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AN INTENSIVE CASE OF SAHARAN DUST INTRUSION OVER SOUTH EAST ROMANIA*

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Abstract. The aim of this study is to analyze the prognosis for a case of high concentrations (above 50 μg/m^3) particulate matter- PM_{10} over South East Romania between 11.06.2010 – 20.06.2010. LIDAR measurements have been carried out during this period to find possible aerosol intrusions at different atmospheric levels. DREAM-DUST model highlighted intensive Saharan dust intrusions over Romania during the studied period. At the same time HYSPLIT backward trajectory model confirmed the air mass circulation out of Sahara towards Romania. The weather conditions were favourable, the absence of precipitations preventing the wet deposition of the dust. Ground based sun photometer measurements near Bucharest and Black Sea coast have been considered and proved the microphysical properties typical for dust particles during several days of the studied period.
Key words: aerosols, AOD, sun photometer, DREAM, PM_{10}.

1. INTRODUCTION

Spatial and temporal variation of aerosol particles is very important for human health and also for air quality and climate change studies.

The presence of aerosols in the atmosphere has a significant role since it controls the Earth-Atmosphere radiative budget. Thus, aerosols contribute in reducing global warming by scattering and absorption of short wavelengths radiation [1]. Besides this there are also concerns about the effects of aerosols on human health [2]. The PM_{10} (particulate matter with an aerodynamic diameter less than 10 μm) in concentrations equal or above 50 μg/m^3 are dangerous for the respiratory system [3].

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Suspended particle levels are monitored in ambient air quality networks because of their potential impact on human health, visibility and climate. In the last decade a review of the National Air Quality Standards has been carried out in certain countries, prompted by the results of a number of epidemiological studies showing a close relationship between fine particles and health efects [4]. In 1987, the monitoring of TSP (total suspended particles) was replaced by PM_{10} (particulate matter <10 μm, aerodynamic diameter) measurements in the United States as a result of a review of the National Standards [5]. In Southern European environments, natural PM_{10} sources may cause a number of PM_{10} exceedances. One major source of aerosol is long range transported Saharan dust affecting both Europe and Eastern US [6, 7, 8]. The residence time of dust particles depends on the meteorological conditions, wind speed and precipitation that favor the dry and wet deposition, respectively. Prior studies in the Western Mediterranean basin have shown that natural mineral particulate sources such as high-dust Saharan air mass intrusions interfere with the monitoring of the incidence of anthropogenic emissions on ambient air PM_{10} levels [9]. Desert dust is one of the major constituents of natural aerosol particles in the atmosphere and the African Sahara is the largest desert area and also the primary dust source on Earth [10]. Particles originating from there are transported over several thousands of kilometers over the Atlantic Ocean as far as North America [11], and over Europe reaching northern latitudes as far as England, Northern Germany and Denmark [12]. A desert dust outbreak is also one of the main causes, which leads to high PM_{10} particle mass concentrations in Southern Europe [13, 14].

The columnar AOT (Aerosol Optical Thickness) is an aerosol optical property that is commonly used as aerosol load indicator. Worldwide the AOT is routinely monitored by sun-photometers and also accessible from satellite measurements. When is used in conjunction with other aerosol and meteorological measurements, sun photometry has the capability of highlighting characteristic features of different air masses and the aerosol sources that affect them [15, 16, 17, 18]. Aerosol concentrations and size distributions can be derived remotely through solar direct beam measurements at a range of wavelengths and zenith angles. The aerosol single scattering albedo can be also retrieved. The amount of light absorbed by each particle is measured by its single scattering albedo (SSA) – the ratio between the light extinction due to scattering alone and the total light extinction from both scattering and absorption. If the single scattering albedo lies below a critical value, the combined aerosol-Earth system reflects less energy back to space than the Earth's surface alone, leading to a net warming of the Earth. But this critical single scattering albedo depends strongly on the Earth's local albedo [19, 20]. The AERONET (Aerosol Robotic Network) maintains a global network of sunphotometers for this purpose [15]. There are ~450 instruments registered in the network and INOE Bucharest_Inoe site is operational in Romania since July 2007 along with other equipments for measurements of optical properties of aerosol [21].

