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DESCRIPTION AND COMPARISON OF AEROSOL PROPERTIES OVER CLUJ-NAPOCA - ROMANIA AND KOFORIDUA – GHANA, USING AERONET NETWORK DATA

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ABSTRACT. This article presents a description and a comparative study of the optical and microphysical properties of aerosols measured above Cluj-Napoca city in Romania and above Koforidua city in Ghana. Atmospheric aerosols have a major impact on climate and our health. We analyzed the Aerosol Optical Thickness at 440 nm (AOT), the Ångström parameter (α 440 – 870 nm), the fine and coarse volume concentrations and the single scattering albedo, in order to describe the aerosol properties at these 2 stations. We used daily averages which are calculated for every day when the available number of measurements is higher than 3. At CLUJ_UBB station, the Aerosol Optical Thickness at 440 nm wavelength has values between 0.031 and 0.699, with an average of 0.229 ± 0.11. At Koforidua_ANUC station, the AOT440 has values between 0.106 and 2.580, with an average of 0.742 ± 0.50, much higher than the values measured at CLUJ_UBB. The aerosol at the two locations has different properties, at Cluj-Napoca the urban industrial type is predominant while at Koforidua the predominant type is mineral dust.

Key words: *aerosol, sun-photometer, AERONET network*.

INTRODUCTION

An aerosol is defined as a set of liquid or solid particles suspended in a gaseous medium. In the atmosphere, these particles are mainly located in the troposphere. Desert dust carried by wind or soot resulted from biomass fires are examples of atmospheric aerosols (Seinfeld et al., 2006). These aerosols can be of natural or anthropogenic origin (aerosols resulting from human activities) and have different sources depending on geographical location, weather and environmental conditions (Boucher et al., 2013). The aerosols are classified into several categories: terrigenous aerosols or dust from deserts or bare ground, oceanic or spray aerosols from maritime areas, soluble aerosols like sulphates and nitrates, very common in urban environments, biomass fires and house fires, industrial emissions, traffic and volcanic aerosols (Ramanathan et al, 2001; Ştefănie et al., 2015).

Aerosols have a major impact on climate and human health. Due to their small size, they have a negative effect on human health that can be associated with a significant mortality rate. Health effects are mostly associated with small particles in the fine or accumulation mode. The inhalation of these fine particles, results in different diseases such as different allergies, asthma and lung cancer (Pope et al., 2002). In the environmental field, aerosols affect the climate in a variety of ways: directly by diffusion or radiation absorption, and indirectly by acting as condensation nuclei for cloud formation or altering optical properties and clouds life (Boucher et al., 2013).

In this study, we analyze and compare the optical and microphysical properties of aerosols derived by means of passive remote sensing, using the Aerosol Robotic Network – AERONET column integrated data measured with sun photometers at two stations: Cluj-Napoca (Romania) in South-Eastern Europe and Koforidua (Ghana) along the Gulf of Guinea and Atlantic Ocean in Western Africa.

The AERONET global network provides information regarding the aerosol optical and microphysical properties and precipitable water content using solar-powered CIMEL Electronique 318 A (figure 1) spectral radiometers that measure Sun and sky radiances at a number of fixed wavelengths within the visible and near infrared spectrum (Holben et al., 1998). Data collected at the stations are automatically transferred to the AERONET processing system through the internet. Afterwards, the data are processed with inversion algorithms and then made available to users in near real time: level 1 data – unscreened and level 1.5 – automatically cloud screened. The level 2 data – cloud screened and quality assured are available only after the calibration of the instrument at a calibration center. CLUJ_UBB AREONET station is located at the Faculty of Environmental Science and Engineering in Cluj-Napoca city (Lat.: 46.76833° Long: 23.55139° E.; elevation: 405 m), Romania (Ajtai et al., 2013) and Koforidua _ANUC AERONET station at the All Nations University College in Koforidua City (Lat :6.109° N, Lon :0.302° W, 205 m), Ghana.

Fig. 1. CLUJ_UBB site AERONET sun-photometer

Over Romania, the most common aerosol type is the urban industrial. Nevertheless, very often, long range transport of aerosol may occur. Mineral dust from Sahara is transported with the south western winds, especially during the spring (Ştefănie et al., 2015). Also, biomass burning aerosol from Balkan Peninsula and Eastern Europe occur frequently during the summer months. The biomass burning aerosol may have also a local origin. Volcanic ash may be present in the atmosphere after large volcanic eruptions in Sicily or Iceland (Ajtai et al., 2010).

