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Analysis of Aerosol Optical Thickness in Timisoara from AERONET Global Network Observations

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Original scientific paper

Aerosol particle thickness measurements were performed at the "Politehnika" University in Timisoara (Romania) during March 2011 using a CIMEL SUN solar photometer, as part of the global AERONET network. The aerosol optical thickness (AOT) represents a parameter of optical visibility in an atmospheric air column from the instrument towards the sun, affected by the presence of aerosol particles (e.g. smoke particles, desert sand). Precision analyses were performed to determine the types of aerosols present. Results were recorded during June 2011. The aerosol optical thickness (AOT) was increased on the 9th of June because of sands that drifted on air currents from Northern Africa to the western part of Romania.

Analiza optičke debljine aerosola u Temišvaru u okviru globalne mreže AERONET

Izvornoznanstveni članak

Mjerenja gustoće aerosolnih čestica provedena su na Sveučilištu Politehnika u Temišvaru (Rumunjska) u ožujku 2011. s CIMEL SUN sunčanim fotometrom u okviru globalne mreže AERONET. Aerosolna optička debljina (AOT) predstavlja parametar optičke prozirnosti zračnog stupca atmosfere od instrumenta prema suncu uvjetovan prisustvom aerosolnih čestica (npr. dimnih čestica, pustinjskog pijeska). Izvršene su precizne analize kojima se mogu odrediti tipovi aerosola. Rezultati su zabilježeni tijekom lipnja 2011. godine. Aerosolna optička debljina (AOT) je 9. lipnja bila povećana zbog pijeska koji je zračnom strujom nanesen iz sjeverne Afrike u zapadni dio Rumunjske.

1. Introduction

The paper is an attempt to describe different types of aerosols and their path through the atmosphere in the Romanian city of Timisoara. The town is one of the most developed ones in Romania, famous for its history and rapid progress into a modern but traditional location of human development (Popescu F., 2009). Air pollution in a modern city has become a serious environmental problem, because of the combined effects of various pollutants upon the physical and mental health of citizens and the quality of urban life in general (Popescu F., 2011 a), (Popescu F., 2011 b), (Ionel, I., 2010). Main possible aerosol sources are urban pollution from roads and power plants. The burning of fossil fuels produces around 21.3 billion tones (21.3 gigatones) of carbon dioxide per year, but also produces nitrogen oxides and sulfur dioxide emissions, which contribute to smog and the formation of fine particulate matter (Nisulescu C., 2011).

Aerosols are liquid or solid particles suspended in the air, with radii normally ranging from 0.1 to 10 μm. They have a direct radiative forcing because they scatter and absorb solar and infrared radiation in the atmosphere. The size distribution of aerosols is critical to all climate influences. Fine aerosols scatter more light per unit mass and have a longer atmospheric lifetime than coarse aerosols (Kokhanovsky A., 2008). Measurement of aerosol optical thickness can provide important information about the concentration, size distribution, and variability of aerosols in the atmosphere.

In the federal network AERONET – Aerosol Robotic NETwork (Holben B.N. et al., 1998) are connected over 650 instruments in the world, of which, currently, 4 are located and running in Romania (Figure 1), among them one in Timisora, at the POLITEHNICA University, in the multifunctional lab for thermal machines and renewable energies (www.energieregen.mec.upt.ro). The network imposes standardization of instruments, calibration, data acquisition, processing and distribution according a special technique and mathematical model. AERONET collaboration provides globally distributed observations of spectral aerosol optical depth (AOD), inversion products, and precipitable water in diverse aerosol regimes. For Romania, the network is based on

