Sahara dust events over South-Western Bulgaria during the late spring of 2013

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SAHARA DUST EVENTS OVER SOUTH-WESTERN BULGARIA DURING THE LATE SPRING OF 2013

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Abstract

The Basic Environmental Observatory (BEO) at Moussala peak is the main site for permanent uninterrupted in-situ observations of atmospheric aerosol properties in south-eastern Europe. It is a region, which suffers a very severe impact of Sahara dust storms due to a long-range air mass transport. Despite the large distance away from the southernmost part of the region, direct Sahara dust events (SDEs) are common for the BEO site, mainly during late winter and spring. Moreover, in many cases particles of Saharan origin have been detected over Moussala, mainly after a SDE occurring over central and south-eastern Europe. This paper reports seven events registered at Moussala BEO by a 3563 TSI Nephelometer during the period between April 1 and June 30, 2013. The impact is also estimated quantitatively of the mineral dust particles on the overall optical depth for the period reported.

Key words: aerosols, optical depth, mineral dust, sahara dust events, SDE, nephelometer

Introduction. The atmospheric aerosol particles have a major impact on Earth's radiative balance. Most of the important sources of atmospheric aerosols are natural, such as volcano ash, sea salt and mineral dust from deserts. Their contribution is with pre-industrial history and is expected to expand with the global climate change. Especially in the case of mineral dust, the model predictions and estimations of its contribution to atmospheric aerosols are very sensitive to the climate, landscape, air mass transport and carbon dioxide [1].

Sahara desert is the most important region as a source of mineral dust, the estimates being obtained show that it contributes to almost a half of the mineral dust contents. Aerosol particles of large size of Saharan mineral dust origin travel in all directions over large areas. The local events of their transport in the atmosphere are known as Sahara dust events (SDEs). Neighboring Europe,

HPC computing systems of the Institute of Information and Communication Technologies – BAS are used for data processing (`gta.grid.bas.bg`).

mainly in its southern part, is exposed most frequently to SDEs; the outbreaks there reach up to about 1/3 of the daytime. However, since Europe's area exposed to SDEs is very large, the seasonal intensities differ from west to east. The total contribution to the concentration of particles with aerodynamic diameter up to 10 micrometers (PM10) is also geographically different, but is relatively high over the whole southern part of the continent [2, 3].

The Balkan peninsula is the main region in south-eastern Europe exposed to very strong intensities of SDEs of African origin. It is separated from East Sahara by the Mediterranean Sea; the parts closest to Africa being southern Greece with the Ionian islands, Cyprus and Turkey. South-western Bulgaria is located in the central part of the peninsula, where the SDEs intensities are weaker than in most of the peninsula's southern parts. However, despite the larger distances, the seasonal pattern with highest intensities in spring and early summer is retained and rainfalls with mineral dust are not unusual, especially in the highest sites. Such a site is Moussala peak (2925 m a.s.l., 42.11′N, 23.35′E) where the BEO is located. Because of the high altitude and the remoteness from sources of industrial pollutants, such as black carbon, the site is the best location for detection of long-distance particle transport. This report is based mainly on aerosol data obtained by a 3563 TSI Nephelometer installed in the observatory. The results are confirmed by satellite data from the AIRS satellite. The SDE over Sofia on May 29th 2013 is also confirmed independently by ceilometer-lidar measurements in Sofia during the period reported [4].

Methodology. The light scattering measurements at the three wavelengths of 450, 550 and 700 nm by an integrating nephelometer at Moussala BEO began in 2006. The Continuous Light Absorption Photometer (CLAP) was added in 2012. The nephelometer has operated almost uninterruptedly, its winter operation being supported by a permanent inlet heater. The data acquired consist of continuous one-minute time series; they are reviewed regularly for measurement irregularities. These observations have provided the first reliable assessment of the free troposphere conditions in the region [5].

The data time series used in this report were pre-processed by a data quality procedure. Thus, the data of intensive parameters were restricted only to measurements performed at ambient relative humidity of less than 95%. All data beyond this humidity threshold were removed, so that extremely low concentrations and the noise related to them were neglected. Finally, the data were processed by a 55-minute time window (the size of data between two segmentations of the nephelometer) auto-regressive ARMA filter with a three-sigma confidence interval for removal of outliers [6].

