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ESTIMATION OF ÅNGSTRÖM ATMOSPHERIC TURBIDITY OVER BUCHAREST, ROMANIA

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Abstract. The aim of this paper is to investigate the air turbidity in the urban environment. The turbidity is determined at three sampling sites covering different types of pollution in Bucharest area during 1st of June 2014 to 31st of May 2015. The optical parameters used in computing Ångström turbidity were determined based on the mass concentration of particulate matter with diameters smaller than 10 μm (PM_{10}) measured at urban stations Bucurestii Noi and Cercul Militar and at the suburban station Magurele. The PM_{10} mass concentrations were used as input data for OPAC software to compute aerosol optical depth (AOD), Ångström's turbidity coefficient (β) and Ångström exponent (α). Air turbidity was also computed using a parameterization based on solar irradiance at ground level and a parameterization between PM_{10} and AOD. The comparison between turbidity values obtained from the Ångström equation and the two different parameterizations have shown differences for the three stations due to different type of pollutant, local pollution sources and weather conditions. Linear relationships between Ångström coefficient and Linke factor were established for each site and compared with those for other worldwide climates.

Key words: air pollution, PM_{10}, Ångström turbidity, Linke factor.

1. INTRODUCTION

The study of aerosol particles has a major importance because of their effects on human health, ecosystems, air quality, visibility at local and regional scales [1–3] and on Earth's radiative balance [4–6]. Aerosols can have both natural (volcanic, sea salt, desert, biogenic etc.) and anthropogenic origins (fossil fuel and biomass burning, traffic etc.). Either natural or anthropogenic, aerosols have effects that depend largely on their atmospheric concentration, size and composition [7]. It is of strong interest to study in more detail the aerosol-solar radiation interaction especially in urban and industrialized regions because of the presence in these areas of the highest levels of aerosols [7]. Among other techniques, aerosol burdens are measured using ground-based instruments such as sun photometers [8]. The main optical parameter provided by sun photometers is the aerosol optical depth (AOD); it gives information about the extinction of solar radiation due to the aerosol present in the atmospheric column above the sun photometer. AOD is related to Ångström's turbidity coefficient β through Ångström relation [9]. Knowledge of both AOD and β is of high interest worldwide for atmospheric composition and air quality researches, key-issues in climate modeling, for agro-meteorology and climatology [10–13]. Solar energy conversion systems technology also requires estimations of air turbidity because the performance of such systems is strongly influenced by the air quality and weather conditions in sense that a high turbidity leads to a reduction of the output electric current of solar cells [14–16]. Atmospheric column AOD can be linked to ground PM_{10} or $PM_{2.5}$ aerosol (aerosol particles with sizes less than 10 μm, respectively less than 2.5 μm) through empirical relationships either directly or using various models based on meteorological parameters [17–19]. Information about atmospheric turbidity can be obtained from radiation and/or aerosol measurements also using ground-based measurements and parameterizations [20–25].

The aim of this paper is to determine the atmospheric Ångström's turbidity coefficient in the same air mass in Bucharest area at three sampling sites with a different pollution level: Cercul Militar (urban pollution dominated by traffic in the very center of Bucharest) and Bucurestii Noi (urban pollution, influenced by construction activities, typical for many areas in developing Bucharest), and Magurele (suburban pollution) in various seasons.

The paper is organized as follows. Some theoretical considerations with regard to Ångström turbidity coefficient β are presented in Section 2. Data and methods used are indicated in Section 3 and the results are detailed and discussed in Section 4. The conclusions end the paper.

2. SHORT THEORETICAL CONSIDERATIONS

The attenuation (due to gases, water vapors and aerosols) of solar radiation that reaches the Earth's surface in absence of clouds can be expressed by atmospheric turbidity that is usually described by two indices: Linke's turbidity factor (LT) and Ångström's turbidity coefficient (β). While LT [26] gives information about the overall spectrally integrated attenuation due to all atmospheric components, β is obtained from spectral measurements and represents an indication of only the aerosol loadings of the atmosphere [9].

The atmospheric turbidity expressed by β is used in atmospheric physics in order to characterize the air mass due to its conservative character, but it is important for the air quality-monitoring field, as well. The spectral range used to characterize the air turbidity is 0.4–0.75 μm. In this range, the aerosols are the dominant atmospheric constituent that determines the extinction of solar radiation (if water vapor contribution is considered negligible). Therefore, the spectral optical parameters of interest are: aerosol optical depth (AOD), Ångström exponent (α) and Ångström turbidity coefficient (β). The relationship between these parameters is described by the Ångström equation [9]:

$$\mathrm{AOD}(\lambda) = \beta \cdot \lambda^{-\alpha} \quad (1)$$

Equation (1) indicates that the Ångström turbidity coefficient β is equal to aerosol optical depth at a wavelength of λ = 1 μm; accordingly, β depends on aerosol concentration and α is related to size of the aerosol particles. Scientific literature indicates β has typical values between 0 (an ideal clean atmosphere) to 0.5 (very turbid atmosphere) with moderate values from 0.1 to 0.3. The exponent α ranges from 0 to 4 [21, 24, 27, 28]. The larger the values of α, the higher the ratio of small to large particle in atmosphere; smaller α corresponds to predominance of larger particle in atmosphere. In most situations, α ranges between 0.5 and 2.5, and a value of 1.3±0.5 is considered as typical for natural atmosphere.

