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Aerosol Microtops II sunphotometer observations over Ukraine

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Atmospheric aerosols and their impact on climate study are based on measurements by networks of ground-based instruments, satellite sensors, and measurements on portable sunphotometers. This paper presents the preliminary aerosol characteristics obtained during 2009-2012 using portable multi-wavelength Microtops II sunphotometer. Measurements were collected at different Ukraine sites in Kyiv, Odesa, Lugansk, Rivne, Chornobyl regions. The main aerosol characteristics, namely aerosol optical thickness (AOT) and Angström exponent, have been retrieved and analyzed. Aerosol data processing, filtering and calibration techniques are discussed in the paper.

Key words: aerosol, atmosphere, Angström exponent, database

INSTRUMENT AND METHOD

The Microtops II is a portable hand-held sunphotometer for direct solar irradiance measurement in different wavelengths (see e. g. [5, 8]). Four instruments with different spectral channels were used during observations: two instruments equipped with filters for wavelengths 440, 500, 675, 870 and 936 nm; one for 440, 675, 870, 936 and 1020 nm, and one for 340, 440, 675, 870 and 1020 nm. The Microtops II advantages are: high accuracy, portability, simplicity in use, and low cost. Furthermore, the instrument can be linked directly to a hand-held GPS receiver via a serial cable, which allows carrying out observation at different sites. Obtained characteristics include information on time and location, pressure, temperature, Sun-Earth distance, and the signal from photodetectors. The aerosol optical thickness (AOT) calculations are performed using a microprocessor. The instrument can store information of 800 measurements before data have to be transferred to computer as ASCII files. The aerosol characteristics obtained from Microtops II measurements include AOT, Angström exponent and precipitable column water vapour. AOT value is determined according the Bouguer-Lambert-Beer law:

$$I_\lambda = I_{0\lambda} D^{-2} \exp^{-\tau_\lambda \mu}, \qquad (1)$$

where I_λ is the intensity of the light at the wavelength λ at the observation site, $I_{0\lambda}$ is the intensity of the light without the Earth atmosphere, D is the Sun-Earth distance in astronomical units at the time of observation, τ_λ is the optical thickness of all atmosphere components, and $\mu = \sec\theta$ is the air mass, where θ is the solar zenith angle. The optical thickness values were calculated for each direct measurement of the solar irradiance, for different air masses [8].

Angström exponent is used to estimate the dependence AOT on the λ. Angström exponent is related to the particle size distribution and depends on the ratio of the concentration of small to large aerosols. If the Angström exponent is close to or less than 1.0, then the coarse mode of aerosol particles dominates in the atmosphere (with particle diameters 1-10 μm), and if it is greater than 1.5, the fine mode dominates (with particle diameters of 0.01-1 μm).

DATA PROCESSING

Four Microtops II sunphotometers were used during the measurement period. Dedicated software with three-stage data processing was developed, and three different levels of data quality were formed. They are analogues of AERONET data levels[1], which consist of: raw measurements (level 1.0), cloud-screened data (level 1.5), and re-calibrated data (level 2.0). The sunphotometer calibrations were performed using the Langley plot technique, using the method of transfer calibration with the data obtained by sunphotometer CE318-2 (which has been located at the AERONET Kyiv site since

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[1]http://aeronet.gsfc.nasa.gov/

March 2008) [4].

The data of all observations from the Microtops II instrument were presented similarly to raw level 1.0 data. The level 1.5 data measurements were constructed from observations filtered from haze, cloud and inaccurate pointing measurements. Dedicated software with three types of data filtering was developed for measurement reconstruction for all spectral bands. The first filter removes cloud screening data that are beyond 2σ range of session (five measurements) mode AOT. The second filter expels measurements that are beyond 2σ range of session mean AOT, and the third filter removes data beyond the 2σ range of the daily mean AOT. The Langley method (see e. g. [3, 7]) was used for calibrating the sunphotometer. From (1) we have:

$$\ln(V_\lambda) = \ln(V_{0\lambda} D^{-2}) - \tau_\lambda \mu. \qquad (2)$$

In equation (2): V_λ is the signal from photodetectors measured by the instrument, $V_{0\lambda}$ is the signal from photodetectors without atmosphere. The value $\ln(V_\lambda)$ exhibits a linear dependence, with slope $-\tau_\lambda$ and intercept $\ln(V_{0\lambda} D^{-2})$. The $\ln(V_{0\lambda} D^{-2})$ value was retrieved using the Langley plot, and the value $V_{0\lambda}$ is the new calibration constant determined from the intercept.

