Aerosol typing results from AERONET data classification and NATALI retrieval

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Abstract: This study examines the results of two different methods for aerosol typing applied to active and passive remote sensing measurements, performed at a site in Magurele/Bucharest, Romania. In particular, we analyze the aerosol types reported as derived from AERONET (AErosol RObotic NETwork) measurements and NATALI (Neural Network Aerosol Typing Algorithm Based on Lidar Data) results as they are integrated within the DIVA platform.
Each method has its own strengths and limitations but the study is focused on finding a better characterization of the aerosol types by using all available optical properties of aerosols measured at a particular site.

1. Introduction

Taking into consideration the aerosol type will potentially improve not only the assessment of the wider environmental effects of aerosols, such as on air pollution and haze, visibility, climate change, radiative forcing, and human health, but may be also helpful in predicting surface particulate matter (PM) concentrations, one major information needed by air quality scientists and public authorities.

Several techniques have been developed for the classification of aerosols types based on the retrieved parameters from the remote sensing data both active (e.g. [1]) and passive (e.g. [2]).

Detailed information on particle microphysical and optical properties in the atmospheric integrated column are obtained in near real time by the automated network of ground-based remote sensing sensors known as AERONET (AErosol RObotic NETwork) [3], which measures solar and celestial radiance. Aerosol optical depth (AOD), Ängström exponent (AE), single scattering albedo (SSA), and fine mode fraction from the AERONET database can be used to categorize different types of aerosols [4].

The variety of aerosol products accessible for investigating aerosol properties has risen due to the ongoing advancements in satellite measuring capabilities, but there are many challenges in deriving aerosol typing from satellite-based passive remote sensing of aerosol properties, therefore the ground based networks measuring aerosols are of great help.

In this study we are analyzing two different methods for aerosol typing applied to active and passive remote sensing measurements performed at a site in Magurele/Bucharest, Romania.

2. Methodology

NATALI- Neural Network Aerosol Typing Algorithm Based on Lidar Data, a neural network aerosol-typing algorithm based on lidar data [5], integrated within the DIVA platform [6], serves as one of the typing methodologies in this study.

DIVA represents a pilot hub to collect, manage, archive, and effectively utilize observational data from the forthcoming integrated atmospheric composition ground-based network infrastructure. Within the DIVA archive can be found photometer Level 1 and Level 2 data, lidar data, ceilometer and spectrometer data, and, last but not least, GRASP results for the participating sites.

The Generalized Retrieval of Atmosphere and Surface Properties (GRASP), algorithm is a versatile way of synergetic retrieval of a variety of atmospheric properties from a multitude of remote sensing observations [7]. In the case of this study, the main results used from the GRASP algorithm are the aerosol extinction coefficient, the aerosol backscatter coefficient, the aerosol particle depolarization ratio, the wavelengths, and the altitudes. These are part of the results generated exclusively from the lidar data.

Using these properties, the following computations are performed: the Ängström exponent from 350 nm and 550 nm wavelengths, color ratios corresponding to the 350-550 nm, 350-1000 nm, 550-1000 nm wavelength intervals, lidar ratios at 350 nm, and 550 nm, and depolarization ratios at 350 nm and 550 nm.

These calculated values serve as inputs for the NATALI model, which then determines the probabilities for each aerosol type (13 classes, when the quality of the provided optical products is high enough) to exist within a layer of at least 300 m total thickness. The aerosol class names are then correlated with altitudes retrieved from the GRASP algorithm, ranging from 800 m up to 7000 m above sea level. A color bar is applied to the representation, facilitating visualization of the differences in the probability of aerosol classes within the vertical profile of the atmosphere.

As for the second typing method, level 2 photometer data archived within the DIVA platform are used. These datasets provide the aerosol optical depth (AOD) at 440 nm and 870 nm, along with their respective wavelengths. Using these values, the Ängström exponent (AE) is computed. Together with the AOD, the AE is one of the parameters for the cluster method for the classification and analysis of dominant aerosol types. The method is a common practice in the aerosol typing of AERONET data, therefore a series of thresholds have been described throughout the years. In this study, the data is categorized based on thresholds outlined by [2] and further synthesized by [4] with six classes of aerosols: polluted, continental, biomass burning, desert dust, mixed, and marine (table 1).

Aerosol Type	AE [440-870 nm]	AOD 440 nm
Marine	<1.2	<0.2
Desert Dust	<1.15	>0.2
Continental	>1.2	<0.2
Mixed	1.15 - 1.52	>0.2
Polluted	>1.52	0.2 - 0.4
Biomass Burning	>1.52	>0.4

Table 1 Thresholds for aerosol typing of AERONET data

2.1. Site of measurements

Our group has participated in the AERONET network since July 2007, with the installation of a Cimel sun photometer in Magurele, 5km south of Bucharest, Romania, while performing lidar measurements since 2005 [8].