Linke turbidity factor LT represents the number of clean and dry atmospheres necessary to produce the same attenuation of the extra-terrestrial solar radiation that is produced by the real atmosphere. LT varies with air mass even when the atmospheric conditions remain constant and it can vary from 1, clean atmosphere, to 10, a very turbid one [21]. Some relationships between LT and β were previously established [12, 29] and used by many authors [25, 30, 31]. Eltbaakh *et al.* (2012) provides a review of all atmospheric indices and of the models used to determine them [24].

3. DATA AND METHODS

3.1. SITE DESCRIPTION AND DATA USED

The PM_{10} data used in this study was collected during one year (from 01 June 2014 to 31 May 2015) at two sites in Bucharest urban area (Bucurestii Noi and Cercul Militar) and a site in the suburban area (Magurele), whose geographical distribution is presented in Fig. 1. Bucurestii Noi (44.483°N, 26.041°E; 93 m) site describes the urban pollution, influenced by construction activities, typical for many areas in developing Bucharest, Cercul Militar (44.429°N, 26.121°E; 80 m) site characterizes the urban pollution dominated by high traffic in the very center of Bucharest, and the Magurele site (44.349°N, 26.034°E; 72 m) will represent the suburban pollution. Extensive details regarding site description are included in references [32, 33]. PM_{10} mass concentrations were obtained for Bucurestii Noi and Magurele sites by sampling using single-stage low-volume air samplers LVS Sven Leckel, flow rate 2.3 m^3h^{-1}, on quartz fiber filters and stored in laboratory in controlled atmosphere (temperature 20 ± 1°C, relative humidity 50 ± 5%) for at least 48 h before weighing, following the standards SR EN 12341:2002 [34] and SR EN 14907:2006 [35]. The PM_{10} mass concentrations at Cercul Militar site were obtained from Bucharest Environmental Protection Agency. The database also contains the meteorological parameters: temperature, pressure, relative humidity, speed and direction wind, and solar radiation. A database containing 10 values per each month, which replicates the corresponding monthly PM_{10} mass concentration distribution was extracted from the 1-year measurements dataset; this smaller database was investigated in present paper.