In South Western Africa, in the Gulf of Guinea countries – Ghana, Togo, Benin there is an important presence of aerosol especially mineral dust from Sahara, marine aerosol, smoke from biomass fires and urban industrial aerosol generated in the big cities like Accra, Lomé and Porto-Novo. However, the natural sources of aerosol have an important contribution, as the two winds that blow across the entire region. First, the Harmattan wind, from December to March, which blows from the Saharan Desert to the South, brings large amounts of mineral dust. Also, it can transport aerosol resulting from biomass fires in the African savannah. Second, the monsoon system of periodic winds from the tropical regions that blows from South to the North from July to September. Regarding the precipitations, we have two rainy seasons: the big season from April to June, and a small rainy season between September and October, and two dry seasons: the big dry season due to the Harmattan and the small dry season due to the monsoon.

METHOD AND PARAMETERS

The two stations which provided data for our study are located in different regions: South Eastern Europe – Romania and in Western Africa - Ghana, the stations having different geographical and meteorological conditions.

We compared the available measurements – daily averages - from January 2016 to December 2018. For CLUJ_UBB station, level 2 data were available for the entire period except the month of December 2018, when we used level 1.5 data. For Koforidua_ANUC station, level 2 data were available until April 2018, for the remaining period level 1.5 data being used. We should underline that sky-radiance measurements in general introduce sampling bias, because cloudy days are underrepresented in the database.

The AERONET network provides two types of data: direct Sun spectral data based on the extinction of light through the atmosphere and inversion data derived from the angular distribution of the sky radiance. In this study we analyzed the main two parameters derived from direct Sun measurements: the AOT - Aerosol Optical Thickness and the Ångström parameter α.

The Aerosol Optical Thickness or optical depth is defined as the integrated extinction coefficient over a vertical column of unit cross section. The AOT is the degree to which aerosols prevent the transmission of light.

The Ångström parameter describes the dependency of the aerosol optical thickness on wavelength. The first derivative of AOT with wavelength in a logarithmic scale is known as the Ångström parameter (Holben et al., 1998).

Regarding the inversion products, the AERONET network provides aerosol properties such as size distribution, the real and imaginary part of refractive index, spectral single scattering albedo, phase function, asymmetry factor and others. These properties are retrieved from sky spectral radiance and polarization measurements by inverse procedures (Dubovik and King, 2000). In our study we analyzed the fine and coarse volume concentrations (Cvf and Cvc) and the single scattering albedo (Kaufman et al., 1994).

The fine and coarse volume concentrations ($\mu m^3/\mu m^2$) are retrieved within the size range of $0.05\ \mu m \leq r \leq 15\ \mu m$. Fine and coarse mode separation is obtained using the inversion code which finds the minimum within the size interval from 0.439 to 0.992 μm. The single scattering albedo, SSA(λ), is represented by the ratio of scattering efficiency to total extinction efficiency at wavelengths corresponding to the sky radiance measurements (Holben et al., 2001).

RESULTS AND DISCUSSIONS

The measurements from the 2 stations included in our study are analyzed and compared. We used daily averages which are calculated for every day when the available number of measurements is higher than 3.

In table 1 we present the monthly available number of days with measurements at each station. There are more measurements performed in the months with clear sky conditions. At CLUJ_UBB station in Romania we have a high number of measurements from April to September, except the month of July. The lack of data for this month is due to calibration of the instrument performed in 2017, when no data where available. At Koforidua_ ANUC station the numbers of days with measurements are more frequent from January to April and from September to December.

Table 1. Available number of days for each month of the year

Station/Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
CLUJ_UBB	28	28	38	57	75	51	31	59	49	41	36	30	523
Koforidua_ANUC	76	55	70	52	39	37	38	23	51	43	48	51	583

Aerosol Optical Thickness – AOT_{440}

At CLUJ_UBB station, the Aerosol Optical Thickness at 440 nm wavelength has values between 0.031 and 0.699, with an average of 0.229 ± 0.11. The error of the mean value is the standard deviation used in order to highlight the spread of the values. The daily values are characterized by significant variation, but the yearly average is in good agreement with other urban industrial sites – Paris, France: 0.26, Greenbelt, USA – 0.24 (Dubovik et al., 2002).

At Koforidua_ANUC station, the AOT_{440} has values between 0.106 and 2.580, with an average of 0.742 ± 0.50, much higher than the values measured at CLUJ_UBB. The monthly minimum, maximum and average values for the two stations are presented in table 2 (CLUJ_UBB) and table 3 (Koforidua_ANUC).

