METHODS AND TOOLS USED TO INVESTIGATE INTERACTION BETWEEN AEROSOLS AND CLOUDS

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Abstract: *The interaction between aerosols and clouds is a relevant factor in global, regional and local climate change. The scientific community is trying to provide relevant theoretical and experimental benchmarks on aerosol loading, cloud formation patterns and trends. Aerosol–cloud interactions play a vital role in global climate change and are associated with one of the greatest uncertainties. In recent decades, due to its unique geographical location, the North Indian Ocean (NIO) has been gaining significant attention among scientific communities. Deep understanding of aerosols and their interaction with clouds in this region is very important both regionally and globally.*

The paper provides both an overview of the most used methods and tools used in experimental approaches in the field, as well as an analysis methodology regarding aerosol-cloud interaction scenarios.

Keywords: *clouds, aerosols, 4D sniffer, uRAD monitor, meteorological survey, interferometer, radiometer*

Acronyms

ACTRIS	*Aerosol, clouds, and gases research infrastructure*	*AOD*	*Aerosol optical depth*
AERONET	*Aerosol RObotic NETwork*	*LARSS*	*Laser Airborne Remote Sensing Signal*
LIDAR	*Light detection and ranging*	*NIO*	*North Indian Ocean*
UEFISCDI	*Executive Agency for Higher Education, Research, Development and Innovation Funding*		

1. INTRODUCTION

1.1. General considerations

The interaction between aerosols and clouds is a relevant factor in global, regional and local climate change. The scientific community is trying to provide theoretical and experimental benchmarks on aerosol loading, cloud formation patterns and their trends. Clouds, together with aerosols, contribute the greatest uncertainty to terrestrial energy and hydrological calculations [1, 2, 3, 4]. Aerosols act directly on cloud properties due to their influence on internal cloud processes. [4, 5], see Fig. 1.

Research shows progress in understanding both the microphysics of aerosols that contribute to the activation of cloud nuclei [5, 6, 9] and the transport phenomena that allow the supply of aerosols far from the source areas (Euro-Atlantic) [7, 8].

At the same time, numerical simulations have demonstrated the impact of aerosols (such as mineral dust) on cloud processes as a function of concentration and the chemical composition of the atmosphere [10, 11, 12].

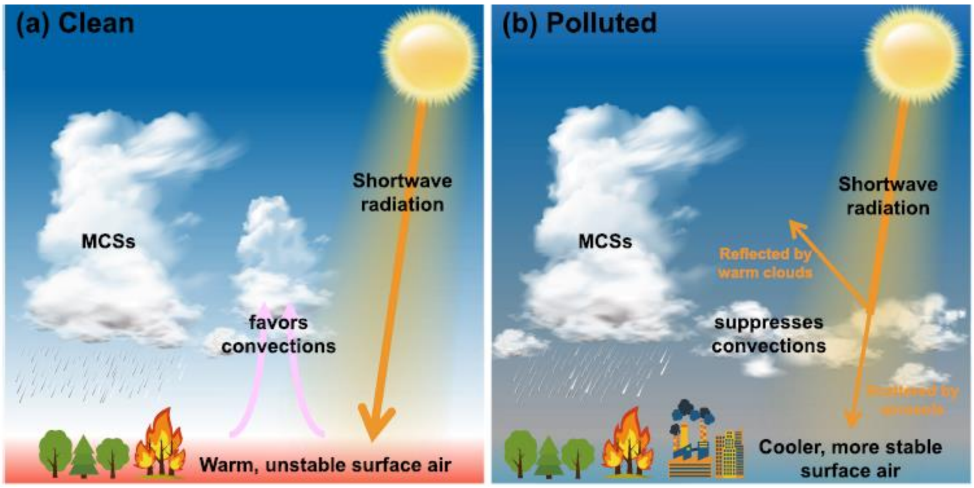


FIG. 1. Anthropogenic impact of aerosols, [3]

General approaches on aerosol-cloud interactions are transposed in a series of scientific papers from 2016 Jiwen Fan et all [13], from 2021 Wehbe [14], from 2023 Hamish Gordon [15], Michibata et all [16], satellite-based estimates of the radiative forcing of aerosol-cloud interaction Hailing Jia et all [17] or the evaluation of the stability of the aerosol-cloud interaction index by simulating radar or LIDAR signals (LARSS) C.M. Zambrano et all [18].