MARS (**M**ăgurele centre for **A**tmosphere and **R**adiation **S**tudies) is the new atmospheric observatory (Figure 1) with state of art instrumentation performing measurements since 2020, close to the old location [9].

Figure 1 Aerial view of MARS site in Magurele, Romania

3. Results

We have started our study by looking at several interesting cases where aerosol layers were measured by the multiwavelength lidar RALI.

An example of Range Corrected signal (RCS) time series at 1064nm can be seen below for 29.04.2020 (Figure 2). The black horizontal lines are denoting the limits of the aerosol layers as they are depicting by an automated gradient method.

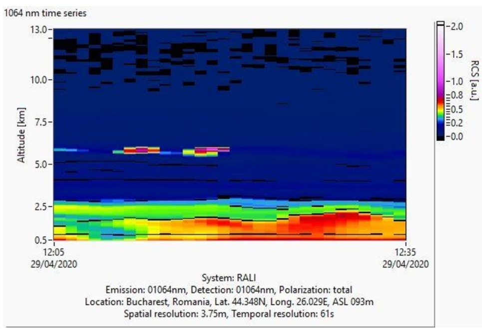

Figure 2 RCS time series at 1064nm measured during 29.04.2020

Two study cases are presented below for 11.06.2018 and 29.04.2020.

A NATALI outcome characterized by a comprehensive anthropogenic aerosol profile consistently corresponds to a high-density continental cluster in the AERONET data. In instances where multiple aerosol types are identified by both approaches, combinations such as high-altitude anthropogenic layers paired with low-altitude mixed smoke layers in NATALI results align with dispersed polluted and continental clusters observed in AERONET data.

Conversely, scenarios involving low-altitude anthropogenic layers along with high-altitude mixed smoke layers correlate with highly dense continental clusters. Results also show that alternating layers between the mixed dust and mixed smoke aerosol classes resulting from NATALI correspond to a tight cluster made out of polluted and mixed aerosols, as per the AERONET classification. It was also observed that low-altitude coarse dust layers paired with alternating layers of mixed smoke and smoke can be associated with clusters of continental and polluted aerosols distributed tighter closer to the "border" of the threshold (Figure 3 lower panels).

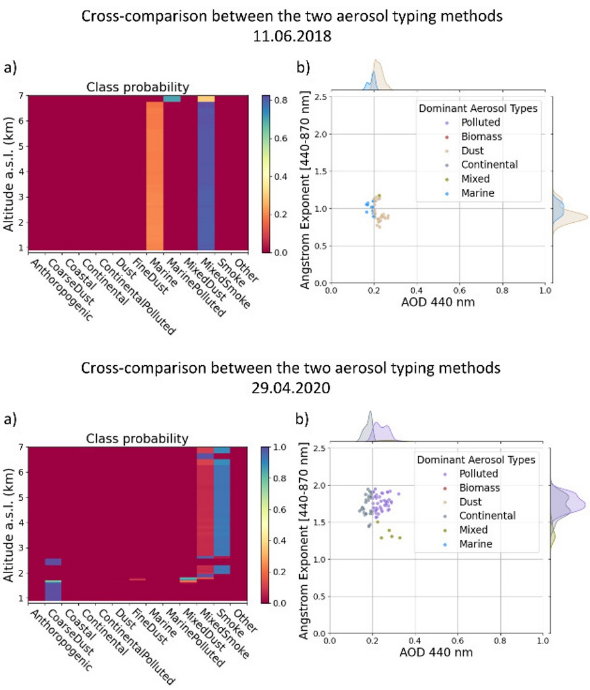

Figure 3. Scatter plot of AOD (440 nm) versus AE (all measurements) during 11.06.2018 (upper right panel) and 29.04.2020 (lower right panel).

Colours indicate the aerosol types for the panels on the right and class probability for the plots on the left panels.

Somewhat a similar behavior, regarding the placement of the cluster in the AERONET classification, can be observed in the case of high-altitude layers of marine polluted and nearly complete profiles of constant probability of marine and mixed smoke layers, in which the marine, dust, and mixed aerosols form a highly dense cluster along the "border" of the thresholds. (Figure 3 – upper panels).

To obtain information about possible sources of the aerosol layers above the measuring site, we have also used the results of the backtrajectories from HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory model) [10]. BSC-Dream dust forecast model [11] results corresponding to dust load (g/ m^2) for 11.06.2018 (Figure 4 right panel) are indicating a clear Saharan dust transport over Romania, in accordance with the AERONET classification.