As a quantitative measure for SDE detection, we used the scattering and absorption data at the wavelength of 550 nm only. For qualitative estimation, the corresponding Angstrom exponent (AE) was used, calculated for the 550 nm and 750 nm pair as [5]:

$$\alpha = -\ln(\sigma_1/\sigma_2)/\ln(\lambda_1/\lambda_2),$$

where σ is the scattering coefficient and λ is the wavelength.

The selected parameters are sufficient for a quick detection of a SDE arrival with a high level of confidence and for estimation of the dust contribution in terms of intensities and quality. AE values of less than unity, with even possible negative values, are a good measure for the presence of dry mineral dust particles [7, 8]. Thus, a SDE arrival is assumed when the AE and the absorption and/or total scattering diverge simultaneously, the former with a sharp drop, the latter with higher values. For automatic detection of a synchronized response figure of merit in time (FMT) is used for time series $M(\bar{x}, t_i)$ and $P(\bar{x}, t_i)$ for a fixed location x and time t:

$$FMT(\bar{x}) = \frac{\sum_i \min(M(\bar{x}, t_i), P(\bar{x}, t_i))}{\sum_i \max(M(\bar{x}, t_i), P(\bar{x}, t_i))}.$$

The FMT is not a quantitative method, but it evaluates for a fixed location the overlapping concentration histogram, as normalized to the time series of the maximum concentration. For our case, the AE trend is inverted as $\exp(-a)$ and both time series are normalized between 0 and 1.

The results obtained were confirmed by satellite data and traced back to the origin with back trajectories computed by HYSPLIT [9,10]. The dust source was confirmed once again by satellite data, namely, dust score data computed from several different infrared channels of NASA Aqua/AIRS satellite [11]. The score values larger than 360 indicate the existence of mineral dust. However, this score should not be assumed as being a quantitative measure since this satellite is not trained on the Balkan Peninsula territory. Thus, the dust scores with flag for land uncertainties equal to -1 over Moussala were only considered as a qualitative confirmation of SDE detection, rather than a quantitative measure. The wrongness due to clouds were excluded because of very high error [11].

SDE events over Moussala. During the period between April 1st and June 29th, four SDE events were confirmed by the FMT method for a 30-min moving data window. In addition, three alleged African mineral transports were registered with low concentrations of particles, one in May and two in June, without a direct SDE (Fig. 1). We assumed that a SDE had occurred if consecutive series had been registered of FMT values higher than 0.12 and with a time of persistence of more than 3 h.

The first SDE was registered on April 5th, with time of arrival between 00 and 01 UTC. It lasted for almost two days with weak concentrations. It was confirmed only in the beginning by midnight sattelite data and missed by the next scans. The peak of SDE was registered over Greece and western Turkey; its arrival over Moussala may thus be assumed as part of its most distant and weak northward boundary. The next two SDEs with only one day separation were registered over Moussala on May 16th–17th and 19th–21st. Despite being more

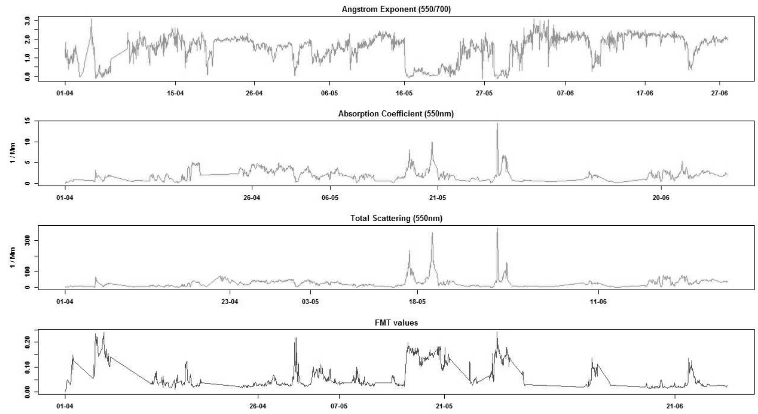

Fig. 1. From the top down – one-hour time averages for the period April 1st, 2013 to June 26th, 2013 of the Angstrom exponent (550/700 nm), absorption coefficient (550 nm), total scattering (550 nm) and computed FMT values for the pair Angstrom exponent and absorption coefficient

intensive and persisting longer than the previous one, the Moussala was again assumed as a boundary site for the SDEs with main presence over the southern and western parts of the Balkans.

The strongest SDE during the period of observations occurred from May 28th until the end of May 30th. The source is located as the first particles arrived early in the morning on May 28th, but the continuous trend began after 1500 UTC/28.05. The intensities of the total scattering and absorption peaked after midnight of May 29th, while the Angstrom exponent became negative to less than -0.1. Then the event began to degrade until late afternoon on May 30th, when the last traces of mineral dust were detected by the integrating Nephelometer. The satellite data with Dust score and transport trajectories computed with HYSPLIT are illustrated in Fig. 2.

