Arabian and Saharan Dust Optical and Microphysical Properties: Synergy of CARO Limassol Polly^{XT} Lidar, and Sun Photometer observations using GRASP algorithm.

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Introduction

Earth's atmospheric radiative energy budget is strongly influenced by aerosols in the atmosphere [1]. Desert dust from the Middle East and the Sahara/North Africa regions is considered one of the major types of atmospheric aerosols globally. The Eastern Mediterranean, particularly Cyprus, is influenced by the transport of air masses from the Sahara Desert and the Arabian Peninsula. Many studies have shown that some optical and microphysical characteristics of these two aerosol types differ [2]. A study by Nisantzi et al. (2015) [2] conducted in Cyprus, found that the Lidar ratio of Saharan dust is 53 ± 6 sr, while that of Middle Eastern dust was significantly lower, at 41 ± 4 sr at 532 nm. Additionally, the real part of the refractive index for Middle Eastern dust was higher, measured at 1.55, compared to 1.45 for Saharan dust in the 500–550 nm wavelengths [2]. The main objective of the present study is to investigate the optical and the microphysical characteristics of desert dust from both regions by utilizing the synergy between the Polarization Polly^{XT} Raman Lidar and the Cimel sun/sky photometer, in Limassol city of Cyprus. The analysis is performed using the Generalized Retrieval of Atmosphere and Surface Properties (GRASP) algorithm [3].

GRASP is a highly flexible inversion algorithm applicable in a variety of domains, including observations from both active and passive remote sensing methods. Developed by Dubovik et al. (2014) [3], the algorithm is based on the general principles of numerical inversion and atmospheric radiation modelling. Lopatin et al. (2013, 2021) [4, 5] first proposed the application of the GRASP algorithm, utilizing the synergy between multi-wavelength Lidar and the Aerosol Robotic Network (AERONET) sun/sky photometer observations [4,5]. Information derived from the synergy of lidar, and sun photometer is complementary: the backscatter provided by the Lidar signal enhances the columnar sensitivity of aerosol properties, while the photometer measures the quantity and microphysical properties of particulate matter, related to its source, thus providing additional constraints, crucial for lidar data quantitative interpretation. The combination of the data from these instruments provides advanced vertical profiles of the microphysical characteristics of the aerosol [4, 5, 6]. Previously it was demonstrated by Lidar and Radiometer Inversion code [6] that a combination of a three-wavelength elastic lidar with depolarization, and sun-photometric observations that aerosol can be characterized as a vertically resolved mixture of fine, coarse spherical and coarse non-spherical particles.

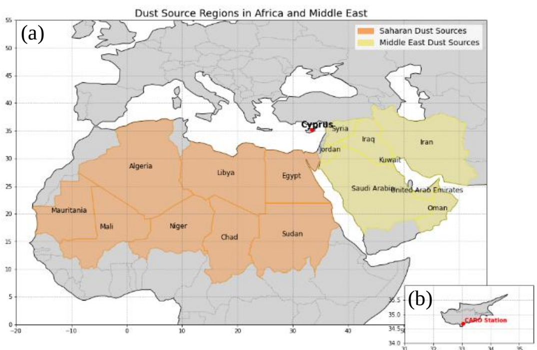

Figure 1. (a) Map of the dust source regions in Africa and Middle East. (b) Cyprus Atmospheric Remote Sensing Observatory location. It is often influenced by dust transportation from Sahara and Middle East regions.