Symbols/Oznake

V	- the digital voltage, in V - izlazni napon sunčevog fotometra
V_0	- extraterrestrial voltage, in V - kalibracijski napon izvan atmosfere
m	- optical air mass - optička masa zraka
d_0	- the average earth–sun distance, expressed in astronomical units (AU) - srednja udaljenost Zemlje od Sunca, u astronomskim jedinicama (AU)
$\tau_a(\lambda)$	- aerosol optical depth - aerosolna optička debljina
$\tau_R(\lambda)$	- Rayleigh optical depth - Rayleigheva optičke debljina
$\tau_g(\lambda)$	- optical depth due to absorption by gases such as O_3, NO_2, and H_2O - optička debljina uzrokovana apsorpcijom plinova kao što su O_3, NO_2 i H_2O
λ	- wavelength, in nm - valna duljina

the infrastructure and techniques developed in the frame of two main research projects RADO (www.inoe.inoe.ro/RADO) and ROLINET (www.inoe.inoe.ro/ROLINET).

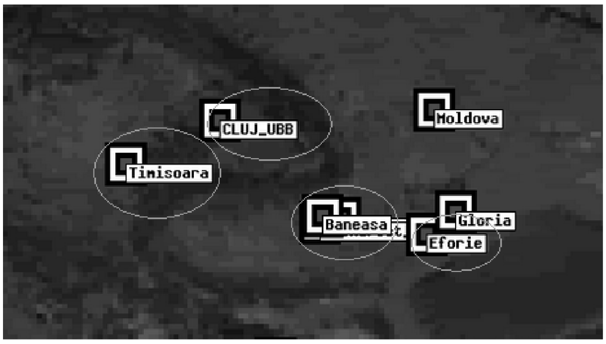

Figure 1. Sun photometer stations in Romania
Slika 1. Sun fotometar stanica u Rumunjskoj

2. General description

The instrument used in this paper is a CIMEL ELECTRONIQUE 318 spectral radiometer manufactured in Paris; France. This is installed at the Mechanical Engineering Faculty (45.74 N; 21.22 E), frame of "Politehnica" University of Timisoara (Figure 2 - right).

The sun photometer is composed of an optical head, an electronic box and a robot (Figure 2) and it is described in detail in (Holben B.N. et al., 1998). The optical head has two channel systems: the sun collimator (33 cm), without lens, and the sky collimator (33 cm) with lenses. This instrument has approximately a 1.2° full angle field of view. The electronic box contains two microprocessors for real time operation for data acquisition and motion control. In automatic mode, a 'wet sensor′ detects precipitation and forces the instrument to park and to protect the optics. The robot is moved by step-by-step motors in two directions: in the zenith and azimuth planes.

The sun photometer accomplishes two basic measurements, either direct sun or sky, both within several programmed sequences. The direct sun measurements are made in nine spectral bands (340, 380, 440, 500, 670, 870, 940, 1020 and 1640 nm) requiring approximately

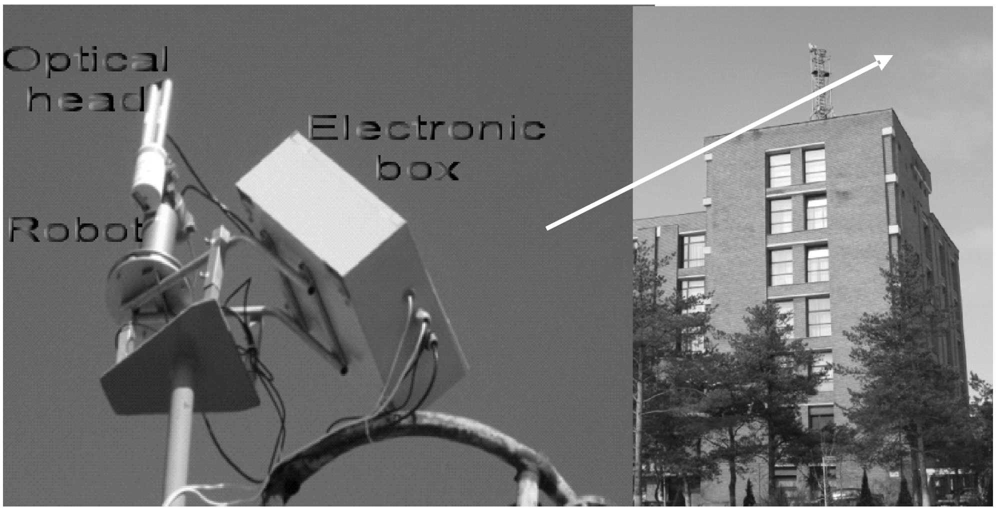

Figure 2. Sun photometer located at the Politehnica Univerity of Timisoara
Slika 2. Sun fotometar lociran na Sveučilištu Politehnika u Temišvaru