In order to verify Microtops II measurement reliability, a cross-calibration was performed through transferring parameters from the more accurate AERONET sunphotometer, e. g. CIMEL CE318 of the Kyiv site (see e. g. [6, 3]). The light intensity measured by both instruments must be the same for simultaneous measurements at the same site. Then, using (1) for the ratio of the CIMEL CE318 signal and the Microtops II signal, the correction constant $V_{0\lambda}^{Mic}$ for the Microtops II sunphotometer was determined from equation:

$$V_\lambda^{CIM} / V_\lambda^{Mic} = V_{0\lambda}^{CIM} / V_{0\lambda}^{Mic}. \qquad (3)$$

New verified data were formed in the new set of level 2.0 data, following the calculation and insert of the new calibration constants. Next, the optical thickness of Rayleigh scattering was re-calculated (see e. g. [1]).

Aerosol distribution and behaviour data in the atmosphere over Ukraine for the period of 2003-2011, obtained from the satellite POLDER/PARASOL and POLDER-2/ADEOS-2 measurements and AERONET ground-based sunphotometer data, were analysed earlier [2]. In this paper, the study of aerosol optical characteristics in several Ukrainian regions, using Microtops II level 2.0 measurements, is discussed.

OBSERVATION RESULTS AND CASE STUDIES

Microtops II sunphotometer observations were conducted in several regions of Ukraine with the purpose of studying two main aerosol characteristics: AOT and Angström exponent. The mean AOT and Angström exponent values were averaged over the observation period and calculated for Odesa, Lugansk, Chornobyl and Rivne regions. These measurements are presented in Tables 1 – 4. Angström exponent has been calculated using measurements at 440 nm and 870 nm wavelengths.

The observations in Kyiv city were carried out on a regular basis for the entire four-year duration (see Fig. 1, Fig. 2). There was an increase AOT value observed in May every year, and in June 2010 and July 2011-2012. The peaks of Angström exponent value at 1.6±0.6 and 1.99±1.0 were observed in August of 2011 and 2012, respectively. This trend can be explained by a decrease in humidity and an increase in industrial and transport emissions in the Summer.

The measurements in Odesa (see Table 1) show the main aerosol characteristic peaks in August 2010 which correspond to a period of forest and peat wildfires in Russia. Comparing Aerosol characteristics over Kyiv and Odesa sites gives similar AOT values for the same period. For example, AOT at the 870 nm wavelength are approximately 0.09 over Kyiv in the period from 21 to 25 July 2009, and are 0.13 over Odesa in the period from 26 to 30 July 2009. Similar results were obtained in 2010, when the AOT value over Odesa (period from 15 to 18 September) was close to 0.14, versus a value of 0.09 over Kyiv (from 19 to 21 September). The results of South to North transect between Odesa and Kyiv, made on November 21, 2009, are presented in Fig. 3 and Fig. 4. AOT values grew in proximity to Kyiv (see Fig. 3) with minimum values near Uman region. Angström exponent plot (see Fig. 4) shows increasing of the aerosol coarse fraction in the Kyiv region.

The measurements in Lugansk from July 1 to October 31, 2010 with Microtops II are shown in Fig. 5 and Fig. 6. Aerosol characteristic monthly means are presented in Table 2. Using the back-trajectory analysis it was defined that high AOT values in the first half of July are explained by the industrial airmass coming from the central region of Ukraine. Airmass from South-West Russian regions and the North Caucasus was observed over Lugansk site from July 14 to August 13. AOT maximum values (see Fig. 5) were observed between August 14 and 18, 2010. This peak can be explained by the airmass transport from forest and peat wildfire territories in Russia. This has been confirmed by back-trajectory analysis of the Lugansk data. For example, in August 12 the observed AOT was equal to 0.18 at 870 nm, and on August 14 AOT values increased to 0.5. After August 18, the wind direction changed and the airmass from North-West and North regions of Ukraine was observed over Lugansk. AOT values decreased and reached minimum in November 2010. The Angström exponent that month demonstrated low values (approximately 0.18, see Table 2), which