The rest of the cases of mineral dust transport over Moussala peak were mainly connected to casually transported particles from SDEs in other parts of the Balkan Peninsula as southern Greece or southern Italy. The dust arrived mainly at high altitudes, so that only traces of dust with very low concentrations were detected. A similar event, for example, was a SDE with direction to Italy on May 1st. The casual dust particles from the main event were detected over Moussala on May 2nd (Fig. 3). Similar transport with very low concentrations was registered on June 10th originating from a SDE over the eastern Mediterranean. The mineral dust registered on June 23th was with too low concentration for the Nephelometer's sensitivity threshold. Finally, the meteorological data contradict the hypothesis of local dust sources, especially for both cases in June, namely, lack of stormy weather in the previous days, a very moderate wind speed (7.9 m/s and 4.2 m/s for the first and the second event), different relative humidity (86 % and 76 %) and changing wind direction during the events.

The data from the AIRS dust score confirmed only three direct SDEs over

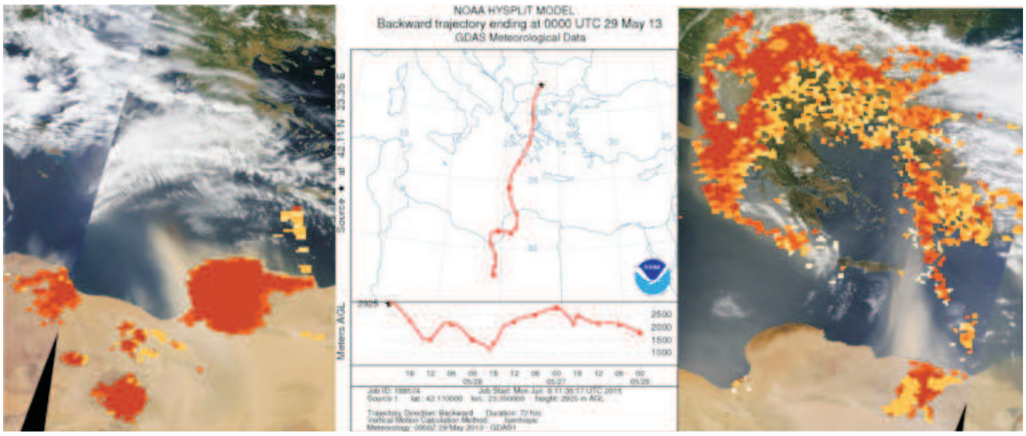

Fig. 2. From left to right: 1) Satellite image of a SDE source in northern Africa on May 27th; The dust score location is illustrated with coloured regions; The darker colours show higher score. 2) 48-hour back trajectories from Moussala from May 29th 00 UTC to the North Africa area with highest dust score on May 27th as shown on the previous satellite picture. 3) Satellite image of a SDE over Moussala on May 29th. The satellite images are obtained directly from NASA Earth Data [12]