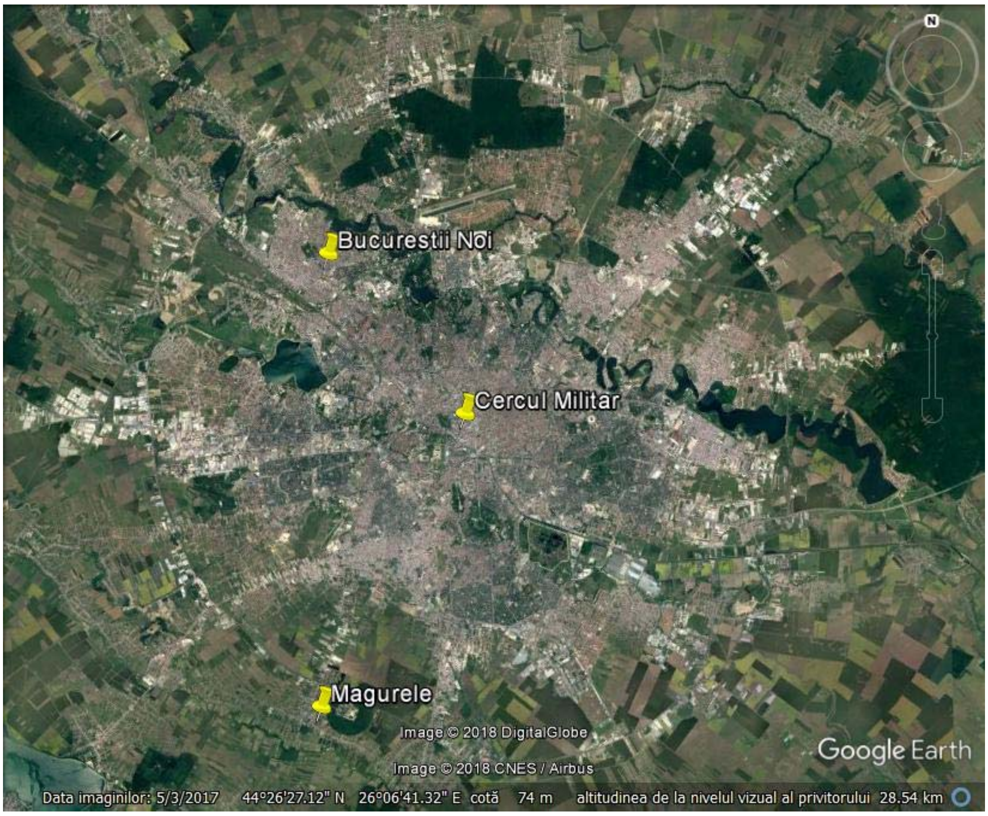

Fig. 1 (color online) – Sampling sites in Bucharest Greater Area.

3.2. METHODOLOGY

PM_{10} mass concentrations at all three sites were then used to compute the AOD at the wavelength of 500 nm, Ångström turbidity β and Ångström exponent α using the OPAC software package model [36] for two spectral ranges (350–500 nm) and (500–800 nm) and next, using the Stefan and Filip parameterization [17], denoted from hereafter the SF model:

$$PM_{10} = 69.9\text{AOD} + 24.99 \tag{2}$$

Equation (2) has been previously derived using ground-level PM_{10} measurements and column AOD from sun photometer recordings at 500 nm. The aerosol type in OPAC model was selected considering the dominant aerosol type for each site and season, namely urban polluted (JJA, SON, MAM) and continental polluted (DJF) for Bucurestii Noi and Cercul Militar and continental average (JJA, SON, MAM) and urban (DJF) for Magurele.

Third, we computed the Ångström turbidity β using the model presented by Djafer and Irbah [25], that combines widely used parameterizations [24, 30] and measurements of local meteorological parameters. We denote it from hereafter DI model. Equation (3) gives us the Ångström turbidity β by DI model:

$$\beta = \frac{\text{TL} - \left[\dfrac{h + 85}{39.5 \cdot \exp(-w_p) + 47.4} + 0.1 \right]}{16 + 0.22 w_p} \tag{3}$$

In DI model, the amount of available precipitation (w_p) is computed from local temperature T and relative humidity RH, as shown in equation (4):

$$w_p = 0.493 \frac{RH}{T} \exp\left(26.23 - \frac{5416}{T} \right) \tag{4}$$

and TL factor is computed using the solar constant (I_0 = 1367 Wm^{-2}), the direct solar irradiance (I_n), the Sun's elevation angle (h), the instantaneous (R) and mean Sun-Earth (R_0) distances and the optical air mass (m_a) at local pressure, as it is shown in equation (5):

$$TL = (0.9 + 9.4 \sin(h)) \cdot \left(2 \ln\left(I_0 \frac{R_0}{R} \right) \right) - \ln(I_n) \cdot f(m_a) \tag{5}$$

where the term $f(m_a)$ is a factor direct dependent on the local optical air mass m_a, as equation (6) indicates:

$$f(m_a) = \frac{6.6296 + 1.7513 m_a - 0.1202 m_a^2 + 0.0065 m_a^3 - 0.00013 m_a^4}{9.4 + 0.9 m_a}\,. \tag{6}$$

4. RESULTS AND DISCUSSIONS

4.1. SEASONAL ATMOSPHERE LOADINGS AT ALL SITES

The seasonal and spatial heterogeneity of PM_{10} measurements is represented in Fig. 2 that indicates a different variability between PM_{10} levels at the urban site

Bucurestii Noi *versus* the Cercul Militar (traffic) and the suburban Magurele sites. An inter-sites comparison during the period June 2014 to May 2015 indicates that highest annual PM_{10} values were found at Bucurestii Noi (52.75 ± 21.75 μg m^{-3}), followed by Cercul Militar (35.11± 16.69 μg m^{-3}) and Magurele (29.87 ± 12.66 μg m^{-3}). In winter 2014–2015 and spring 2015, Bucurestii Noi area had highest PM_{10} mass concentrations.