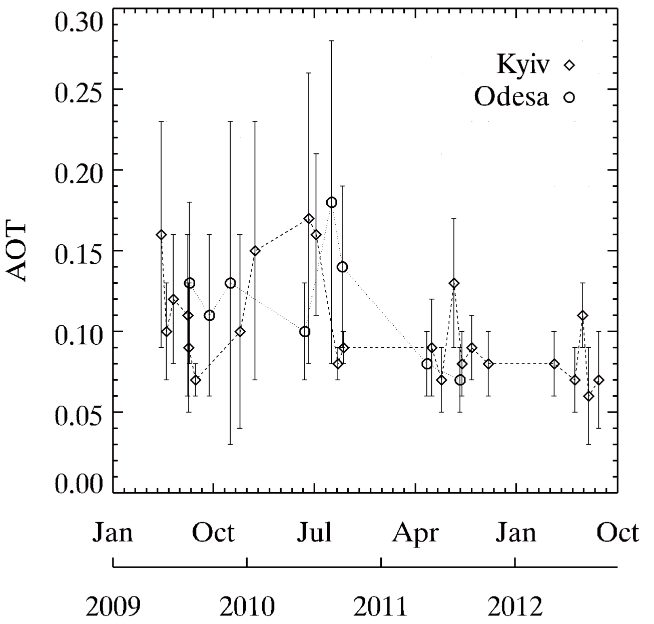

Fig. 1: AOT mean values at wavelength 870 nm for all periods of observation in Kyiv and Odesa.

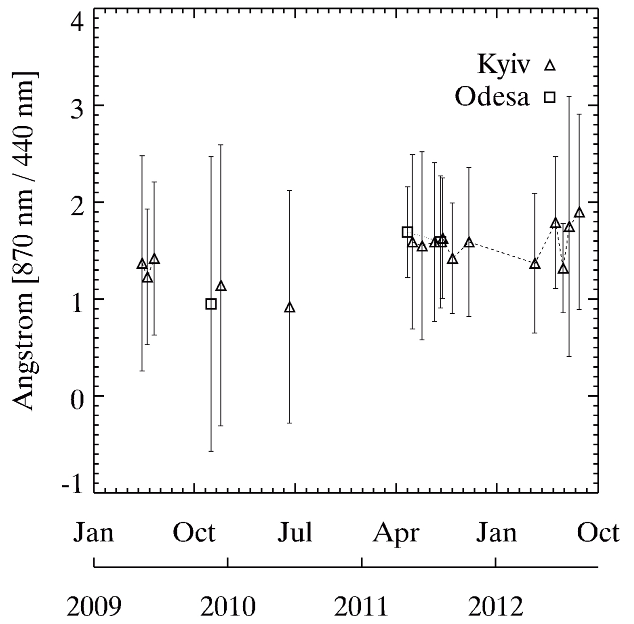

Fig. 2: Angström exponent values between 440 nm and 870 nm for all perionds of observation in Kyiv and Odesa.

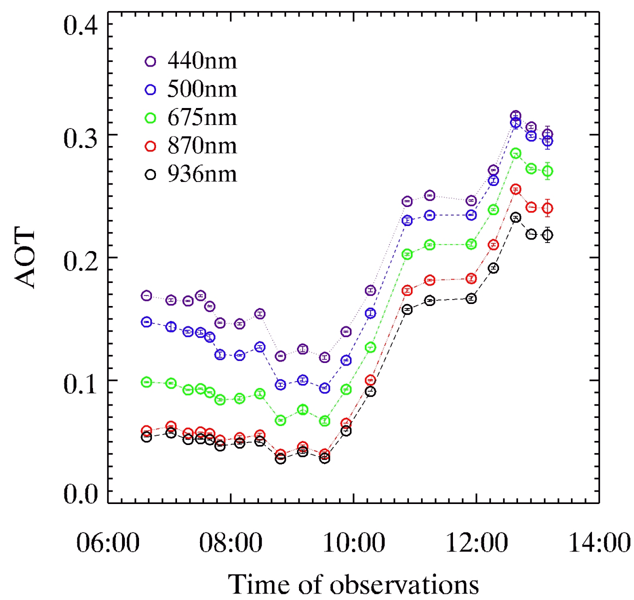

Fig. 3: AOT values during Odesa – Kyiv transect measurements in November 21, 2009.