1.2. Application of aerosol data analysis

Numerical data analysis can highlight the complex phenomena associated with aerosols, the main applied areas are:

a. environmental quality management and monitoring with the identification of aerosol concentration and pollution sources through online monitoring, generation of predictive models and issuing policies for assessing and combating pollution [19, 20];

b. climate change research (atmospheric radioactive behavior) with the quantification of the impact of aerosols on local, regional and global temperature, the role of aerosols on precipitation and climate modeling [21, 22];

c. public health by assessing the risk and impact of exposure to different types of aerosols, identifying disease outbreaks and developing public health intervention policies [23, 24];

d. agricultural productivity by predicting crop yields based on aerosol-related factors (air quality and climate), pest and disease control, optimizing irrigation activities based on aerosol-based meteorological models [25, 26];

e. atmospheric chemistry by analyzing the chemical composition of aerosols and their generating sources, studying kinetic reactions and understanding the role of aerosols in acid rain [27, 28];

f. environmental monitoring by assessing ecosystem health and biodiversity, soil and water quality [29, 30];

g. renewable energy by assessing the potential impact of aerosols on alternative (renewable) energy sources, air pollution control and energy (efficiency) optimization [31, 32];

h. transport through visibility monitoring (aerosol concentration monitoring), vehicle emissions (emission reduction technologies) and specific infrastructure design, [33, 34];

i. urban planning through land use planning, urban greening (increasing air quality in urban areas) and urban transport (sustainable transport modes), [35, 36];

j. natural disasters through monitoring and forecasting of wildfires (aerosol analyses) volcanic eruptions (impact of volcanic aerosols on air quality) and forecasting of dust storms and their effects on the environment [37, 38].

2. METHODS AND INSTRUMENTS USED IN THE ANALYSIS OF AEROSOL-CLOUD INTERACTION

2.1. Method

Aerosol-cloud interactions are a complex and dynamic field of atmospheric science with significant implications for global climate. To better understand these processes, researchers use a wide range of methods and instruments, both on the ground and in the atmosphere.

Ground-based data acquisition is achieved using terrestrial aerosol monitoring networks using photometers (light intensity), snow gauges, spectrometers (chemical composition); weather stations (atmospheric parameters), weather radar (three-dimensional images of atmospheric parameter distributions), and LIDAR (vertical profile measurement of clouds and aerosols), Fig. 2. [39, 40, 41]

