertime) with simultaneous lidar/sun-photometry data are analyzed. In general, in a Saharan-dust influenced region as Tenerife area, LR values of 56 sr and 43 sr could be used in elastic lidar retrievals of the optical properties for particles present, respectively, in 'pure dust' and 'BL mixed dust aerosols' scenarios.

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1. Introduction

The Lidar Ratio (LR, extinction-to-backscatter coefficient ratio) is an aerosol-type dependent parameter, related to the chemical composition, particle shape and size distribution of aerosols. Then this parameter can provide valuable information on optical/microphysical properties of aerosols. Hence, the LR has been (i.e., Cattrall et al., 2005; Mona et al., 2006; Müller et al., 2007; among others), but even at present is still a crucial task in aerosol research, where a special emphasis is devoted to dust, as shown by many recently published works focused, directly or indirectly, on this subject (i.e., Campbell et al., 2012; Schuster et al., 2012; Amiridis et al., 2013; Omar et al., 2013; Tesche et al., 2013; among others). Moreover, data from diverse observational platforms and techniques (CALIPSO, AERONET, MODIS, EARLINET, …) and analysis from several models (BSC-DREAM, NAAPS, …) were used for assessment of the Aerosol Optical Depth (AOD), mainly, regarding the LR value retrieved for dust aerosols in the extinction inversion algorithm applied to lidar measurements. In this sense, unlike height-resolved LR retrieval from Raman lidars, an a-priori constant LR value must be introduced in the elastic inversion algorithm to obtain the aerosol extinction. However, the LR value assumed by CALIPSO/CALIOP (a space-borne elastic lidar) for pure dust (40 sr) is under discussion. Instead, a higher value of 58 sr is proposed by EARLINET (European Aerosol Lidar NETwork, www.earlinet.org) in the basis of multi-year lidar measurements of Saharan dust intrusions over Europe. In addition, the elastic approach must be carefully applied to realistic aerosol conditions when a multiple contribution of different types of aerosols can coexist, i.e., as occurring in the Boundary Layer (BL), where a mixing of different particles can be expected, mostly during dust intrusions.

The aim of this work is the presentation of a LR discrimination retrieval in a two-layer aerosol system (Boundary Layer, BL / Free Troposphere, FT) in order to estimate the LR for both (1) pure dust particles and (2) BL mixed dust aerosols under Saharan dusty conditions. In particular, the dataset period analyzed in this work is from January to December of 2009.

2. Experimental

2.1 Measurement area: a dust-influenced region

The geographical situation of the Canary Islands offers a suitable region for dust monitoring as they are located downwind of the Saharan sources. Measurements are carried out in two aerosol stations, managed by the Spanish Meteorological Agency (AEMET) / Atmospheric Research Centre of Izaña, and located in the Tenerife Island at two distant altitudes: the Santa Cruz de Tenerife observatory (SCO) and the Izaña observatory (IZO), being both stations very close at about 40 km distance.

SCO station is a subtropical coastal site (28.5ºN 16.2ºW, 52 m a.s.l.), belonging to several aerosol networks: NASA/AERONET (aeronet.gsf.nasa.gov) and NASA/MPLNET (mplnet.gsfc.nasa.gov), and besides it forms part of SPALINET (Spanish and Portuguese Aerosol LIdar NETwork, www.lidar.es/spalinet). IZO (28.3ºN 16.5ºW) is placed in a pristine environment at 2367 m a.s.l., being representative for Free Troposphere (FT) stations. It also is a NASA/AERONET site.

2.2 Instrumentation: MPLNET elastic lidar system in synergy with AERONET sun-photometers

Synergetic measurements of both height-resolved lidar and columnar-integrated sun-photometry observations were performed, respectively, by using a MPLNET Micropulse Lidar v. 3 (MPL-3), and two AERONET Cimel (C-318) sun-photometers. This ‘tandem’ MPL-3/Cimel system is co-located in the SCO site, with a second Cimel sun-photometer sited at IZO.

The MPL-3 is an elastic lidar, operated by the Instituto Nacional de Técnica Aeroespacial (INTA), with the following main features: highly-pulsed (2500 Hz) and low-energy (10 μJ, max.) laser at 523 nm, Cassegrain-type telescope receiving system, small, easy-handle system with coaxial configuration, high autonomy and low attendance, operational in full-time continuous mode (24 h day^{-1}/365 days $year^{-1}$), and routine measurements (MPLNET settings) are 75-m vertical resolution and 1-minute integrating time. Both the AERONET Cimel sun-photometers are operated by the AEMET/Izaña Atmospheric Research Centre, and the retrieved inversion products level 1.5 (Cloud Screened) and 2.0 (Quality-assured) used are the spectrally resolved Aerosol Optical Depth (AOD) and Ångström Exponent (AEx). In particular, the Cimel 500-nm channel data are used in correspondence to the closer wavelength to that of the MPL-3 laser (523 nm).