Several regional models for simulation and prediction of the atmospheric dust cycle have been developed over the past decade [22]. These models are essential to complement dust-related observations and to understand the dust cycle. In this context, the BSC Dust Regional Atmospheric Model (BSC-DREAM) [22] has reached a level of delivering reliable operational dust forecasts (http://www.bsc.es/projects/earthscience/DREAM/) [7].

The lidar technique proved to be a suitable tool for the study of aerosol long-range transport. Main advantage of lidar is the real time observation of aerosol layering, which can be further used to identify the origin and the path of air mass. This technique has its limitations, but in combination with modeling and complementary techniques such as sun photometer, important information about aerosol origin, type and distribution can be derived [8, 23, 24, 25].

This study is focused on detailed analysis of an intensive case of air pollution in Romania. The importance of this study is supported by negative effects which may have such loading of the atmosphere to human health in Romania. Next section is focused on the methodology, followed by results and conclusions sections.

2. METHODOLOGY

In order to perform this study case we used complementary forecast/ simulation models and ground based remote sensing measurements.

The absence of rainfall in Romania was checked throughout the period, both with Hysplit model, and the observations derived from wet deposition maps from DREAM.

a) *The DREAM model*. DREAM – Dust Regional Atmospheric Model [22] is a regional model designed to simulate and predict the atmospheric cycle of mineral dust aerosol, its lifting from the ground, injecting into the atmosphere and then transport through short, medium, and long distances, considering dry or wet deposition. The model also includes the effects of the particle size distribution on aerosol dispersion With a high resolution (1/3 X 1/3), the model is built on 24 vertical levels, with a daily prediction of 72 hours, initialized at 12UTC with 0.50 NCEP (National Centers for Environmental Prediction) data. Additionally, the wind fields at 3000 m are superimposed.

b) *The Hysplit model*. HYSPLIT4 model (Hybrid Single-particle Lagrangian Integrated Trajectory) [26] is operated online by the National Oceanic and Aeronautical Administration (NOAA). This can be used to calculate the back trajectory of air masses at different starting points but in our case we used only one starting point at INOE station (44.36N, 26.03E). The model offers the possibility to select a point in time with high precision (year, month, day, hour) and establish the running time (number of days backward trajectory or prediction) and levels at which we are interested to follow the movement of air masses (between 1 and 3 levels). Weather variables can be selected and plotted subsequently over the trajectory (precipitation, mixed layer depth, ambient temperature, etc.).

c) *Sun photometer*. The optical properties of aerosol particles can be studied by using sunphotometer measurements, thereby determining information related to the form and their nature [27]. Data used for this analysis: daily Aerosol optical depth (AOD) at 500 nm and Ångström coefficient (440–870 nm) for Bucharest Magurele INOE (latitude 44° 20’53’’ N, longitude 26° 01’ 46’’ E, altitude 90 m) and Eforie Nord (latitude 44° 04’30’’ N, longitude 28° 37’ 55’’ E, altitude 40 m) stations for 10 days (11-20.06.2010) available online at http://aeronet.gsfc.nasa.gov/. AOD is a measure of aerosol concentration in the column, which depends on wavelength as a standard parameter measured with sunphotometer. Ångström exponent (Å) is the slope of the wavelength dependence of AOD in logarithmic coordinates. In the solar spectrum, Å is an indicator of the size of the particles in the atmosphere. Thus, values Å > 1 are mainly determined by fine mode particles, while for Å <1 values are determined by the presence of larger particles [28]. An essential physical feature of aerosol particles is their concentration. Particle concentration can be characterized in two ways: by number of particles in unit volume of air or mixing ratio, *i.e.* the aerosol mass of the total mass of air.

d) *Lidar measurements*. Since the end of 2005, monitoring of long range transported aerosols is regularly performed at INOE site, in the SSW part of Bucharest, using a lidar system RALI [29]. This is a multiwavelength Raman lidar, used for measurements in the lower and upper troposphere (15–20 km maximum range at 3.75 m range resolution). The capability of the lidar technique to derive range resolved vertical profiles of aerosols optical parameters (backscatter and extinction coefficient) with very high temporal resolution (a few seconds up to a few minutes) was used to identify the altitude of layers and the temporal evolution of intrusions. Using these altitudes as inputs in atmospheric models, the source of aerosols can be identified [30].

