Analysis of optical properties of aerosols by means of photometry

D. CĂLINOIU*, I. IONEL*, G. TRIF-TORDAI
"Politehnica" University of Timisoara, Faculty of Mechanical Engineering, Blv. Mihai Viteazu, No. 1, Ro-300222, Timisoara, Romania

In this paper one demonstrates, based on the measurements achieved, that aerosol optical and microphysical properties and the dominating aerosol type depend on the seasonal climate. In situ measurements of aerosol optical properties were accomplish during an episode starting March to December 2011 at the "Politehnica" University of Timisoara sun photometry station (45.74N; 21.22E), located in the western part of Romania. During different periods such as spring, summer and autumn, the aerosol optical depth (AOD), single scattering albedo (ω), Angstrom coefficients: Angstrom parameter (α) and Angstrom turbidity (β) of urban – industrial aerosols were depicted and the characteristic results were interpreted.

(Received May 29, 2012; accepted September 18, 2013)

Keywords: Aerosol optical depth (AOD), Angstrom parameter, Angstrom turbidity, Single scattering albedo

1. Introduction

Rapid development of industry and transports has resulted in increasing changes and loading stress and disturbances upon to environment, climate and atmosphere [1]. In the last century, Earth's average temperature at surface increased by 0.6° (relative to 1975), according with the Intergovernmental Panel on Climate Change (IPCC) [2, 3].

Aerosol can directly contribute and affect global radiation budget by scattering and absorption of solar and terrestrial radiations [4], and they also indirectly affect the radiation, by changing cloud's microphysical [5 - 7] and their chemical properties. Consequently it is absolutely necessary to monitor aerosols, by diverse possibilities and techniques, and at different levels, not only at soil. The mentioned global effects strongly depend on the physical and optical properties of aerosol particles. Several studies about accuracy of aerosol optical properties from sun and sky radiance measurements were conducted by Dubovik [8-11].

Therefore, aerosol measurements on global scale are essential. This is achieved for example at ground - based by automatic sun and sky scanning spectral radiometer, by means of so – called sun photometer. These instruments have the advantage that they are able to produce continuous aerosol optical thickness (AOT) time series, with high accuracy, fact that is essential for the measuring procedure.

The Aerosol Robotic Network (AERONET) is an international network of sun photometers, based on an international project founded in 1993 by NASA GSFC (http://aeronet. gsfc.nasa.gov/) and LOA – PHOTONS (http://www-loa.univ-lille1.fr/photons/). It consists of more than 500 automatic sun/sky radiometers worldwide, and represents one of the major two existing networks of the scientific community efforts to reduce existing uncertainties in aerosol forcing estimates [12].

Up to now (2012), in Romania four stations, equipped with sun photometers, are mounted. Partially they support the network AERONET (http://aeronet.gsfc.nasa.gov).

The goal of AERONET is to assess aerosol optical properties, thus providing much of the ground - based validation data required for future remote sensing programs. Also the network provides basic information necessary for improved assessment of aerosols impact on climate forcing and changes [12].

All data presented in this paper were acquired with the sun photometer from "Politehnica" University of Timisoara, which operate in AERONET global network.

2. Experimental

Several studies of solar radiation modeling [13] and for the air pollution [14] have occurred in Timisoara, in the recent years. For example, the air pollution was analyzed by means of classical standard methods, but using a powerful LIDAR system as well [15], thus depicting other particularities of the local pollution level and characteristics of the particles, especially, on a vertical distribution. Thus the effects of the traffic in an urban structure and the planetary boundary layer dynamics have been studied [16], [17].

The Timisoara sun photometry station is part of the AERONET network and is located at the "Politehnica" University (45.74N; 21.22E). The sun photometer number in the network AERONET is 645. The mentioned instrument is placed on the roof of Mechanical Engineering Faculty, in Timisoara. Timisoara is one of the largest Romanian cities, with a population over 300 thousands inhabitants and more than 170 thousands automobiles.

The sun photometer consists of an optical head, an electronic box and a robot (Fig. 1) [18].

Fig. 1. Main components of the sun photometer from Timisoara.

The optical head has two channel systems: the sun collimator, without lens, and the sky collimator, with lenses. The sun tracker is equipped with a 4-quadrant detector. The electronic box contains two microprocessors for real time operation meant for the data acquisition and the motion control. In automatic mode, a ‘wet sensor′ detects precipitation and forces the instrument to park and to protect the optics. The robot is automatically moved by step-by-step motors in two directions: the zenith and azimuth planes.