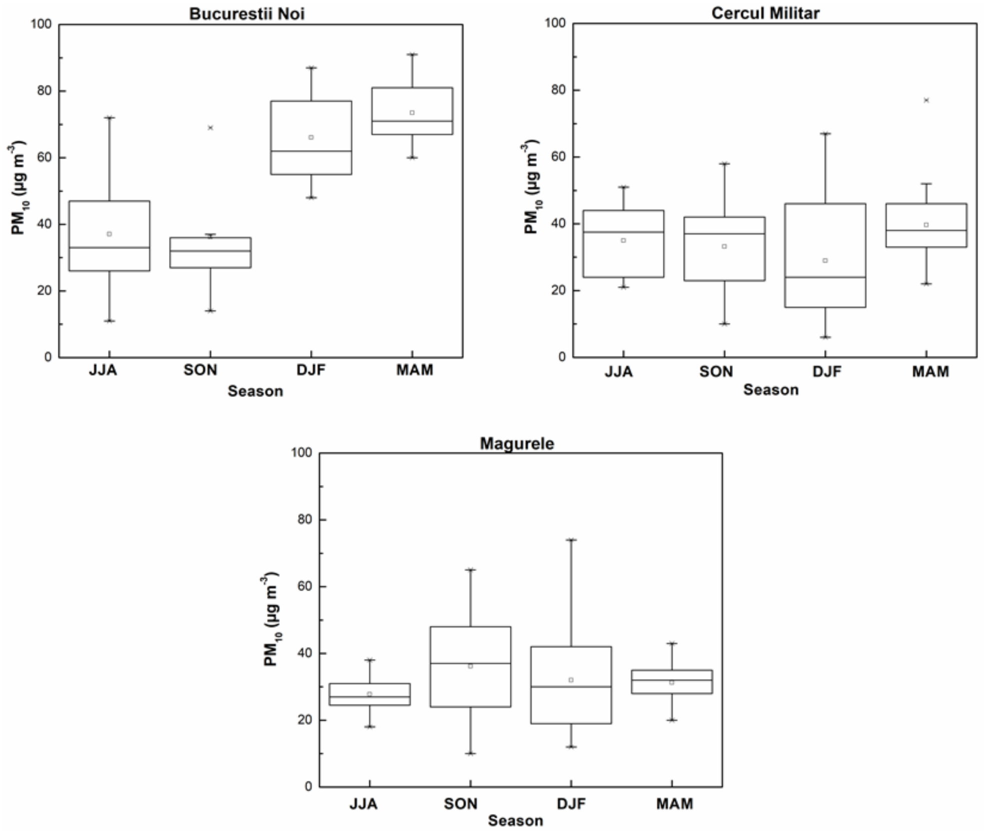

Fig. 2 – Statistics of seasonal PM_{10} mass concentration at all sites (JJA = summer, SON = autumn, DJF = winter, MAM = spring) during the sampling period. Squares indicate mean seasonal values, and the whiskers of the boxplots represent 1% and 99% of values.

This appeared because starting with the beginning of January 2015 the levels of daily PM_{10} mass concentrations were significantly higher than in previous year, due to decreased level of precipitations combined with the local construction activities at the underground line which were kept at the same level as in 2014.

These high PM_{10} concentrations at Bucurestii Noi were also captured in the temporal variation of aerosol optical depth values calculated both using OPAC and SF model, as Fig. 3 shows.

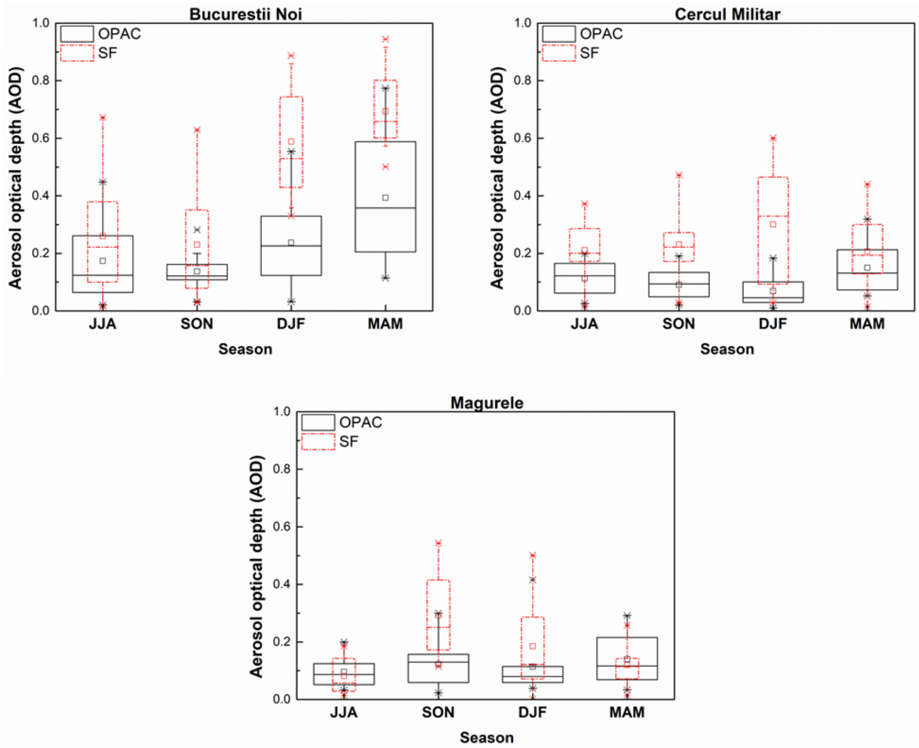

Fig. 3 (color online) – Statistics of seasonal aerosol optical depth at wavelength 500 nm for all sites using OPAC and SF models.