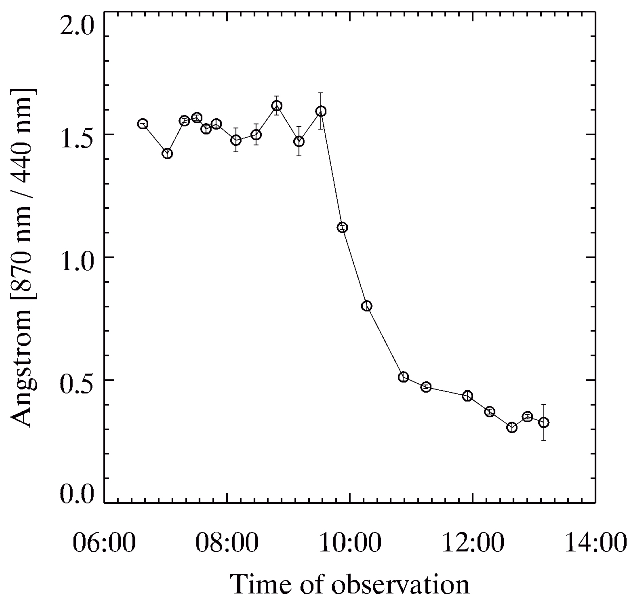

Fig. 4: Angström exponent values during Odesa – Kyiv transect measurements in November 21, 2009.

indicates the dominance of coarse-mode aerosol particles. In August the Angström exponent values in Lugansk increased to 1.3 and became similar to the values measured in Kyiv in the same period by the AERONET sunphotometers. It should be noted that the fine-mode aerosol particles, produced by biomass burning, was registered over Ukraine in mid-August 2010.

There were three field campaigns (see Table 3) of observation in the Chornobyl region in the spring-summer season. Aerosol mean characteristics (AOT and Angström exponent) exhibit similar values in all periods of spring observations. Angström exponent values show that aerosol particles probably have the same physical properties. AOT values decreased at all wavelengths, while the Angström exponent increased in the end of June. More observation is needed to postulate the explanation of phenomena of Angström exponent increasing and AOT decreasing in mid-summer. There were two summer and one autumn short observation periods in Rivne (see Table 4). In the other cities, larger AOT and Angström exponent values were observed in summer period than in autumn. Angström exponent values are close to 1.6, which shows dominance of fine-mode particles over Rivne in the summer season.

Microtops II measurements were provided during the Central Ukraine trip from June 14 to 18, 2009. The most interesting result was obtained on June 16, when observations were carried out along the road from the Khotsky village in the Kyiv region to Dnipropetrovsk city (see Fig. 7, Fig. 8). AOT value peaks were observed near Pershotravneve village (between 7 and 8 at the morning), at Kremenchuk city (close to 11 o'clock) and near Myrushyn Rig (at midday). Measurements were carried out over Kremenchyk (a large industrial city) from 9 to 11 o'clock, in which data exhibits aerosol pollution increasing. The Angström exponent value has a minimum (see Fig. 8) that hours.

Other transect measurements were made during the East Ukrainian trip on August 16–21, 2011. Results of that observation are shown in Fig. 9. Larger AOT values are seen in the Lugansk region (August 17–19). Significant decreasing of AOT data corresponds to observations in Zaporizhia (August 19–20) and Kryviy Rig (August 21). On thosed days the atmosphere cleared due to August 16 rainfall in Kryvyi Rig and a thunderstorm August 17 in Zaporizhia. The Angström exponent (see Fig. 10) was decreased those days, which corresponded to the reduction of fine-mode of aerosol as a result of the rain.

The comparison of the measurement results in Kyiv and Odesa shows larger AOT values over Odesa in 2009 and 2010, and similar aerosol characteristics in 2011 (see. Fig. 1, 2). Comparison of the data measured in Kyiv, Lugansk and Odesa in summer-spring period of 2010 shows similar AOT values over Kyiv and Lugansk and slightly higher values over Odesa. Measurement results in Rivne exhibit aerosol characteristics close to data obtained in Kyiv and Odesa. The atmosphere in the Chornobyl region was cleanest in the summer time (see Table 3). Observed Angström exponent values were 1.5 on average over all regions except Lugansk (results show coarse-mode particle domination). Heavy industrial emissions in the Eastern region of Ukraine can explain these relatively low Angström exponent values.