3. RESULTS AND DISCUSSION

Model simulations BSC-DREAM8b PM_{10} during 2010 has revealed a special case of particulate matter PM_{10} pollution both in terms of concentration and in terms of persistence in the Romanian atmosphere. During 11^{th} to 20^{th} of June 2010 the concentrations exceeded the threshold of 50 $\mu g/m^3$ during 10 consecutive days. The most intense event, prognosis of 13^{th} June 2010, with concentrations up to 300 $\mu g/m^3$ at 14 UTC over Romania is shown in Fig. 1.

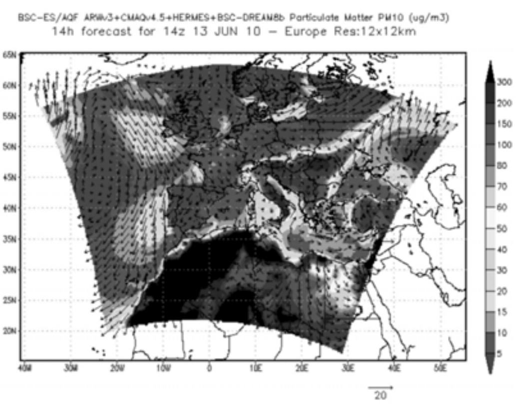

Fig. 1 – Model simulations BSC - DREAM8b PM_{10} over Europe showing high concentrations up to 300 µg/m^3, over Romania, 13 June 2010, 14 UTC.

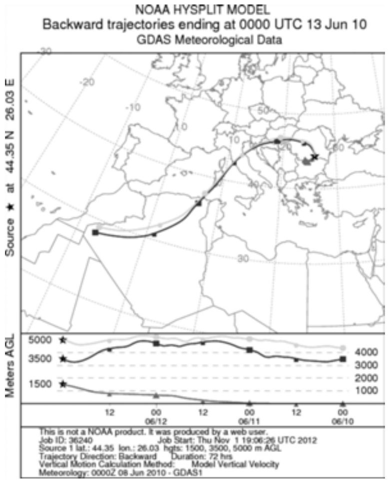

Fig. 2 – Air masses back trajectories calculated with Hysplit model for 13 June 2010, arriving at INOE station, 1500, 3500 and 5000 m.

To identify the origin of air masses arriving above our country during this period, we used the back trajectory model, Hysplit 4, for each of the 10 days. During 8 of the 10 days air masses migrate from the Sahara region. No precipitations or severe cloud conditions occurred during the studied period.

Figure 2 highlights air masses arriving over Bucharest on 13th June 2010, at 3.5 and 5 km altitude respectively transported from northwestern Sahara. For the 1.5 km atmospheric level, air masses got local influences during three previous days. This makes us think that loading the atmosphere with PM_{10} during this period is mainly Saharan dust type. To validate this idea we used DREAM-DUST forecast model. The model estimations of the spatial evolution of dust in terms of vertical integrated dust mass on surface unit (g/m^2) are presented in Fig. 3.

Saharan dust intrusions are predicted to cover Romania during the period studied, values ranging from 0.05-1g/m^2.

The massive export of dust from the Sahara is observed starting June 9th , over Central Europe while the center of the dust plume spread over eastern parts of Europe including Romania only on June 10th. On June 13th, the dust plume covered Romania and the dust load reached high values. The dust concentrations over Europe gradually decreased to smaller values on the following days.

The vertical profile of dust concentration in the atmosphere above the Magurele station on 13th of June 2010 (Fig. 4) pointed out that between 1.8 and 5.8 km dust concentrations are up to 220 µg/m^3. Turning now to lidar measurements the height of the intrusion observed in the vertical profile is consistent with the height at which air masses were advected over Bucharest from Sahara.