2.3 Inversion procedure: LR discrimination retrieval in a two-layer (BL/FT) aerosol system for dust

The inversion procedure for LR discrimination for dust particles in a two-layer (BL/FT) aerosol system is based on the particular situation of those two aerosol stations: they are close in horizontal distance but located at distant altitudes. Two main reasons are highlighted for the selection of these two stations:

1) Both stations represent a two-layer aerosol system itself under dust intrusion occurrence. IZO is located at the FT, usually in a clean environment, hence dust is the only aerosols present when a dust intrusion occurs. In this case, the FT aerosols to be examined are pure dust particles. In addition, SCO is located at the BL, where a mixture of dust with other local and steady aerosols is mostly present. Hence, the BL aerosols to be examined in this case are dust-mixed aerosols.

2) Synergetic measurements can be carried out in both stations. In the case of IZO measurements, the elastic inversion is applied using the AOD constraint with IZO data (AOD^{IZO}) under a Pure Dust Scenario (PDS), i.e. there is no aerosol mixing, obtaining the LR for pure dust particles (LR^{FT}, the only FT aerosols present under dusty conditions). In the case of SCO measurements, the elastic inversion is applied but the AOD constraint with SCO data (AOD^{SCO}) is used instead together to considering a Mixed Dust Scenario (MDS), i.e. the LR at FT heights is fixed to those LR^{FT} values obtained from the previous IZO inversion, and hence the LR retrieved is for the BL mixed-dust aerosols (LR^{BL}).

This LR discrimination retrieval is applied to MPL-3 measurements, which are hourly-averaged. Since the AOD convergence required is performed with AERONET sun-photometry data (also hourly-averaged) only day-time lidar profiles are examined.

2.4 Selection of the dusty cases: Saharan dust signature criterion

Dusty conditions are defined by using the criterion for Saharan dust particles, as adopted from Córdoba-Jabonero et al. (2011), based on two points:

1) AERONET AOD/AEx data for evidence of coarse particles. High-moderate AOD at 500 nm (AOD > 0.2) and low AEx for 440/675 nm wavelength pair (AEx < 0.5) are assumed as threshold values, which must remain longer than 40% of the day-time period.

2) HYSPLIT backtrajectory analysis for the Saharan origin of the air masses. 5-day backtrajectories are calculated at four selected altitudes (a.g.l.): 500 m (surface), 1500 m (max. BL top), 3000 m (FT heights) and 5000 m (above IZO station), and three predominant origins are examined: No-African (Atlantic ocean) sources, Sahara area (North-Africa latitudes > 20ºN) and Sahel region (North-Africa latitudes 0-20ºN).

Dusty cases are selected by using these AOD and AEx data at SCO site and confirming the Saharan origin of air masses. Therefore, 71 days of 2009 were identified as 'dusty', among those 65 were selected in coincidence with MPL-3 data. The highest frequency of the arrival of Saharan dust intrusions over Tenerife is in summertime (JJA, 55.4 %), as expected, being respectively, 11 days (16.9 %), 14 days (21.5 %) and 4 days (6.2 %) for spring- (MAM), autumn- (SON) and winter- (DJF) times.

3. Results

3.1 Evaluation of the LR for Saharan pure dust particles

There are discrepancies regarding the LR used by CALIPSO/CALIOP for the aerosol type called 'pure dust' (40 sr), as considered a low value for Saharan dust aerosols. In particular, a LR of 58 sr is proposed instead (Amiridis et al., 2013), based on multi-year EARLINET observations over Europe. In addition, an inverse relationship is found between LR and real refractive index (Schuster et al., 2012), based on AERONET retrievals: Saharan dust presents a lower value of the real refractive index than that found for dust from Middle East (ME) area, for instance, obtaining correspondingly a higher LR (55 sr) for the Saharan area. But also, that CALIPSO LR assumed for pure dust might be a correct value for dust in other regions (i.e., a LR of 43 sr is found for ME dust, as shown in Schuster et al. (2012)).

Hence, our results obtained from Tenerife/IZO measurements (dust is the only aerosols present under Saharan dust intrusion occurrence), can give a perspective more realistic about the LR value to be used in elastic lidar-derived AOD inversion for pure dust particles coming from Sahara region. 434 lidar profiles were examined for that purpose and the LR seasonal frequency for pure dust particles is shown in Fig. 1.