The AOD values generally situate below 0.2–0.3 for all sites, as inferred from both OPAC and SF models. However, SF model overestimates the AOD values predicted by OPAC at sites in the inner city, whereas at Magurele both models give almost the same results in summer and spring. Highest differences between AOD values by both OPAC and SF models can be seen for winter and spring seasons at Bucurestii Noi site. A part of difference in AOD estimations could arise from different way of model inference. The parameterization of SF model was inferred from measurements in Magurele area in May 2010 for particles with $\alpha = 1.3$, whereas OPAC computes $\alpha = 1.19 \div 1.51$ (Bucurestii Noi), $\alpha = 1.19 \div 1.44$ (Cercul Militar), and $\alpha = 1.17 \div 1.49$ (Magurele), indicating therefore variations of particle sizes from site to site with a dominance of fresh, smaller ones.

4.2. MONTHLY AND SEASONAL TURBIDITY AT ALL SITES

The monthly variation of β represented in Fig. 4 shows a pattern of fluctuations that follows the variations in PM_{10} mass concentrations with differences due to each model.

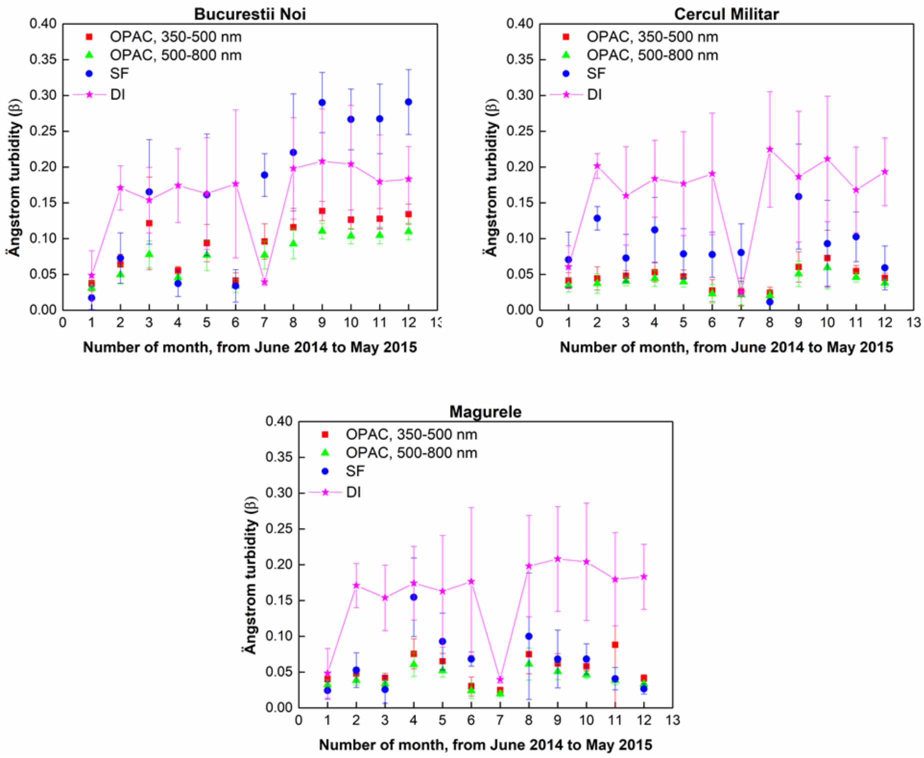

Fig. 4 (color online) – Monthly Ångström turbidity at all sites using OPAC software for spectral ranges of 350–500 nm, and 500–800 nm for RH = 50%, and using SF and DI models.

The monthly variation of β indicates values up to 0.3 at Bucurestii Noi and up to 0.2 at Cercul Militar and Magurele, with two minima in June and December 2014 that correlates quite well with higher winds from northeast and western sectors. Moreover, while June was characterized by a mean relative humidity of about 70% with an average temperature of about 20°C and an incoming solar radiation of 1.5 times higher than that in December 2014, many overcast or nearly overcast days (about 67%) with very elevated relative humidity and lowest temperatures appeared in December (Fig. 5). In this later case, it is more possible that aerosol particles to be scavenged from air as cloud condensation nuclei or to remain as interstitial in fog or cloud [37], leading therefore to a lower amount of aerosol in the atmosphere layer up to cloud base that could contribute to local turbidity. It seems that the superposition of above factors determined β values in the range 0.03–0.1.