Cyprus Atmospheric Remote Sensing Observatory (CARO), of the Eratosthenes Centre of Excellence, is the National Facility (NF) of the Republic of Cyprus for aerosol and cloud monitoring using remote sensing techniques. The station is part of the ACTRIS (Aerosols, Clouds, and Trace Gases Research Infrastructure) network, operates continuously and follows data quality assurance protocols [7]. The ground-based station (GBS) is equipped with a PollyXT (POrtabLe Lidar sYstem) a multi-wavelength Polarization Raman Lidar [8] which allows the measurement of vertical profiles of the particle backscatter coefficient (β) at wavelengths 355, 532, 1064 nm, the particle extinction coefficient (α) the volume and particle linear depolarization ratios and lidar ratios at 355 and 532 nm [9]. Additionally, the CUT-TEPAK AERONET site in Limassol hosts an AERONET Cimel sun/sky photometer operational since 2010. It performs direct and diffuse sun and sky measurements of Irradiance and AOD at eight wavelengths (340, 380, 440, 500, 675, 870, 1020 and 1640 nm), enabling the retrieval of key column properties. Microphysical parameters of the vertical column of the atmosphere can be derived by the AERONET inversion algorithm including the size distribution (dV(r)/dln(r)), the real and the imaginary part of the refractive index (η_R, η_I), the single scattering albedo (SSA) and the scattering phase function (PF) [10,11].

Data & Methodology

The methodology for retrieving the profiles of microphysical parameters of the aerosol layers is based on the application of the GRASP inversion algorithm with the synergy of lidar and sun/sky photometer measurements. The GRASP method performs a statistically optimized inversion for measurements from both instruments, using a multi-term least-squares approach and incorporating a priori information about aerosol properties [4, 5]. In Figure 2, the input and output of GRASP algorithm are presented.

Input data for GRASP algorithm:

- Lidar: Level 1b, normalized lidar signals at 355, 532, 1064 nm and volume depolarization at 355 and 532 nm [13, 14].
- Sun-photometer: Level 1.5 data of direct-sun, total optical depth (TOD) and sky radiance measurements at 340, 380, 440, 500, 675, 870, 1020, 1064 nm.

GRASP algorithm retrieves key properties of aerosol like the volume size distribution, the real and the imaginary part of the refractive index, sphericity fraction and vertical distribution profiles, that could be distinguished between several aerosol modes, thus allowing to estimate a wide variety of vertically resolved optical properties e.g. backscatter, extinction, SSA and LR.

In this study the microphysical characteristics of two desert dust events are analyzed: one originating from Sahara and the other one from Middle East, both observed in Limassol. The cases were selected to be daytime, cloud-free conditions, with large AOD load and high particle depolarization ratio values.

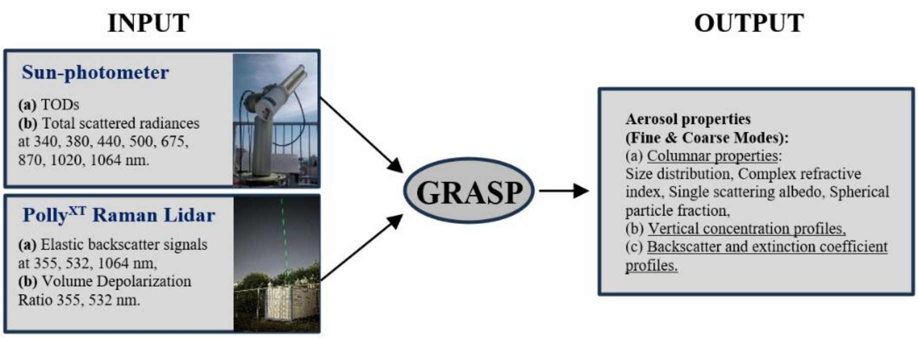

Figure 2. Input and output of GRASP algorithm.

Preliminary results and Discussion

A Sahara dust event on 02 March 2024 captured by the Polly^{XT} Lidar and CUT-TEPAK sun-photometer of CARO NF in Limassol. Figure 3 below shows the attenuated backscatter coefficient at 1064 nm and the volume depolarization ratio at 532 nm. The vertical extends of the dust layer at 6:00 – 12:00 UTC was between 2-4 km from the ground. The origin of the plume according to the HYbrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model as shown in Figure 4 was the Saharan region of North Africa (Egypt).