As seen in Figure 2, at CLUJ_UBB station, the monthly AOT_{440} has the highest values during the summer months – July and August, mainly due to the low level of precipitation.

Table 2. Monthly AOT_{440} averages measured at CLUJ_UBB station

Station/ Month		**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
CLUJ_UBB	Min	0.06	0.03	0.07	0.05	0.07	0.06	0.11	0.06	0.06	0.05	0.04	0.04
	Avg	0.20	0.19	0.25	0.21	0.22	0.25	0.26	0.29	0.22	0.19	0.18	0.47
	Max	0.59	0.55	0.57	0.40	0.51	0.50	0.63	0.63	0.69	0.63	0.44	0.17

Table 3. Monthly AOT_{440} averages measured at Koforidua_ANUC station

Station/ Month		**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
Koforidua_ANUC	Min	0.85	0.34	0.10	0.24	0.11	0.10	0.21	0.29	0.10	0.16	0.24	0.48
	Avg	1.4	1.33	0.61	0.54	0.35	0.36	0.51	0.68	0.34	0.44	0.55	1.08
	Max	2.58	2.46	1.45	1.40	0.6	0.79	1.29	1.64	0.66	0.93	0.82	2.59

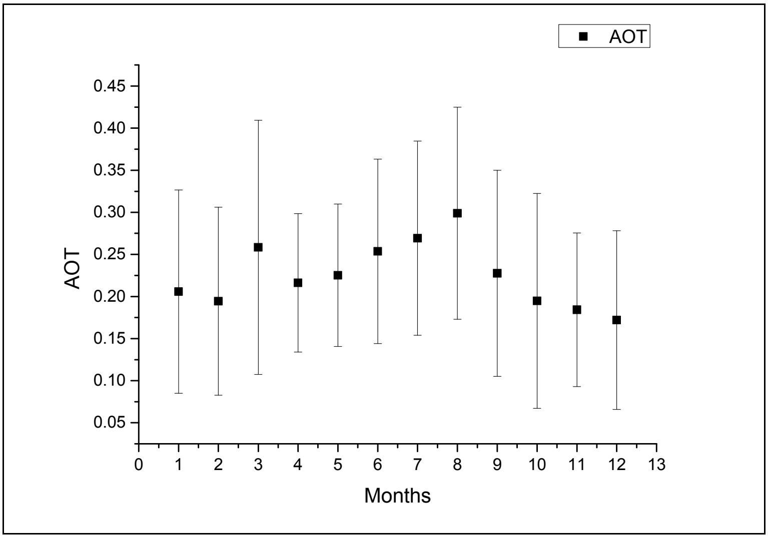

Fig. 2. Monthly AOT_{440} at CLUJ_UBB station

At Koforidua_ANUC (figure 3), the monthly AOT_{440} has the highest values from December to February during the Harmattan winds which bring high amounts of mineral dust from Sahara and also biomass burning aerosol from the savannah.

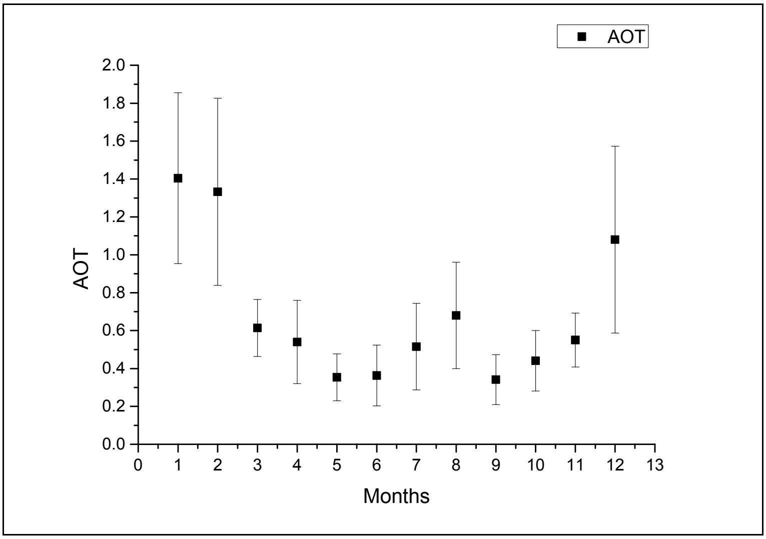

Fig. 3. Monthly AOT_{440} at Koforidua_ANUC station

Ångström parameter – α 440 – 870

The Ångström parameter is a good indicator of aerosol particles size. The large values indicate the presence of fine mode particles like urban industrial and biomass burning aerosols, whereas small values are associated with coarse particles like desert dust and marine aerosols.