10 seconds. The 940 nm channel is used for column water abundance determination. These interference filters are located in a filter wheel which is rotated by a direct drive stepping motor (Figure 3). A sequence of three measurements is taking 30 seconds apart, creating a triplet observation per wavelength, which is used to calculate the aerosol optical depth, the precipitable water and the Ångström parameter. Triplet standard observation are made during morning and afternoon at a 15 minute interval and for an air mass between m = 2 a.m. and m = 2 p.m.

Sky measurements are performed at 440 nm, 670 nm, 870 nm, and 1020 nm. Two basic sky observation sequences are recorded: the "almucantar" and the "principal plane". An "almucantar" is a series of measurements taken at the elevation angle of the Sun for specified azimuth angles relative to the position of the Sun. The range of scattering angles decrease as the solar zenith angles decreases. During an "almuncatar" measurement, observation from a single channel are made in a sweep at a constant elevation angle, across the solar disk and continues through 360° of the azimuth in about 40 seconds. This is repeated for each channel. An almuncatar is made hourly between 9 a.m. and 3 p.m. local solar time.

The standard "principal plane" sequences measures in much the same manner as the "almuncatar", but in the principal plane of the Sun at a constant azimuth angle, with varied scattering angles. This measurements sequence begins with a sun observation, moves 6° below the solar disk, and then sweeps through the sun taking about 30 seconds for each of the four spectral bands. "Principal plane" observations are made hourly, when the optical air mass is less than 2 to minimize the variations in radiance due to the change in optical air mass. These measurements are used to calculate the size distribution, the phase function and the aerosol optical.

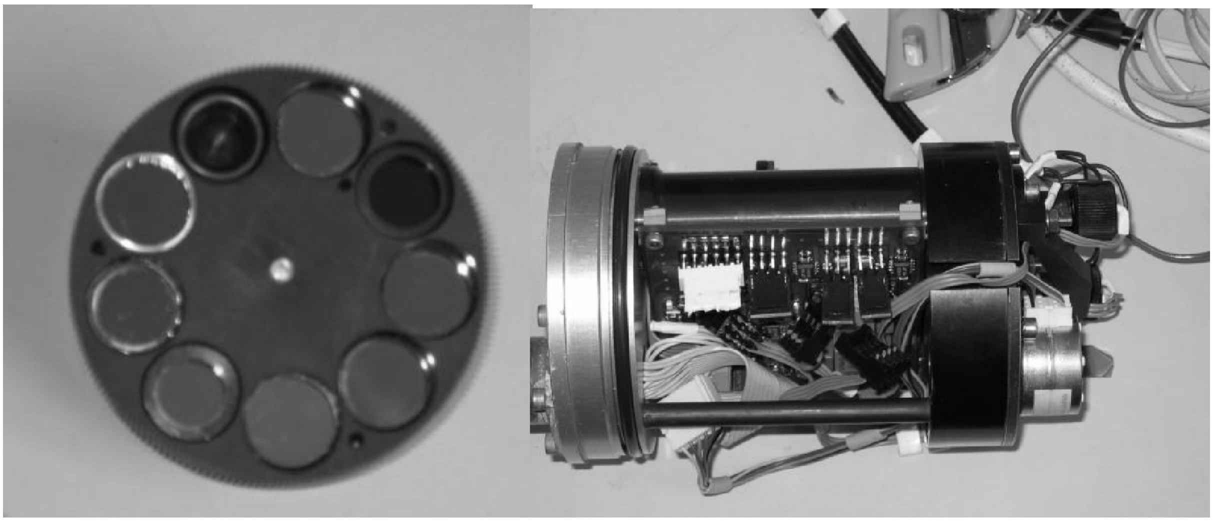

Figure 3. Filter wheel which is rotated by a motor
Slika 3. Rotirajući filter

3. Results and discussions

Transmission of the direct solar beam through a vertical slice of the atmosphere can be calculated with the eq. (1).