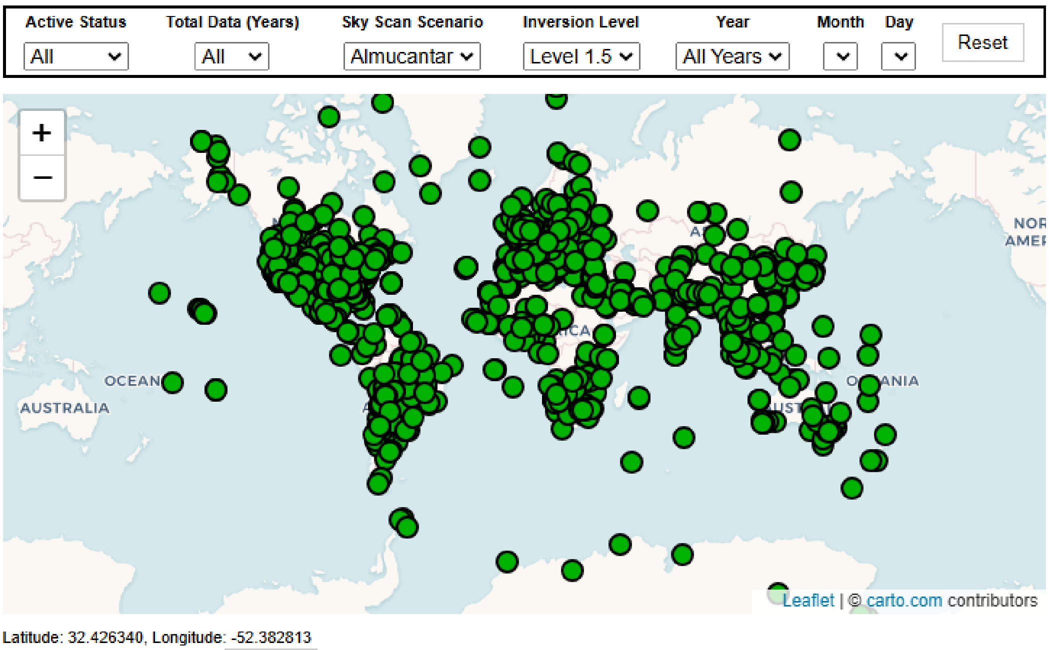


FIG. 2. AERONET data display interface [39]

Atmospheric data acquisition can be instrumented with:

a. weather balloon-type atmospheric probes for measuring vertical profiles of temperature, pressure and humidity (and aerosol concentration);

b. research aircraft (or UAVs), equipped with dedicated sensors for direct atmospheric or in-cloud measurements (aerosols, electrical parameters, water droplets):

c. satellites equipped with radiometers or LIDAR, providing high-resolution global-scale images of aerosols and clouds. [42, 43]

2.2. Instruments

The acquisition and processing of data on aerosol-cloud interaction can be achieved with a series of specific instruments with operating performances proportional to the acquisition and operating cost (accuracy, data resolution), here are some examples:

a. uRADMonitor (web and network data), is a fixed automatic monitoring station (can also be mounted on UAV), the data being exported to the uRADMonitor network, see Fig. 3 and 4. [44, 45]

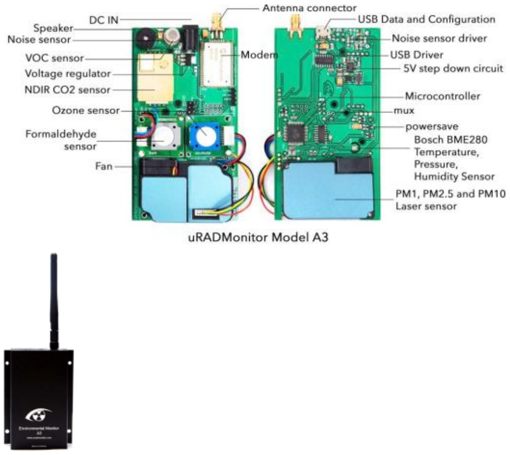


FIG.3. uRAD monitor

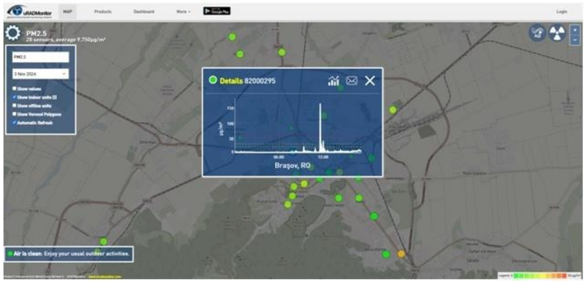


FIG.4. Web interface URAD monitor

b. Polarization-sensitive LIDAR (with two wavelengths) for monitoring vertical profiles of aerosols and clouds (e.g. ceilometu LIDAR), see Fig. 5. [46, 47]

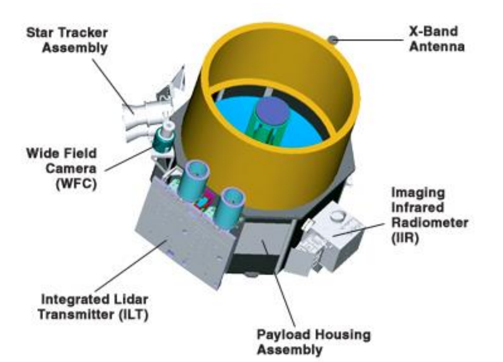


FIG.5. LIDAR – CALIOP [47]