CONCLUSIONS

The first results of the Microtops II sunphotometer measurements in several Ukrainian regions show the reliability of the instrument and method, as well as the appropriate skill of observers. The software with three stage data selection was developed for sunphotometer data processing. The algorithm allows to create a database with different levels of data quality: the raw data of level 1.0, the cloud screened data of level 1.5, and the finally re-calibrated data of level 2.0. The Langley plot calibration and the intercalibration with the Kyiv AERONET CIMEL CE318-2 instrument was applied to Microtops II sunphotometer measurements to improve the data quality. Measurement results show similar average AOT values over all areas except Chornobyl region where the values were lower. Angström exponent values were similar in all regions except Lugansk, which exhibit domination of fine-mode particles. Coarse-mode dominated over Lugansk region in the Summer of 2010. The preliminary Microtops II measurement results show that aerosol pollution over Ukraine is similar to mean values in Europe and 3–5 times less than, for e. g., in India or China industrial regions. AOT values vary from 0.05 to 0.21 for the 870 nm spectral channel, for all periods of observation except the Summer 2010 period of wildfires in Russia, during which AOT increased to 0.7. The fine aerosol fraction prevailed in the atmosphere over Ukraine according the Angström exponent retrievals.

ACKNOWLEDGEMENT

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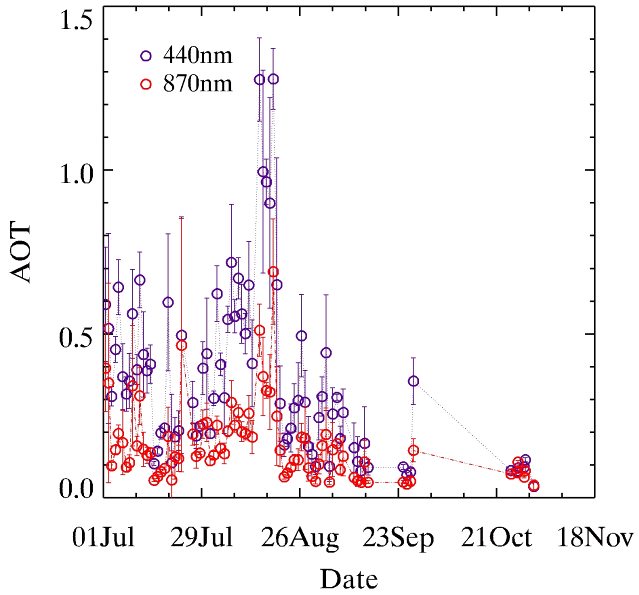

Fig. 5: AOT values variation over Lugansk, observations in 2010.

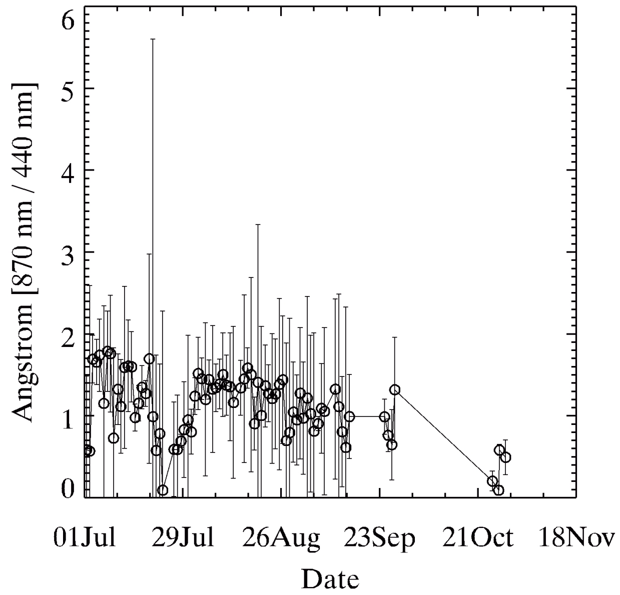

Fig. 6: Angström exponent values variation in 2010 over Lugansk.