$$V = V_0(\lambda)\left(\frac{d_0}{d}\right)^2 e^{-(m\tau_t(\lambda))}, \tag{1}$$

where: V is the digital voltage, in V,

V_0 - extraterrestrial voltage, in V,

λ – wavelength, in nm,

m – optical air mass,

d_0 - the average earth–sun distance, expressed in astronomical units (AU),

d - the earth–sun distance on the day of observation, expressed in astronomical units (AU),

τ_t - total atmospheric optical thickness (AOT).

The air mass is calculated as function of the solar zenith angle.

The accuracy of the AERONET aerosol optical thickness measurements is 0.01 - 0.02 for the wavelength ≥ 440 nm and the uncertainty in measured sky radiances due to calibration error is ~ 5 % (Dubovik O. et al., 2000).

The total atmospheric optical thickness may be composed of several components given by eq. (2).

$$\tau_t(\lambda) = \tau_a(\lambda) + \tau_R(\lambda) + \tau_g(\lambda), \tag{2}$$

where: $\tau_a(\lambda)$ - is aerosol optical depth,
$\tau_R(\lambda)$ - Rayleigh optical depth,
$\tau_g(\lambda)$ - optical depth due to absorption by gases such as O_3, NO_2, and H_2O.

which are calculated following the equations of Gueymard, (Gueymard 2001).

Figure 4 show the AOT variation in June 2011, within the 0 – 2. It is evident that AOT presents large day to day variation, it was cloud free and the atmosphere was relatively clean from 1 to 6, 13 to 18, 20-23 and 26 to 27 June. On 10 - 11, and 23 – 25 June was rainy days. The maximum value for AOT was recorded on June 9, being over 2. The aerosol life time is short. The aerosol always accumulates for a few days, and then breaks down due to a passing cold front or to precipitation. In addition, the large day to day variation of AOT is also driven by many other meteorological factors.

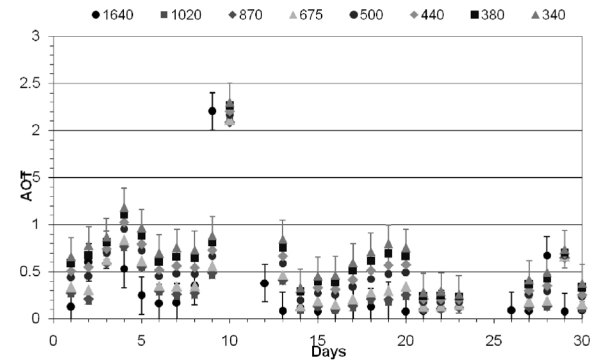

Figure 4. AOT variation in June

Slika 4. Varijacija AOT u lipnju

Spectral Deconvolution Algorithm (SDA) is given in (O'Neill et al., 2001b and O'Neill et al., 2003).

The recognition that the aerosol particle size distribution is effectively bimodal permits the extraction of the fine and coarse mode optical depths (τ_f and τ_c) from the spectral shape of the total aerosol optical depth ($\tau_a = \tau_f + \tau_c$). τ_c is a measure of both coarse mode aerosols and thin cloud contamination (with the qualifier that in the presence of large particle cirrus clouds, τ_c is systematically underestimated due to strong small angle scattering into the sun photometer field of view (O'Neill et al., 2003).

Analyzing fine and coarse mode aerosol depth (Figure 5), it can be observed for 9 June the fine mode is higher. This means that there are intrusions with dust particles. Value of τ_c is 1.859 for 500 nm.