Ångström mean annual values of 0.1 (Bucurestii Noi), 0.04 (Cercul Militar) and 0.03 (Magurele) indicate that Bucharest area is characterized by a moderate pollution that spreads out over the surroundings, air pollution pattern that was previously observed in mass concentrations of main pollutants over 6 years of monitoring [32].

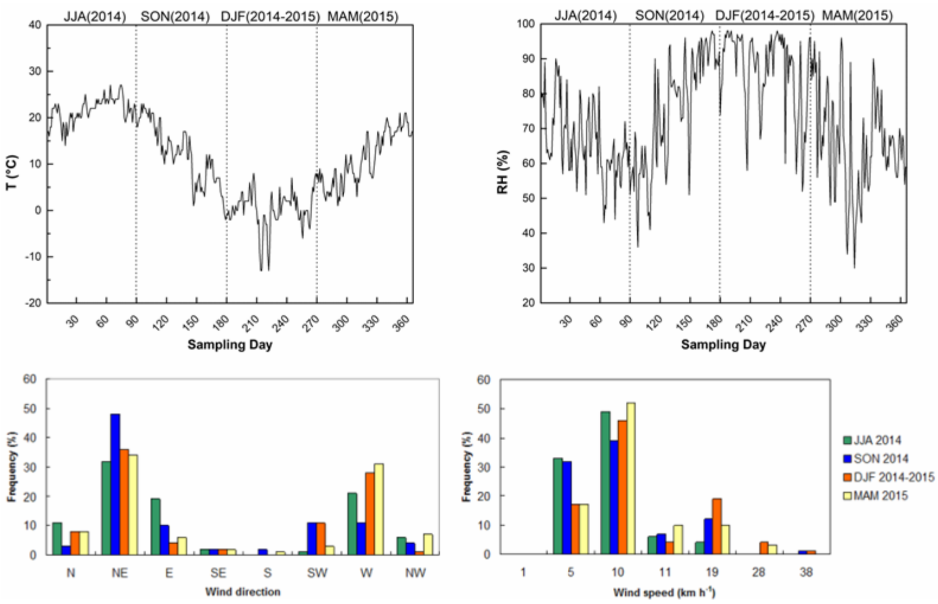

Fig. 5 (color online) – Daily means of observed temperature T (°C) and relative humidity RH (%) and seasonal frequency distribution of wind speed WS (km h^{-1}) and wind direction (sectors).

Seasonal turbidity level calculated in Table 1 indicates highest values in spring in Bucharest inner area and in autumn in its suburban area.

Table 1

Comparison between seasonal averages of Ångström turbidity coefficient for various climates (BN=Bucurestii Noi, CM=Cercul Militar, MG=Magurele)

Site	Bucharest (Romania)			Avignon (France)	Valencia (Spain)	Gardaïa (Algeria)	Dhahran, (Saudi Arabia)	Bahrain
Climate	Temperate			Temperate	Subtropical	Hot desert	Desert	Humid
Season	BN	CM	MG					
JJA	0.084	0.074	0.057	0.160	0.186	0.165	0.153	0.62
SON	0.091	0.078	0.091	0.103	0.125	0.135	0.136	0.25
DJF	0.148	0.088	0.072	0.060	0.046	0.053	0.090	0.13
MAM	0.175	0.095	0.078	0.096	0.076	0.090	0.163	0.41
Mean	0.125	0.084	0.075	0.105	0.108	0.111	0.136	0.353
Reference	This study			[22]	[21]	[25]	[22]	[22]

A comparison with other sites with similar or different climates shows Ångström coefficient in Bucharest is comparable with worldwide turbidity but presents an almost opposite seasonal behavior than turbidity in Avignon, Valencia or Gardaïa and has significantly lower values than those characterizing the very humid climate of Bahrain.

The plot of Ångström coefficient against of Linke factor for three climates is shown in Fig. 6, where for Bucharest we represented the entire dataset from all sites for the whole measurement period.

The equations in Fig. 6 indicate that coefficients for humid and desert climates are very different from that of sites characterized by a temperate climate and only a small difference exists between relationships β-LT in temperate climates when compared the large urban Bucharest with the small rural Avignon.