FIG.6. Radiometer [48]

c. spectral radiometer (photometer), which operates on the principle of measuring solar radiation at certain wavelengths, see Fig. 6. [48]

d. modular aerosol monitoring systems, which can measure the degree of radioactive contamination of the air due to radioisotopes of particles in the air [49]

3. SOFTWARE FOR AEROSOLS DATA ANALYSYS

Data analysis can generate relevant results regarding the management of the phenomena underlying aerosol-cloud interaction, here are a number of software options that can be used:

a. R – opensource software tool that provides a statistical computing environment based on extensive libraries for data manipulation and visualization, it contains aerosol-specific packages OpenAir and dataMaid, [50] *b. Python*, can be used for data analysis, machine learning and web development, based on a number of popular libraries (NumPy, Pandas, Matplotlib) or aerosol-specific libraries (AerosolPy, MetPy) [51]

c. MATLAB, is a commercial software based on a mathematical computing environment (matrix and numerical analysis and integration with Simulink) that contains aerosol-specific modules such as Aerosol Toolbox or Meteorology Toolbox, [52].

d. ArcGIS, is a software tool for analyzing and visualizing spatial data (grouping, interpolation, geostatistics), it can integrate aerosol data with other spatial data: meteorological, georeferencing, population, see Fig. 7 [53].

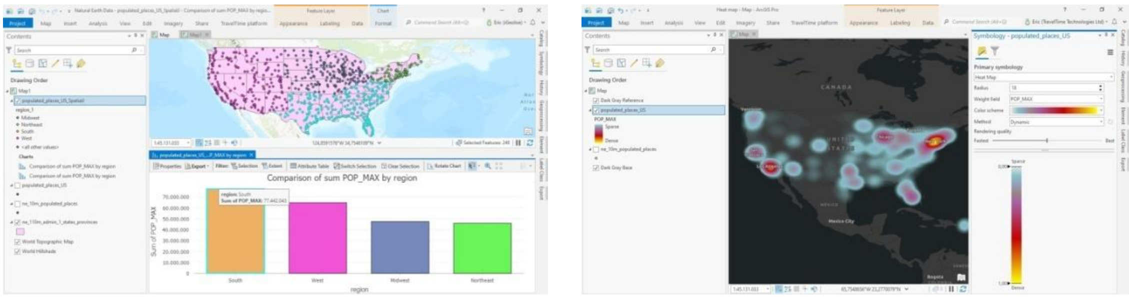
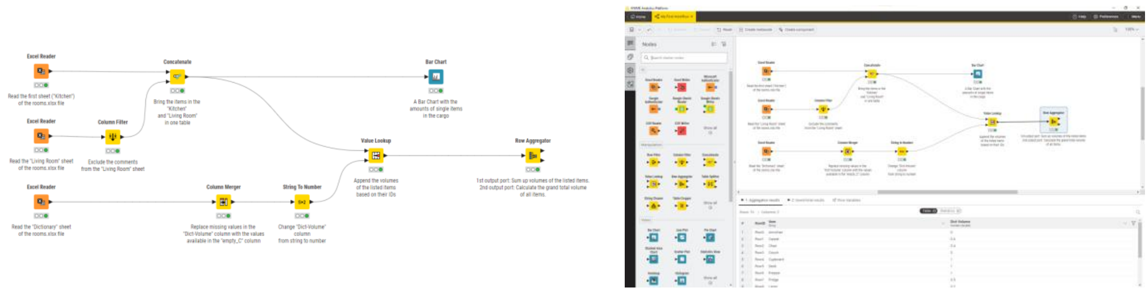


FIG.7. ArcGIS software interface

e. KNIME, is an open-source data analysis platform that provides both a visual interface for aerosol workflows and other relevant data sources, as well as integration with other popular analysis tools such as R and Python, see Fig. 8 [54].



a b

FIG.8. KNIME software a. workflow, b.interface [54]

f. SAS, is a commercial software tool for statistical analysis and data extraction, offers aerosol-specific procedures (spatial analysis, time series analysis), it can be integrated with other SAS products such as Entreprise Guide and Visual Analytics, see Fig. 9 [55].