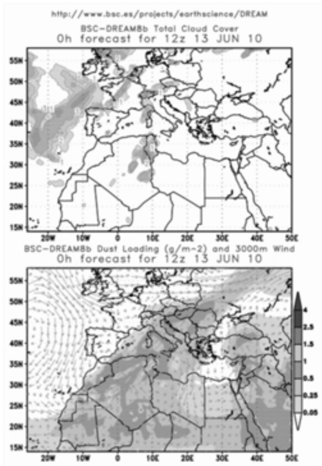

Fig. 3 – DREAM forecast model confirm Saharan dust intrusions in Romania on the day of 13 June 2010 and cloud cover for the same day. Arrows indicate the wind at 3000 m altitude.

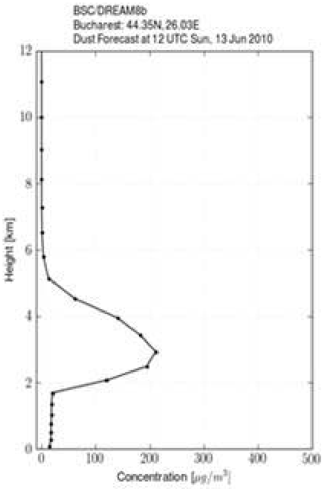

Fig. 4 – Dust concentration profile at INOE station Magurele (44.35N, 26.03E) showing a large peak between 2500 and 5000 m during 13 June 2010, with concentrations reaching 220 μg/m^3.

Lidar data measured on 14 June 2010 between 9:30 UTC -18:30 UTC confirm the existence of an aerosol layer in the atmosphere above the Magurele station between 4 and 5 km, which descends in time below 3 km after 17:00 UTC. Grey shades indicate a change in aerosol type. Black region is due to laser stop for half an hour (Fig. 5).

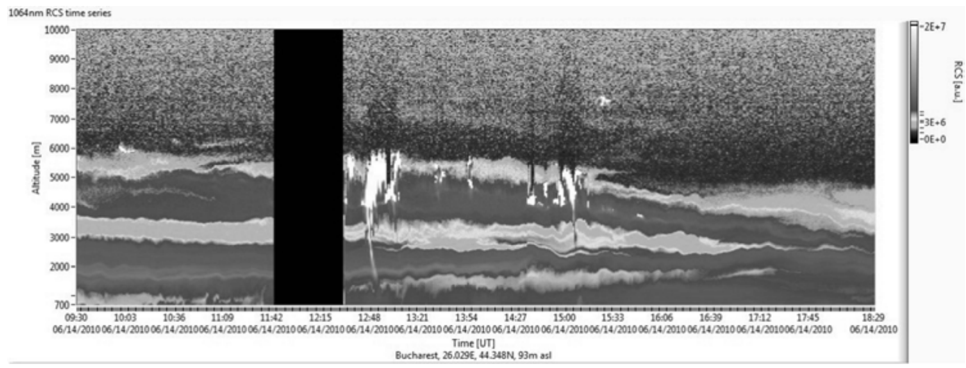

Fig. 5 – Range Corrected Signal (RCS) measurements at 1064 nm, 14 June 2010 between 9:30-18:30 UTC.

A key factor in particle transport analysis is weather conditions. Dry deposition along trajectory depends on particle size and their density. During the entire time period studied, dry deposition is indicated on most days (upper panels Fig. 6), while wet deposition case is an isolated one (right panel bottom Fig. 6).