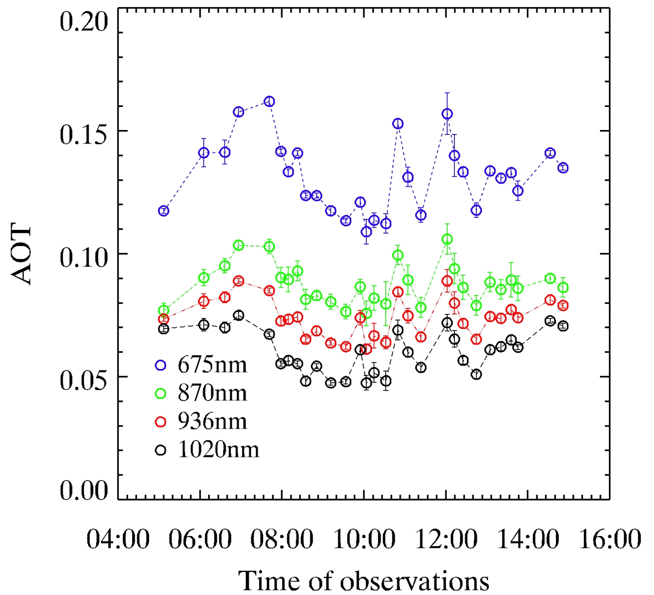

Fig. 7: AOT values during the trip from Kyiv to Dnipropentrovsk in June 16, 2009.

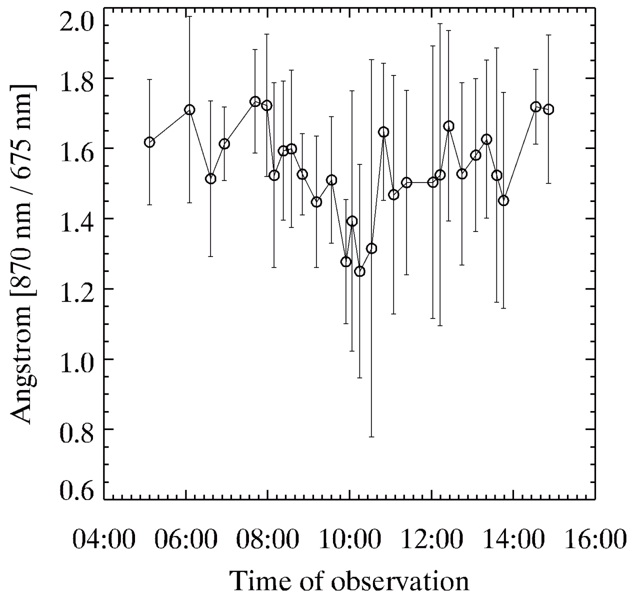

Fig. 8: Angström exponent values during the trip from Kyiv to Dnipropentrovsk in June 16, 2009.

Table 1: Aerosol characteristics in the atmosphere over Odesa

Period	AOT					Angström exponent
	440 nm	675 nm	870 nm	936 nm	1020 nm	
26.7.2009–30.7.2009		0.18±0.06	0.13±0.05	0.12±0.05	0.11±0.05	
25.8.2009–15.10.2009		0.16±0.06	0.11±0.05	0.11±0.05	0.11±0.05	
13.11.2009–19.11.2009	0.25±0.09	0.17±0.10	0.13±0.10	0.12±0.09		0.95±1.53
28.5.2010–15.6.2010		0.14±0.05	0.10±0.04	0.12±0.04	0.13±0.05	
12.8.2010–26.8.2010		0.25±0.15	0.18±0.10	0.17±0.09	0.16±0.07	
15.9.2010–18.9.2010		0.20±0.09	0.14±0.05	0.14±0.05	0.15±0.04	
5.5.2011–6.5.2011	0.27±0.04	0.15±0.02	0.09±0.02		0.08±0.02	1.69±0.47
1.8.2011–6.8.2011	0.20±0.05	0.11±0.02	0.07±0.02		0.07±0.01	1.59±0.68

Table 2: AOT and Angström exponent values in the atmosphere over Lugansk

Period	AOT					Angström exponent
	440 nm	500 nm	675 nm	870 nm	936 nm	
1.7.2010–31.7.2010	0.36±0.14	0.32±0.12	0.23±0.09	0.18±0.08	0.16±0.08	1.06±1.22
1.8.2010–31.8.2010	0.51±0.26	0.45±0.23	0.31±0.15	0.21±0.10	0.19±0.09	1.31±1.55
1.9.2010–31.9.2010	0.19±0.10	0.17±0.08	0.14±0.06	0.09±0.05	0.09±0.04	1.01±1.38
1.10.2010–31.10.2010	0.08±0.02	0.10±0.02	0.11±0.02	0.07±0.02	0.07±0.01	0.18±0.50