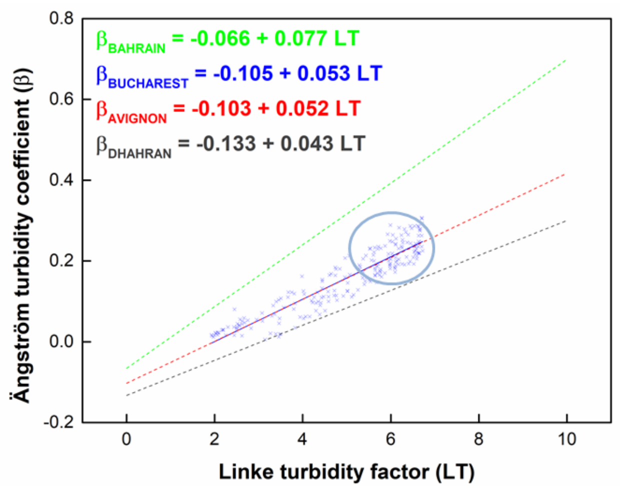

Fig. 6 (Color online) – The relationship between Ångström turbidity coefficient and Linke turbidity factor for various climates [humid (Bahrain), temperate (large urban site, Romania and small rural site, France), desert (Saudi Arabia)].

However, the linear relationship β-LT by measurement site in Bucharest area indicates non-negligible differences both in slopes (0.055 for Bucurestii Noi; 0.052 for Cercul Militar; 0.051 for Magurele) and in intercepts (–0.124 for Bucurestii Noi; –0.097 for Cercul Militar; –0.096 for Magurele). It was clearly found that both the slopes and the intercepts increase (in absolute values) as local pollution increases.

As defined by Linke [26], LT factor describes the optical density of a hazy and humid atmosphere in relation to a pure and dry atmosphere. It means that the attenuation due to scattering and absorption by water vapors of the incoming solar radiation is highly sensitive to the temporal and local variations of water vapor amount in local atmosphere and LT have to indicate it. Scientific literature [26, 38] provides LT values for humid atmosphere of 4 ÷ 6, and LT values above 6 ÷ 7 for polluted air; other literature values [39] give us LT from 1.8 to 2.7 for mountainous areas, depending on the season, LT = 2 ÷ 3 for cold, arctic, continental air and LT = 4 ÷ 5 in case of tropical, warm, continental or maritime air.

We also observe in Figure 6 Linke factor values in Bucharest region from 2 to 7 with a predominance of LT values around 6 and Ångström coefficient of about

0.15 ÷ 0.2, where the density of the determined points on the figure increases. This suggests that in urban Bucharest agglomeration where often the air has a warm tropical nature [17, 32, 33], as the air become more humid, the multiple scattering process is in many times enhanced, and the diffuse radiation predominates.

5. CONCLUDING REMARKS

Based on three models, the atmospheric turbidity was estimated from observations of PM_{10} aerosol mass concentrations, broadband radiation and of meteorological data using three different models. The 1-yearlong variations of estimated turbidity coefficient in Bucharest area for each model (OPAC, SF, DI) have been analyzed. It was found that OPAC and SF models indicate lower values than those obtained using DI model mainly because first two models use ground-based observations on PM_{10} pollution, whereas DI model also adds observations on solar radiation and local meteorological conditions. An exception appears at Bucurestii Noi in spring 2015, when high PM_{10} mass concentrations determined elevated aerosol optical depths. All models capture reasonably well the pollution by aerosol in Bucharest area.

The mean annual values of β (by all models) were determined as follows: 0.1 for Bucurestii Noi, 0.04 for Cercul Militar and 0.03 for Magurele, and a monthly variation of β between sites with values up to 0.3 (Bucurestii Noi) and up to 0.2 (Cercul Militar and Magurele), with two minima in June and December 2014. Due to local climate, geographic conditions and differences in dominant local pollution sources, highest values in spring in Bucharest inner area (up to 0.18) and in autumn in its suburban area (0.1) were determined. Linear relationships between Ångström coefficient and Linke factor were established for each site, compared with those for other worldwide climates and they can serve as models for furthers studies. The study indicates the dominance of diffuse radiation in Bucharest region, as well. Overall, results provide estimations of turbidity by pollution in three locations in Bucharest area, each of them being under the main influence of different pollution sources.

REFERENCES

1. C.A. Pope, D.W. Dockery, J. Air Waste Manag. Assoc. **56**, 709–742 (2006).
2. D.L. Yue, M. Hu, Z.J. Wu, S. Guo, M.T. Wen et al., Atmos. Chem. Phys. **10**, 9431–9439 (2010).
3. G. Iorga, Air pollution monitoring: A case study from Romania, Book Chapter (28 pg) in *Air Quality Air Quality – Measurement and Modeling*, Philip Sallis (Ed.), InTech, DOI: 10.5772/64919 Available from: http://www.intechopen.com/books/air-quality-measurement-and-modeling/air-pollution-monitoring-a-case-study-from-romania (2016).
4. G. Iorga, R. Hitzenberger, A. Kasper–Giebl, H. Puxbaum, J. Geophys. Res. **112**, D01204 (2007).
5. W. Su, N.G. Loeb, G.L. Schuster, M. Chin, F.G. Rose, J. Geophys. Res. 118, 655–669 (2013).
6. M. Mallet, F. Dulac, P. Formenti, P. Nabat, J. Sciare et al., Atmos. Chem. Phys. **16**, 455–504 (2016).