A schematic view of the sun photometer is shown in the Fig. 2. The collimator tube (2) determines the viewing angle (field of view 1.2º). The quartz window (3) is used for the protection of the interior of the instrument. After the rotation of the filter wheel (4), which selects the different wavelength channels, the lens (5) is focusing the light onto a 4-quadrant detector (6), which transforms light into an electrical signal [19]. The photo electricity detected with a voltmeter is proportional to the incoming radiance.

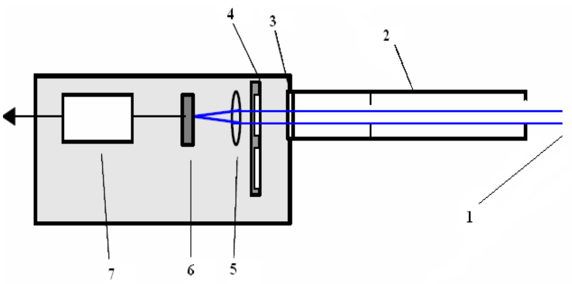


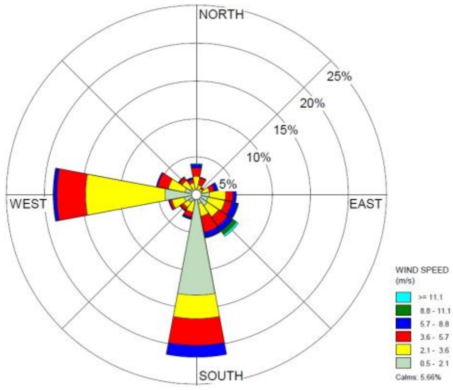
Fig. 2. Scheme of the sun photometer: 1 - direct sun light; 2 – collimator tube; 3 – quartz window; 4 – filter wheel; 5 – lens; 6 – detector (photo diode); 7 – amplifier [19].

The sun photometer accomplishes two basic measurements: (i) direct sun or (ii) sky measurement, both within several programmed sequences. The direct sun measurements are completed in nine spectral bands (340, 380, 440, 500, 670, 870, 940, 1020 and 1640 nm), requiring approximately 10 seconds. The 940 nm channel is used for column water abundance determination.

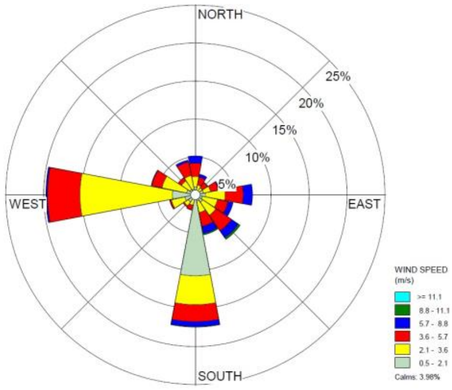
Sky measurements are performed at 440 nm, 670 nm, 870 nm, and 1020 nm. Two basic sky observation sequences were recorded: the “almucantar” and the “principal plane”.

3. Results and discussion

Fig. 3 presents the wind rose for the three seasons in Timisoara. The wind rose plots were generated with WRPLOT View program from Lakes Environmental (weblakes.com). Comparing the data within this figure it can be observed that the predominant blowing direction is toward West and South. The wind influences the local turbidity enhancing the turbulence and the aerosol dispersion.



a)



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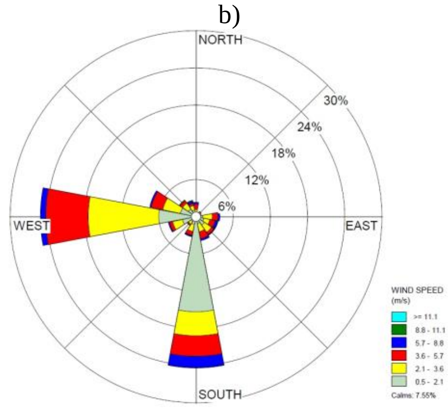

c)

Fig. 3. Wind rose for three seasons in Timisoara: a) spring; b) summer; c) autumn.

In Table 1 are presented the number of days for which AOD values were recorded; the missing values being appointed to unfavorable weather conditions (rain, snow) and device errors.

Table 1. The number of daily observation for AOD from the Timisoara station during March – November 2011.

Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
No. of days	21	29	25	26	17	22	22	20	20

The aerosol optical depth (AOD) is generated applying the Beer - Lambert - Bouger law to irradiance data and by removing the contribution due to Rayleigh scattering and absorption of atmospheric gases. The variation of AOD from Fig. 4 is explained by the temporal variability of the aerosol concentration in the atmospheric boundary layer over Timisoara.

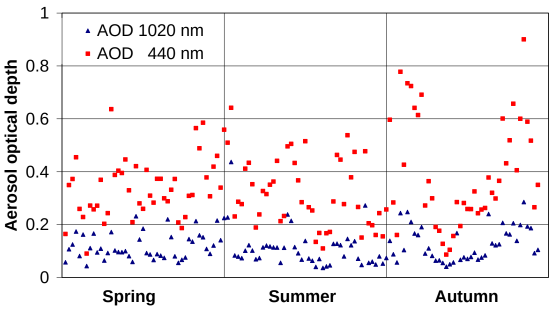

Fig. 4. Aerosol optical depth, as resulted from direct measurements during the analyzed episode.

From the AOD values one can find the α and β, Angstrom coefficients. Equation (1) represents the Angstrom formula [20].

$$\tau_a(\lambda) = \beta \cdot \lambda^{-\alpha} \tag{1}$$

where: τ is aerosol optical depth;
β - Angstrom turbidity;
λ – wavelength, in μm;
α – Angstrom parameter.

The β coefficient is related to the particles concentration. β values of less than 0.1 are associated with a relatively clear atmosphere, and values larger that 0.2 are associated with a relatively hazy atmosphere.

The α parameter can be evaluated from measurements irradiance solar at different two wavelengths (Eq. 2).

$$\alpha = \frac{\ln(\tau_1/\tau_2)}{\ln(\lambda_2/\lambda_1)} \tag{2}$$

where: τ_1, τ_2 is aerosol optical depth;
λ_1, λ_2 – wavelength, in μm

If the value of α < 1 this is a sign that indicates a size distributions dominated by coarse mode aerosols, which can be associated with dust and sea-salt aerosols. Contrary, if the Angstrom parameter α > 1, it indicates the presence of fine mode particles, which can be associated with urban pollution and in same cases with biomass burning [9].

From Fig. 5 it can be observed that the Angstrom parameter values indicate as dominant mostly the fine mode particles.

If value of aerosol optical depth is between 0.2 and 0.6 at 440 nm (Fig. 4) and value of Angstrom parameter is from 1.2 to 1.9 (Fig. 5), then means it is urban – industrial pollution.

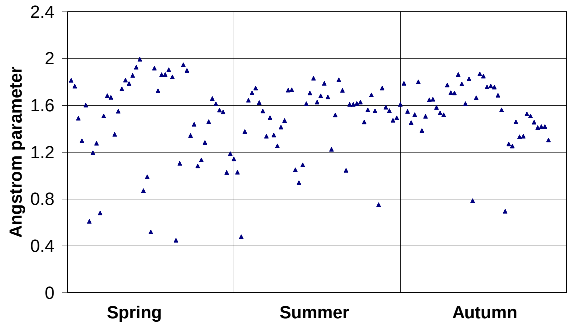

Fig. 5. Angstrom parameter, as resulted from direct measurements during the analyzed episode.

In Fig. 6, the Angstrom turbidity coefficient is obtained using values of α from Fig. 5 at wavelength 440 nm.

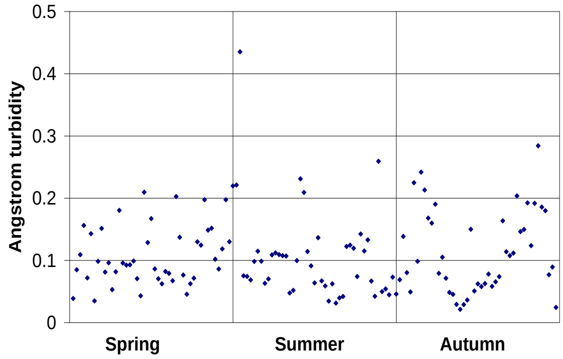

Fig. 6. Angstrom turbidity, as resulted from direct measurements during the analyzed episode.

Fig. 7 presents the frequency distribution of Angstrom turbidity whose values prevail in the interval 0.05 and 0.075. In this case, the turbidity is low. Local pollution influenced the values of the turbidity.