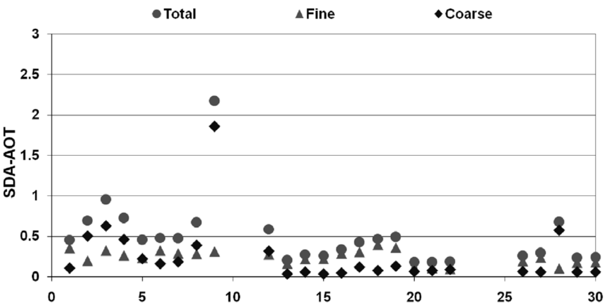

Figure 5. SDA of total, fine and coarse mode optical depth for 50 nm

Slika 5. SDA ukupne, fine i grublje optičke debljine za 50nm

A typical aerosol optical thickness value for visible light in clear air is roughly 0.1. A very clear sky may have an AOT of 0.05 or less. Very hazy skies can have AOTs of 0.5 or greater. It may be easier to understand the concept of optical thickness when it is expressed in terms of the percentage of light that is transmitted through the atmosphere, according to this formula:

$$\% \text{ Transmissin} = 100 * e^{-\tau(\lambda)} \tag{3}$$

This calculation gives the percentage of light at a particular wavelength that would be transmitted through the atmosphere if the sun were directly overhead. For an optical thickness of 0.1, the percent transmission is about 90.5%. The transmission depends on the type of clouds and aerosols (Figure 6).

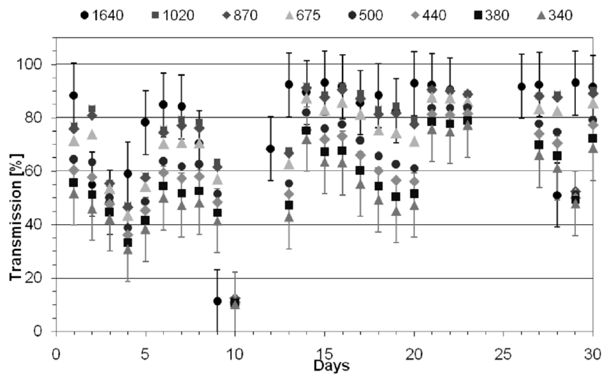

Figure 6. Transmission of sunlight through the atmosphere in June

Slika 6. Prijenos sunčevih zraka kroz atmosferu u lipnju

Figure 7 illustrates the average aerosol thickness of MODIS satellite data (Moderate Resolution Imaging Spectroradiometer) for June 2011. This image was acquired using GES – DISC Interactive Online Visualization and Analysis Infrastructure (GIOVANNI) as part of the NASA. The MODIS retrieval (v4.2) of the AOT over land employs primarily three spectral channels centred at 0.47, 0.66, and 2.1 mm. AOT is derived at 0.47 and 0.66 mm, and interpolated to 0.55 mm. The average

AOT at wavelength 550 nm is between 0.2044 and 0.2392 for Timisoara. The temporal correlation between MODIS and sun photometer is good. The AOT average from sun photometer at 440 nm is 0.507.

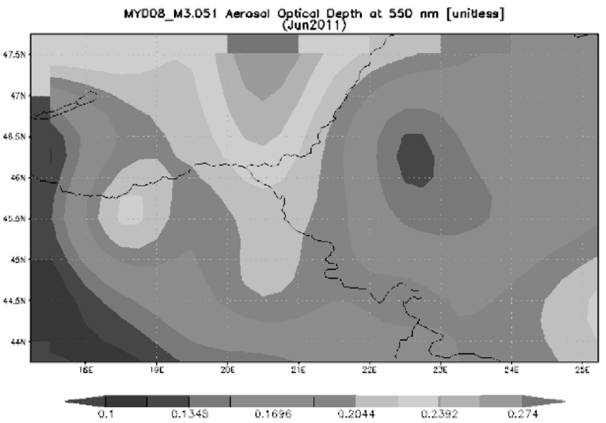

Figure 7. MODIS - average aerosol thickness during June 2011[http://aeronet.gsfc.nasa.gov]