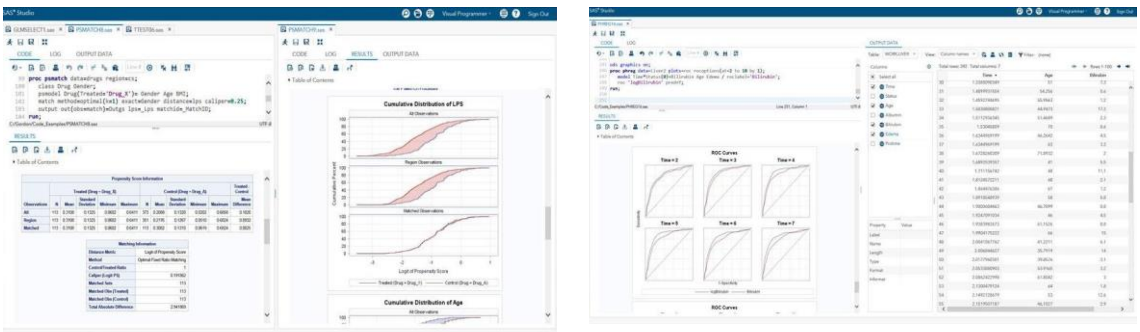


FIG. 9. SAS software interface [55]

g. Statistica, a commercial software tool based on a series of analysis tools (descriptive statistics, hypothesis testing, regression analyses), it can be integrated with other Statistica tools (Miner and Entreprise), see Fig. 10. [56].

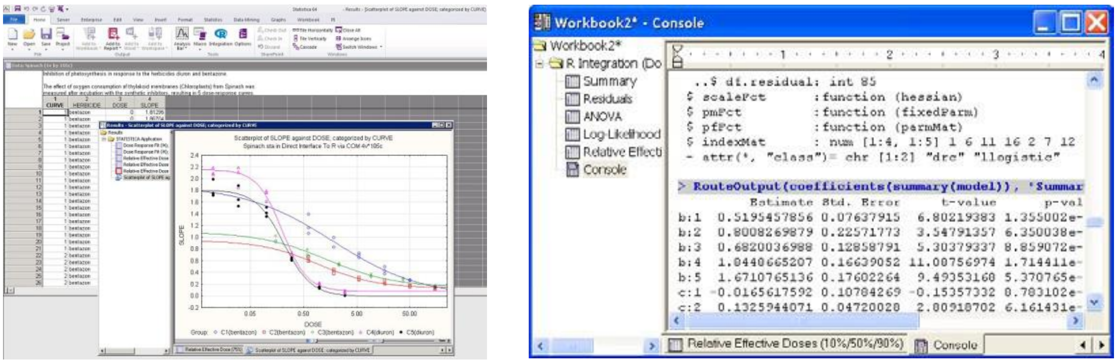


FIG. 10. Statistica software interface [56]

h. SPSS, a commercial software tool for popular or special statistical analysis (aerosol analysis), can be integrated with other IBM products such as Watson Studio or Modeler [57].

4. DATA ACQUISITION FOR AEROSOLS IN ROMANIA

AERONET is a federation of aerosol remote sensing networks (spectral optical depth) owned by NASA and PHOTRONS extended by collaborating entities such as RIMA, AEROCAN, AEROSPAIN, NEON and national agencies, institutes or universities. The data displayed are acquired from the INOE-Măgurele location, using AERONET [39] valid for May 2024, see Fig. 11.