Table 3: Aerosol characteristics in the atmosphere over Chornobyl region

Period	AOT					Angström exponent
	340 nm	440 nm	675 nm	870 nm	1020 nm	
3.6.2009–6.6.2009	0.23±0.07	0.20±0.05	0.12±0.03	0.07±0.02	0.05±0.02	1.55±0.78
30.5.2011–3.6.2011	0.26±0.12	0.18±0.08	0.10±0.04	0.06±0.02	0.06±0.02	1.61±1.18
25.5.2012–3.6.2012	0.26±0.05	0.20±0.04	0.12±0.02	0.07±0.02	0.08±0.01	1.58±0.56
23.6.2012–24.6.2012	0.25±0.06	0.18±0.03	0.10±0.01	0.05±0.01	0.06±0.01	1.92±0.51

Table 4: AOT and Angström exponent values in the atmosphere over Rivne

Period	AOT					Angström exponent
	340 nm	440 nm	675 nm	870 nm	1020 nm	
27.6.2011–5.7.2011	0.42±0.10	0.30±0.07	0.16±0.04	0.10±0.03	0.11±0.03	1.60±0.77
10.9.2011–13.9.2011	0.29±0.07	0.21±0.05	0.12±0.02	0.08±0.01	0.08±0.02	1.48±0.63
4.7.2012–11.7.2012	0.40±0.09	0.29±0.07	0.16±0.04	0.10±0.03	0.09±0.03	1.63±0.76

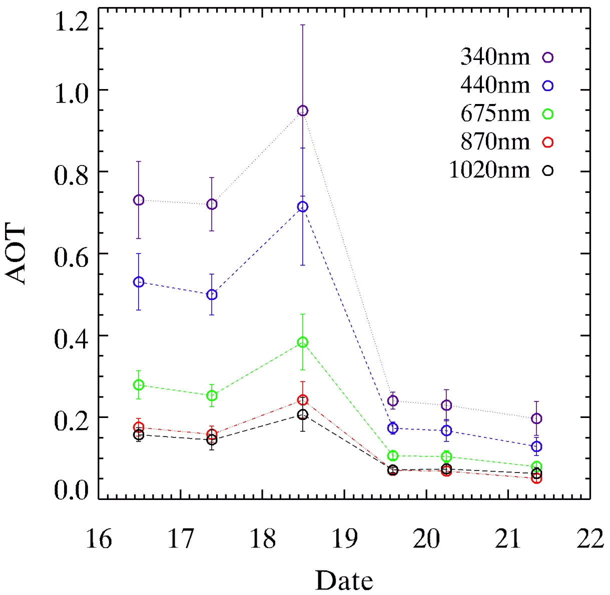

Fig. 9: AOT values during the East Ukrainian transect at August 2011.

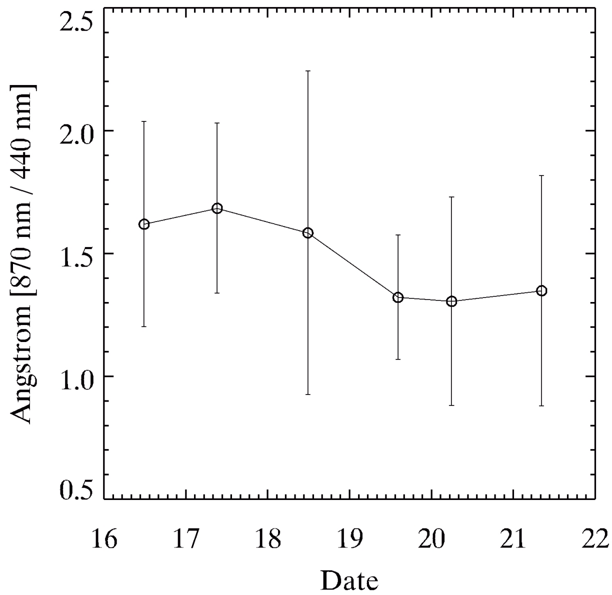

Fig. 10: Angström exponent values during the East Ukrainian transect at August 2011.