Slika 7. MODIS - srednja vrijednost aerosolne debljine tijekom lipnja 2011 [http://aeronet.gsfc.nasa.gov]

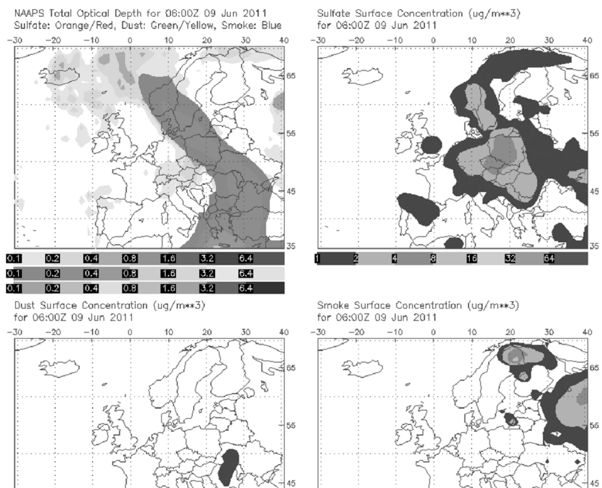

Figure 8. NAAPS model for Europe from 9 June [http://www.nrlmry.navy.mil/aerosol_web]

Slika 8. NAAPS model za Europu od 9. lipnja [http://www.nrlmry.navy.mil/aerosol_web]

A number of naturally occurring and anthropogenic aerosols affect earth. Navy Aerosol Analysis and Prediction System (NAAPS) are a model operational that has the ability to analyze and modeling aerosol. It combines the current and expected satellite data streams with other available data and the global aerosol simulation and prediction. Also, this utilizes several sources of surface-based aerosol measurements (AERONET). Specifically,

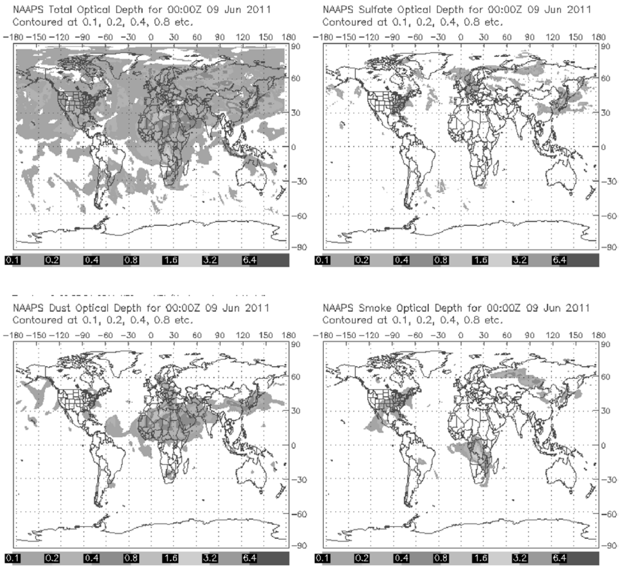

Figure 9. NAAPS model for the world map from 9 June [http://www.nrlmry.navy.mil/aerosol_web]

Slika 9. NAAPS model za zbirnu mapu od 9. lipnja [http://www.nrlmry.navy.mil/aerosol_web]

can be investigated and evaluated the existing aerosol at worldwide. It can be seen by the dust and sulfate intrusions over Europe, these crossing Romania (Figure 8). In Figure 9 can be observed the Provenance of the dust and sulfate intrusions. Dust intrusions arrives at the West Romania from North Africa.

4. Conclusion

A study to classify aerosol properties using direct sun photometer observations has been presented.

Aerosol properties can be analyzed in the whole column atmospheric. This instrument gives important data, but can only be performed when the sky is totally clear.

An optical thickness of less than 0.1 indicates a crystal clear sky with maximum visibility, whereas a value of 1 indicates very hazy conditions. Using predictive models can be found the source of air pollution.

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