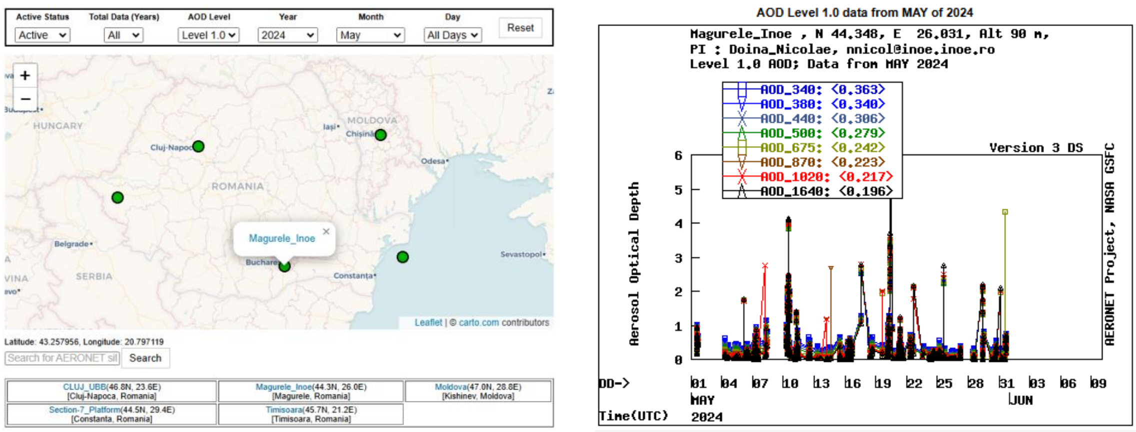


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FIG. 11. AERONET network, a.Romanian location, b. aerosol optical depth AOD [39]

ACTRISS is a pan-European research infrastructure for clouds, gases and aerosols providing freely accessible numerical data on atmospheric constituents and related processes. In Fig. 12a, for May 2024, the aerosol particle backscatter profiles (354 nm LIDAR) are highlighted and in Fig. 12b the vertical resolution profile, [41].

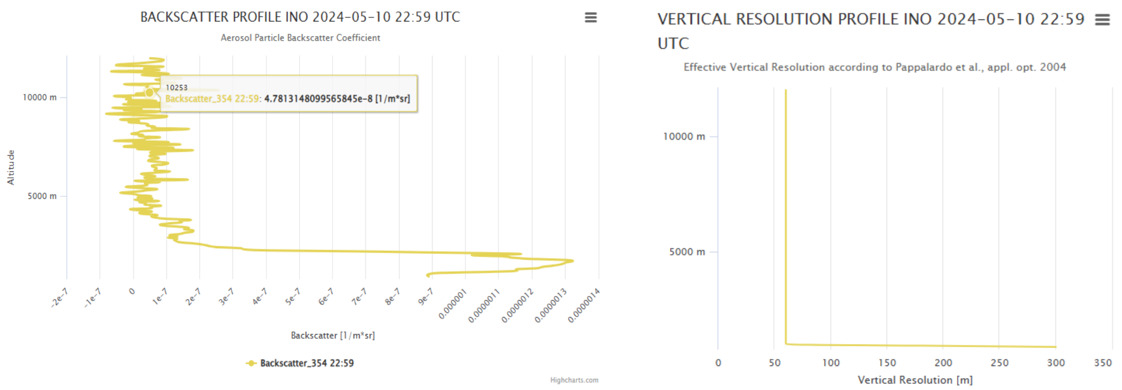

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FIG. 12. ACTRISS network, a.Romanian location, b. aerosol optical depth -AOD [41]

CONCLUSIONS

The present paper provides a panoramic view of the logical approach to aerosol-cloud interaction. The study of aerosol-cloud interaction requires multidisciplinary approaches with an integrated approach, combining both ground and atmospheric data acquisition and data analysis based on numerical models with high degrees of confidence. Understanding these interaction processes can increase the quality of climate predictions and for assessing the impact of human activities on the environment.

Aerosol-cloud interaction requires both the application of atmospheric numerical models through parameterizations of specific processes and data analysis techniques applied to the collected data to identify patterns, correlations and trends associated with field measurements.

Future specific theoretical studies will focus on multicriteria analyses of the methods and tools used in aerosol-cloud interaction to highlight their performance elements

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