At CLUJ_UBB station, the Ångström parameter has values between 0.27 and 2.00, with an average value of 1.48 ± 0.32. The small values are usually due to Saharan dust intrusions, while the high values are due to the presence of fine mode particles like biomass burning and urban – industrial aerosol.

At Koforidua_ANUC station, the Ångström parameter has values between 0.12 and 1.93, with an average value of 0.77 ± 0.36. The values are smaller than those measured at CLUJ_UBB station, due to the continuous presence of coarse mode aerosol particles like mineral dust and marine aerosols.

The monthly minimum, maximum and average values of the Ångström parameter at the two stations are presented in table 4 and table 5.

Table 4. Monthly α 440 - 870 averages measured at CLUJ_UBB station

Station/ Month		**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
CLUJ_UBB	Min	1.06	0.31	0.95	0.27	0.53	0.28	1.40	1.12	1.09	0.85	0.70	1.13
	Avg	1.55	1.31	1.46	1.22	1.41	1.38	1.69	1.75	1.63	1.51	1.38	1.52
	Max	1.88	1.91	1.85	1.86	1.83	1.96	1.97	2.00	1.90	1.80	1.79	1.89

Table 5. Monthly α 440 - 870 averages measured at Koforidua_ANUC station

Station/ Month		**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
Koforidua_ANUC	Min	0.29	0.29	0.14	0.12	0.16	0.17	0.27	1.14	0.19	0.30	0.24	0.22
	Avg	0.86	0.61	0.64	0.41	0.48	0.82	1.15	1.33	0.97	0.74	0.55	0.96
	Max	1.56	0.96	1.14	0.86	1.03	1.41	1.51	1.71	1.62	1.28	0.82	1.93

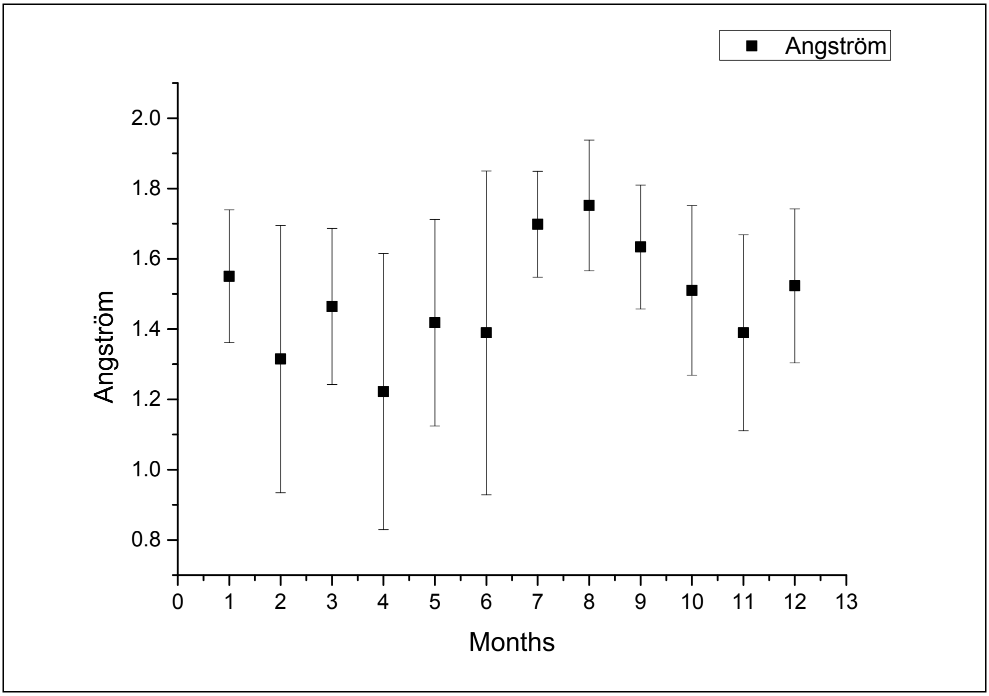

Fig. 4. Monthly Ångström parameter α 440 – 870 nm at CLUJ_UBB station

As seen in figure 4, at CLUJ_UBB station, the monthly α 440 - 870 nm has the high values during the dry months, with biomass burning aerosol intrusions and lower values during the spring months when the Saharan desert dust intrusions are more frequent. Also, the variability of values is higher from February to June.