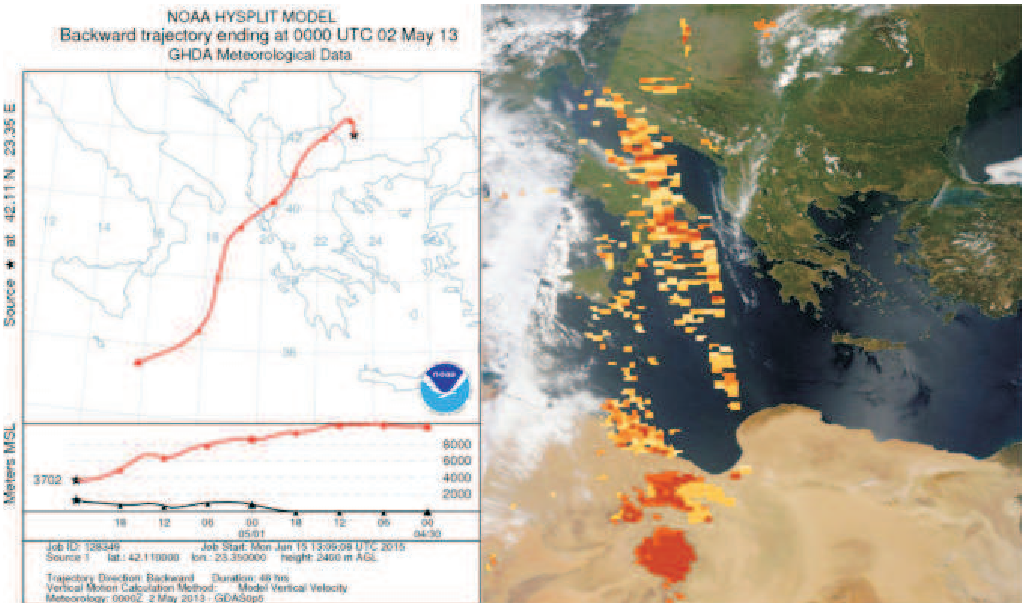

Fig. 3 From left to right: 1) 48-hour back trajectories from Moussala on May 2nd 00UTC; 2) Satellite image of a main SDE over the Mediterranean and southern Italy on April 29th, 2013. The satellite images are directly obtained from NASA Earth Data [12]

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The mean, standard deviation, min, median and max values for data averaged for one hour of the total scattering, absorption and Angstrom exponent for three different sets of data: 1) all data for the period April 1st – June 28th; 2) data for the period April 1st – June 28th with direct SDE excluded; 3) data for the period April 1st – June 28th with all mineral dust data excluded

Parameter	Mean	Std. Dev.	min	median	max
Total Scat. (1/Mm)					
1)	33.7004	33.5134	0.84	28.1718	381.5131
2)	27.7354	16.8051	0.84	27.2461	77.9698
3)	27.9685	16.8331	0.84	27.4067	77.9698
Absorption (1/Mm)					
1)	2.1892	1.4168	0.101	1.9161	14.4478
2)	2.0132	1.1528	0.101	1.8579	5.3366
3)	2.0442	1.1651	0.101	1.881	5.3366
Angstrom Exp.					
1)	1.5175	0.6927	−0.139	1.7184	3.0842
2)	1.7319	0.4781	0.0089	1.8281	3.0842
3)	1.7617	0.4444	0.1001	1.8399	3.0842

Moussala and failed to confirm the SDE on May 16. These results restrict satellite registration of SDEs over Moussala only to events with very high intensities. Moreover, in the cases when concentrations were low and medium, either during persistent SDE or dust transport, the dust score values were less than 320, which was below the required threshold of 360 for confirmation. The main explanation may be the low sensitivity of AIRS dust score for the area over Moussala.

The overall contribution of SDE is shown in Table 1. It is seen as comparison between data series over all measurements and those with excluded dust detection periods that the mineral dust contributes significantly to higher quantitative values, both absorption and total scattering coefficients have higher mean and median values. The maximal measured values during SDE are also higher for almost 5 times for scattering and 3 times for absorption. Conversely, as may be expected, the AE values without SDE data are higher and close to theoretical values of 1.7 mainly because of exclusion of typical for SDE values below 0.5. Moreover, due to the casual character of SDE transport, random time of arrival and extreme parameter measurements, the particle dust events contribute significantly to large data volatility with much larger standard deviation values. Finally, as could be noticed from Table 1, detected indirect long range transports of mineral dust have impact on average AE values, but do not affect the quantitative data because of their low concentrations.

Conclusions. The results presented show the importance of conducting permanent in-situ observations of the aerosol properties over the highest place on the Balkan Peninsula. Such observations would allow one to investigate the influence of drifting particulate matter of different types and origins on the environment dynamics. The concrete experimental results obtained demonstrate the possibility of effective recognition of determinate aerosol species (Saharan dust) of different concentrations by using Angstrom exponent technique, for estimating the aerosol particle size, nephelometric and absorption-measurement photometric facilities, for measuring the integral scattering and absorption coefficients, and back trajectory computing code HYSPLIT and satellite data, for validating the dust origin and localizing the dust event core. Thus, the possibility has been proved as well for dust transport from Sahara to Bulgaria. The contact in-situ approaches like those developed here are reliable tools for calibration of contactless remote lidar and satellite aerosol sensors. They are also important for validating lidar and satellite data. So, the comparison of the results from in-situ measurements performed here and AIRS satellite data shows that both approaches are not interchangeable yet. The satellite sensor sensitivity turns out to be insufficient to find all the Saharan dust events detectable by the contact approach. A further development of the available research infrastructure and methodology needs extending their abilities of simultaneous study and recognition of other sources of migrating aerosol particles, such as vast-scale fires, volcanoes, and so on.

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