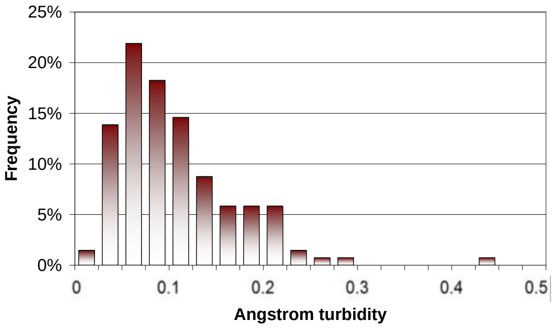

Fig. 7. Frequency distribution of Angstrom turbidity, as resulted from direct measurements during the analyzed episode.

The aerosol optical properties for Timisoara were analysis also in other articles [21, 22].

Other study of turbidity for Romania was made by Stefan S. [23], where in summer 2010, for Magurele, the average Angstrom turbidity has the value 0.13 (at 500 nm), which are related to moderate turbidity.

Table 2 presents the monthly average of AOD for two wavelengths (440 and 1020 nm) and Angstrom parameter in the analyzed period.

Table 2. The average AOD during March – November 2011 episode as resulted from the measurements achieved at the Timisoara station.

AOD	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
440 nm	0.378	0.444	0.485	0.507	0.400	0.297	0.424	0.265	0.442
1020 nm	0.181	0.239	0.212	0.262	0.162	0.094	0.143	0.116	0.159
α	1.284	1.263	1.321	1.138	1.321	1.508	1.475	1.502	1.411

Incident light is scattered and absorbed by the particles. The quantity of absorbed light is directly related to the single scattering albedo (ω) [1]. If ω is 1 the particle only scatters, if ω is 0 the particle is considered a perfect absorber. The single scattering albedo is retrieved only then when the aerosol optical depth loading is larger than 0.4, at a wavelength of 440 nm [9]. The AERONET network retrieves the single scattering albedo due to an inversion algorithm of Dubovik [10].

As it results from the data sampled by Fig. 8, the predominant values for ω are in the interval 0.8 – 1.0 at 1020 nm, and 0.7 - 0.9 at 440 nm. Biomass burning smoke is known as an absorbing aerosol with high concentration of black carbon produced by combustion, with ω values between 0.88-0.95 at 440 nm [8, 24]. For desert dust aerosol, ω values suggest that dust has significantly less absorption than 0.92 - 0.98 at 440 nm [8]. Absorption of urban – industrial aerosol, also demonstrates by Dubovik [8], have the ω values between 0.90-0.98 at 440 nm.

The variation of single scattering albedo for Timisoara can be explained by various stationary and mobile pollution sources, and meteorological condition. From Fig. 8 it can be observed that the value of ω decreases with increasing wavelength; result is urban – industrial aerosol.

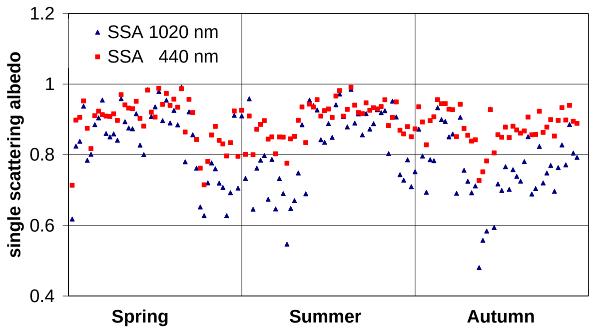

Fig. 8. Single scattering albedo, as resulted from direct measurements during the analyzed episode.

4. Conclusions

The optical properties of aerosol in the region of Timisoara city were analyzed. Following conclusions resulted:

- The monthly average AOD at 440 nm is around 0.40 and the average AOD at 1020 nm is above 0.10. The AOD presents a pick in autumn, which is related also to the high frequency of stagnant weather and hygroscopic growth of aerosol particles, due to higher levels of atmospheric water.
- Angstrom parameter is larger than 1 during the whole seasons of the analyzed episode, which suggest that the aerosol are composed mainly of fine particles. The lower value of Angstrom parameter in spring and during the summer start reflects the influences of dust aerosols from Sahara desert.
- Values of ω < 0.9 lead to warming episodes, while ω > 0.9 indicate a cooling of the climate.

Acknowledgement

The article is based partially on the strategic grant POSDRU/88/1.5/S/50783, Project ID 50783 (2009), co-financed by the European Social Fund-Investing in People, within the Sectoral Operational Programme Human Resources Development 2007-2013.

Also the projects AirQ and TRANSAIRCULTUR are acknowledged.

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*Corresponding author: delia.calinoiu@yahoo.com; ionel_monica@hotmail.com