As shown in Fig. 1, 69% of dusty cases correspond to summertime (JJA), lower than 20% to spring and autumn, and less than 1% to winter (when high LR values are only found, i.e. 70-75 sr). In general, results indicate that high predominance of a given LR range values is not observed. In particular, and respect to the total number of dusty profiles analyzed per season, LR values are mostly in the ranges of: 55-65 sr (22%) and 70-75 sr (26%) in summer. MAM and SON time periods show, respectively, LR values mostly in the ranges of 35-70 sr (16-23%) and 35-65 sr (20-24%). Depending on season, the mean LR values obtained for MAM, JJA, SON and DJF periods are, respectively: 54 ± 14 sr, 56 ± 15 sr, 53 ± 13 sr, and 74 ± 2 sr (but only 2 profiles were available in wintertime).

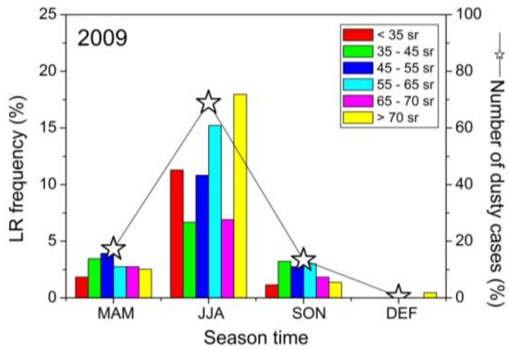

Fig. 1. LR seasonal frequency for Saharan pure dust particles.

These LR obtained values are higher than that LR of 40 sr assumed by CALIPSO for 'pure dust' aerosols in AOD retrievals, but similar, except for wintertime (), to those AERONET-derived LR of 55 sr (Schuster et al., 2012) and closer to that proposed EARLINET LR of 58 sr (Amiridis et al., 2013).

3.2 Determination of the LR for BL mixed dust aerosols under Saharan dust intrusion occurrence

Since measurements are also performed at SCO, a coastal site, dust particles are expected to be mostly mixed with marine aerosols under dust intrusion occurrence. Hence, our results obtained from Tenerife/SCO measurements are related to LR values specific for BL mixed dust aerosols over the presented study area only. This could indicate the degree of dust contribution into the BL marine aerosol mixtures. Results can be different in other particular regions. 349 lidar profiles were examined for that purpose and the LR seasonal frequency for BL mixed dust aerosols is shown in Fig. 2.

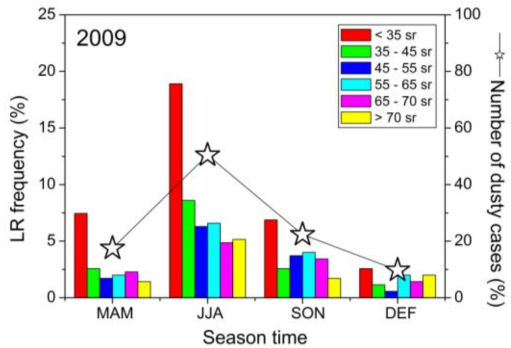

Fig. 2. LR seasonal frequency for BL mixed dust aerosols under Saharan dusty conditions.

As shown in Fig. 2, 50% of dusty cases correspond to summertime (JJA), around 20% to spring and autumn, and around 10% to winter (when a wide range of LR values is found). In general, results indicate that high predominance of LR values lower than 35 sr is observed. In particular, and respect to the total number of dusty profiles analyzed per season, LR values are mostly lower than 35 sr (37.5%) in summer, as well as in MAM and

SON time periods (43% and 31%, respectively). Depending on season, the mean LR values for MAM, JJA, SON and DJF periods are, respectively: 39 ± 23 sr, 42 ± 21 sr, 46 ± 20 sr, and 51 ± 19 sr (a high variability is shown by SD values).

These LR values obtained for spring-, summer- and autumn-time periods are higher than that typically assumed range of 20-25 sr for marine aerosols, reflecting thus the dust contribution to the BL aerosol mixtures. However, a more detailed study should be performed for particular dusty cases.

4. Conclusions

LR values associated to pure dust particles and BL aerosols under dust intrusion occurrence are, respectively, in the 53-56 sr and 39-46 sr range, in general, independently on season, except in wintertime. These lower LR values for BL dusty mixtures respect to those ones for pure dust can reflect the mixing of dust with marine aerosols. The higher LR values (51 sr) found in wintertime respect to those for other seasons is supported by the fact that dust intrusions usually arrive at lower altitudes in winter, and then a higher contribution of dust particles can be found at BL heights, and correspondingly a LR increase is expected.

In general, in a Saharan-dust influenced region as Tenerife area, LR values of 56 sr and 43 sr could be used in elastic lidar retrievals of the optical properties for particles present, respectively, in ‘pure dust’ and ‘BL dusty mixtures’ scenarios. Further studies are on-going using a longer 5-yr dataset period.

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