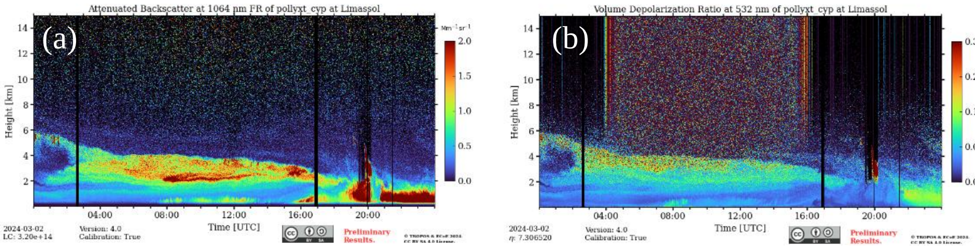

Figure 3. Time-height cross section of the (a) total attenuated backscatter coefficient at 1064nm and (b) volume depolarization ratio at 532 nm measured from CARO Polly^{XT} Lidar on 02 March 2024, over Limassol, Cyprus.

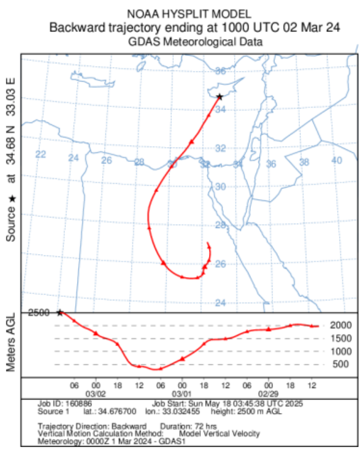

Figure 4. The 72-hour backward trajectory using the HYSPLIT model for the aerosol layer on 2 March 2024 at 10:00 UTC. The air mass originated from Sahara Desert (Egypt) and transported to Cyprus.

Figure 5 presents the GRASP single pixel approach retrieved size distribution, spectral real and imaginary part of the refractive index at 10:04:04 UTC, within ± 15 mins of the almucantar scan of sun-photometer, on 2nd March 2024. The size distribution reveals a predominance of coarse mode aerosols. The spectral variation of the refractive index reveals that fine aerosols have a moderate absorption, which decreases with increasing wavelength, with VIS region to observe the strongest absorption. Coarse-mode aerosols have stronger absorption at shorter wavelengths mostly in UV-VIS range with decline in absorption in the NIR.

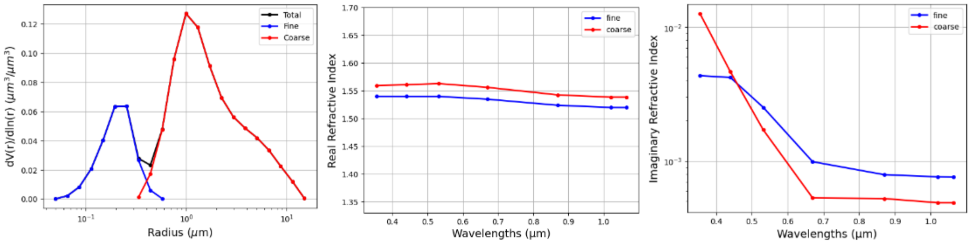

Figure 3. Size distribution, spectral real and imaginary part of refractive index, from GRASP algorithm, single pixel mode, at Limassol, Cyprus, on 02 March 2024, at 10:04:04 UTC (±15 min) UTC.

Conclusions

This study highlights the importance of the retrievals from the synergy of lidar and sun-photometer measurements applying GRASP algorithm for characterizing desert dust events over Limassol, Cyprus. The integration of these complementary datasets provides advanced outcome of vertical distribution and microphysical characteristics of atmospheric aerosols. The preliminary microphysical parameters retrieved from the GRASP algorithm for the Saharan dust case are presented in this paper, showing the difference in the microphysical characteristics of fine and coarse mode aerosols. More results from the GRASP algorithm and a comparative analysis of the characteristics of the Saharan and the Middle Eastern dust events, will be presented at the conference.

Acknowledgements

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