7. J.H. Seinfeld, and Spyros N. Pandis, *Atmospheric chemistry and physics: From air pollution to climate change*, Hoboken, N.J, J. Wiley 2006.
8. B.N. Holben, T.F. Eck, I. Slutsker, D. Tanre, J.P. Buis, A. Setzer, E. Vermote, J.A. Reagan, Y.J. Kaufman, T. Nakajima, et al., Remote Sensing Environ. **66**, 1–16 (1998).
9. A. Ångström, Geograph. Analysis **11**, 156–166 (1929).
10. L. Wang, G. A. Salazar, W. Gong, S. Peng, L. Zou, A. Lin., Energy **81**, 67–73 (2015).
11. C. M. dos Santos, J. F. Escobedo, Atmos. Res. **181**, 312–321 (2016).
12. A. B. Othman, K. Belkilani, M. Besbes, Energy Rep. **4**, 101–109 (2018).
13. Y. Marif, Y. Chiba, M.M. Belhadj, M. Zerrouki, M. Benhammou, Energy Rep. **4**, 84–90 (2018).
14. A.Q. Mallik, Renew. Energ. **21**, 537–552 (2000).
15. M. El-N. Adam, E. F. El-Nobi, World Environ **7**, 1–9 (2017).
16. R. H. Inman, J. G. Edson, C. F. M. Coimbra, Solar Energy **117**, 125–138 (2015).
17. L. Filip, S. Stefan, J. Atmos. Solar Terrestrial Phys. **73**, 1883–1889 (2011).
18. J. Xin , Q. Zhang, L. Wang, C. Gong, Y. Wang et al, Atmos. Res. **138**, 179–188 (2014).
19. S. Voinea, G. Manolache, G. Iorga, S. Stefan, Rom. Rep. Phys. **70**, 705 (2018).
20. R.J. Polavarapu, J. App. Meteorol. **17**, 1368–1374 (1978).
21. J. Cañada, J.M. Pinazo, J.V. Bosca, Renew. Energy **3**, 621–626 (1993).
22. W.E. Alnaser, N.S. Awadalla, Earth, Moon and Planets **70**, 61–74 (1995).
23. H. Che, Z. Yang, X. Zhang, C. Zhu, Q. Mac et al., Atmos. Environ. **43**, 1093–1099 (2009).
24. Y.A. Eltbaakh, M.H. Ruslan, M.A. Alghoul, K. Sopian, Renew. Sustain. Energ. Rev. **16**, 6285–6294 (2012).
25. D. Djafer, A. Irbah, Atmos. Res. **128**, 76–84 (2013).
26. F. Linke, Beitr. Phys. Atmos. **10**, 91–103 (1922).
27. Y.J. Kaufman, *Remote sensing of direct and indirect aerosol forcing*, (Ed.) Heintzenberg, R.J., Aerosol forcing of climate, John Willev, p. 297–334 (1995).
28. T.F. Eck, B.N. Holben, J.S. Reid, O. Dubovik, A. Smirnov et al., J. Geophys. Res. **104**, 31333–31349 (1999).
29. R. Dogniaux, *Representation analytiques des composantes du rayonnement lumineux solaire. Conditions du ciel serein*. Ed. Inst. Royal de Meteorologie de Belgique, A 83, 3–24 (1974).
30. M. Cucumo, V. Marinelli, G. Oliveti, Renew. Energ. **17**, 397–410 (1999).
31. G. Lopez, F.J. Batlles, Ann.Geophys. **22**, 2657–2668 (2004).
32. G. Iorga, G.C. Balaceanu (Raicu), S. Stefan, Atmos. Poll. Res. **6**, 824–834 (2015).
33. G. Manolache, S. Stefan, G. Iorga, Rom. J. Phys., **64**, 808 (2019).
34. Asociatia de Standardizare din Romania (ASRO), SR EN12341:2002, *Air quality-determination of the PM10 fraction of suspended particulate matter – reference method and field test procedure to demonstrate reference equivalence of measurement methods,* Bucharest, 2012.
35. Asociatia de Standardizare din Romania (ASRO), SR EN14907:2006, *Ambient air quality. Standard gravimetric measurement method for the determination of the PM2.5 mass fraction of suspended particulate matter*, Bucharest, 2006.
36. M. Hess, P. Koepke, I. Schult, Bull. Am. Meteorol. Soc. **79**, 831–844 (1998).
37. S. Stefan, *Fizica aerosolului atmosferic*, Edit. All, Bucharest 1998.
38. F. Kasten, VDI Bericht, No. 721 (1989).
39. S. Becker, Int. J. Climatol. **21**, 1561–1576 (2001).