As seen in figure 5, at Koforidua_ANUC, the monthly Ångström parameter has lower values than in Cluj, the mineral dust aerosol being present during the entire year. Also, the variability of the measured values is lower than at CLUJ_UBB station.

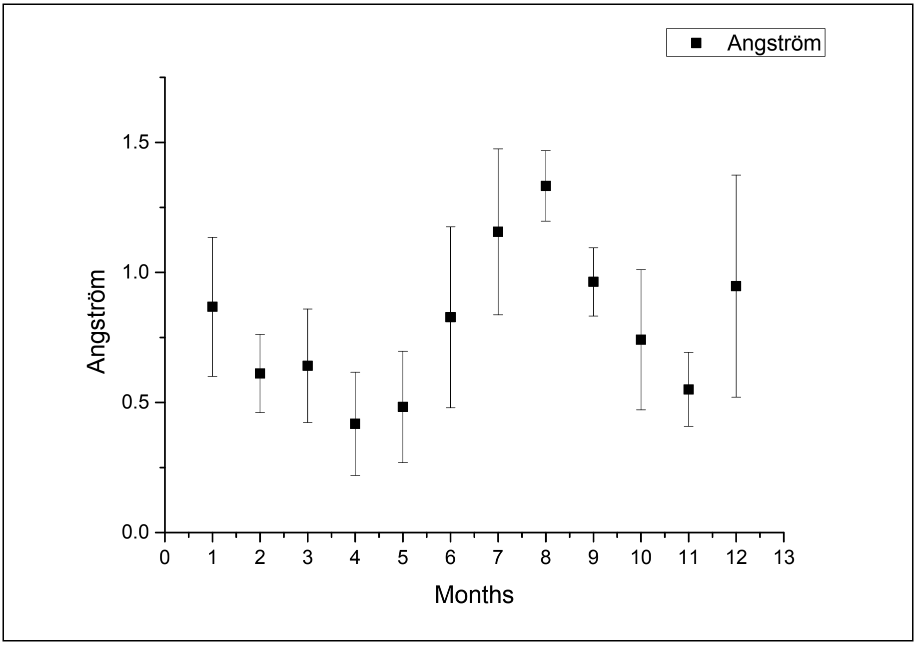

Fig. 5. Monthly Ångström parameter α 440 – 870 nm at Koforidua_ANUC station

Size distribution – the coarse and fine volume concentrations (Cvf and Cvc)

The numbers of days with indirect measurements are fewer. At CLUJ_UBB station we had 309 days with valid measurements, while at Koforidua_ANUC station we had 251 days with measurements.

At CLUJ_UBB station we observed a clear dominance of the fine mode Cvf over the coarse mode Cvc, specific to urban industrial aerosol. The exceptions are mainly represented by the desert dust intrusions. On the other hand, at Koforidua_ANUC station we observed a clear dominance of the coarse mode Cvc. This is typical for mineral dust originating from Sahara and also for marine salt.

Single Scattering Albedo - SSA(λ)

The single scattering albedo is a good indicator of the absorbing properties of the aerosols, high values of SSA(λ) indicate low absorption properties. At CLUJ_UBB station we observed an average value for SSA (440) of 0.92, similar with values measured in other European sites like Paris in France: SSA (440) of 0.94 (Dubovik et al., 2002). At Koforidua_ANUC station, we observed an average value for SSA (440) of 0.88.

CONCLUSIONS

In this paper we analyzed and compared the optical and microphysical parameters of aerosols at two AERONET stations with different geographical and climatic conditions: Cluj-Napoca (Romania) in South-Eastern Europe and Koforidua (Ghana) along the Gulf of Guinea in Western Africa. We analyzed 3 years of measurements made with CIMEL sun-photometers. The aerosol at the two locations has different properties. Over Cluj-Napoca in Eastern Europe, the urban industrial aerosol is present during the entire year. This type of aerosol is characterized by a high Ångström parameter and a pronounced fine mode fraction. Saharan desert dust intrusions are frequent during March and April and biomass burning aerosol intrusions in August and September. At Koforidua in Ghana and other neighboring countries like Togo and Benin the coarse mode aerosol like Saharan dust is dominant, with higher concentrations in April and May. This type of aerosol has a low Ångström parameter. In July and August, in the dry season with the monsoon winds from South, there are fewer days with Saharan dust. Also, other coarse aerosol like marine salt from the Atlantic Ocean is present in the region. The Aerosol Optical Thickness has also much higher values in Koforidua than in Cluj-Napoca, the aerosol pollution levels in the region being higher, especially during the Harmattan winds.

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