HYSPLIT-NOAA model outcomes is showing the 96 hours air mass backtrajectories ending over the measurement area at 500m, 1500m and 3000m of altitude on 11.06.2018 in Figure 4 left panel. The marine aerosols from over the Black Sea are transported over Magurele in accordance with the AERONET classification of the aerosols properties measured in the atmospheric column.

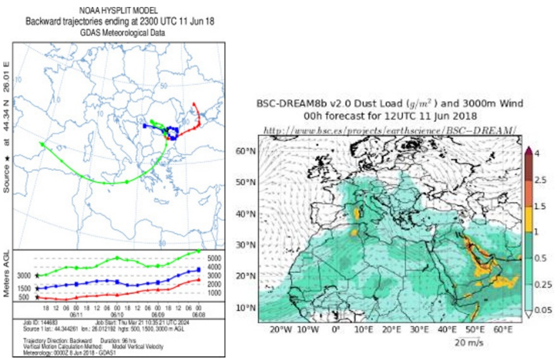

Figure 4 left panel- 96 hours HYSPLIT backtrajectories arriving over Magurele station on 11.06.2018; right panel BSC-Dream dust forecast for Europe on 11.06.2018.

4. Conclusions

Active and passive remote sensing measurements of aerosols are performed at MARS site in Magurele/Bucharest, Romania. Aerosol types can be derived from sunphotometer data and by using NATALI, the

Neural Network Aerosol Typing Algorithm Based on Lidar Data.

Two study cases have been analyzed and similarities underlined, showing the high potential of developing a method to combine both and get a better characterization of the aerosol types measured over a particular site.

Since there is currently no proven technique that can yield accurate results in every situation, a thorough and methodical comparison of existing approaches will be further performed to gain a deeper understanding of the possibility to determine the aerosol source from measured optical properties by active and passive remote sensing techniques.

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6. References

[1] Nicolae, D.; Vasilescu, J.; Talianu, C.; Binietoglou, I.; Nicolae, V.; Andrei, S.; Antonescu, B. A neural network aerosol-typing algorithm based on lidar data. *Atmos. Chem. Phys.* 2018, *18*, 14511–14537 (2018)

[2] Dubovik, O., Holben, B., Eck, T. F., Smirnov, A., Kaufman, Y. J., King, M. D., Tanré, D., and Slutsker, I.: Variability of Absorption and Optical Properties of Key Aerosol Types Observed in Worldwide Locations, J. Atmos. Sci., 59, 590–608, (2002).

[3] Aerosol Robotic Network (AERONET): available at: https://aeronet.gsfc.nasa.gov/

[4] Toledano, C. & Cachorro, Victoria & Berjón, Alberto & Frutos Baraja, A. & Sorribas, Mar & Morena, Benito & Goloub, P. Aerosol optical depth and Ångström exponent climatology at El Arenosillo AERONET site (Huelva, Spain). Quarterly Journal of the Royal Meteorological Society. 133. 795 - 807. 10.1002/qj.54. (2007).

[5] https://natali.inoe.ro/resources.html#software

[6] Diva platform: https://diva.cloudflight.space/hub

[7] Dubovik, O., Lapyonok, T., Litvinov, P., Herman, M., Fuertes, D., Ducos, F., ... & Federspiel, C. GRASP: a versatile algorithm for characterizing the atmosphere. SPIE Newsroom, 25(10.1117), 2-1201408, (2014).

[8] Nicolae, V., Belegante, L., Vasilescu, J., Nemuc, A., Toanca, F., Tudose, OG., Radu, C., Nicolae, D., A multi-year analysis of aerosol properties using the calibrated multi-wavelength polarisation lidar in Magurele, Journal of Optoelectronics and Advanced Materials, volume 25, issue 3-4, page 176-190, ISSN 1454-4164, eISSN 1841-7132, (2023)

[9] Pîrloagă, R.; Ene, D.; Boldeanu, M.; Antonescu, B.; O'Connor, E.J.; Ştefan, S. Ground-Based Measurements of Cloud Properties at the Bucharest–Măgurele Cloudnet Station: First Results. Atmosphere 2022, 13, 1445. https://doi.org/10.3390/atmos13091445, (2022)

[10] Stein, A.F., Draxler, R.R, Rolph, G.D., Stunder, B.J.B., Cohen, M.D., and Ngan, F., NOAA's HYSPLIT atmospheric transport and dispersion modeling system, Bull. Amer. Meteor. Soc., 96, 2059-2077, http://dx.doi.org/10.1175/BAMS-D-14-00110. (2015)

[11]https://www.bsc.es/projects/earthscience/visor/sub_fc8.php?type=dld&dom=med8