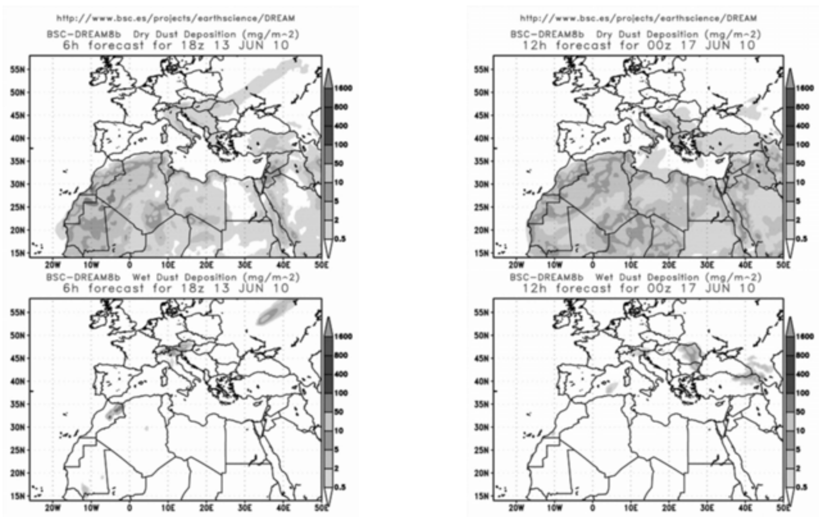

Fig. 6 – Maps of dry deposition (top) and wet (bottom) for 13 and 17 June 2010 provided by DREAM forecast model.

Next we analyze a series of sun photometer measurements at Eforie Nord (on the Black Sea coast) and INOE stations to better characterize the optical properties of aerosol particles. Daily values of AOD and Å for the studied period are displayed in Table 1. The last column shows monthly averages for each parameter. Sun photometer data show AOD values (at 500 nm) above the monthly average (0.317/0.250) between the 12th and 16th of June, and 18th and 20th of June, respectively for INOE station, with a peak value (0.955) reached on the 20th of June. For the Eforie Nord station AOD values above average were between 14th and 16th of June and 20th of June, with a peak on 16th June (0.480). The Ångström coefficient recorded a minimum on 19th June 2010 with a value of 0.407 for the INOE station and 0.699 for Eforie Nord, pinpointing the presence of large particle. Bold values of Ångström coefficient in Table 1 are characteristic to Saharan dust particle type [27]. It can be also noticed that higher than monthly average AOD values (bold in Table 1) coincide with the days of the Ångström coefficient values typical for Saharan dust particle (coincidences shaded in grey). Bucharest sunphotometer data confirmed six days. During the other four days Å values were not less than 1, but AOD values were close to the monthly averages, as can be seen in Table 1 by comparing with values of the last column. While typical AOD values for maritime aerosol (near the Black Sea coast) is less than 0.2 [31], during three days out of the ten Saharan dust influence was sensed by Eforie's sunphotometer (shaded grey in Table 1).

Table1

Values of aerosol optical depth at 500 nm and Ångström coefficient at 440-870 nm measured by sunphotometer at INOE (first two rows) and Eforie Nord (last two rows) between 11 and 20 June 2010

	11.06	12.06	13.06	14.06	15.06	16.06	18.06	19.06	20.06	M
AOD	0.204	**0.474**	**0.386**	**0.443**	**0.352**	**0.549**	**0.399**	**0.741**	**0.95**	0.31
Å	1.597	**0.927**	**0.695**	**0.708**	1.161	**0.901**	1.405	**0.407**	**0.443**	1.08
AOD	0.114	0.104	0.177	**0.264**	**0.390**	**0.480**	0.216	0.243	**0.456**	0.25
Å	1.158	1.219	1.285	1.07	**0.970**	**0.867**	**1.542**	**0.903**	**0.669**	1.19

In terms of aerosol size distribution, in Bucharest and on Black Sea Coast local influences are strong and are combined with intrusion Saharan influences as shown by other studies related to Romania [25, 27, 31, 29, 32].

The aerosol size distributions, retrieved from aerosol optical depth using King's method [33], demonstrated how the large size fraction of aerosol associated with Saharan dust dominated during these events. Figure 7 confirms the existence of Saharan dust particles for 12.06.2010 by showing a typical dust size distribution with a large peak dominating coarse mode, and single scattering albedo increasing with increasing wavelength [27]. High AOD values and supra-unitary Å values (June 15 and 18, 2010 near Bucharest) indicate mixing of local pollution and long-range transported aerosols.

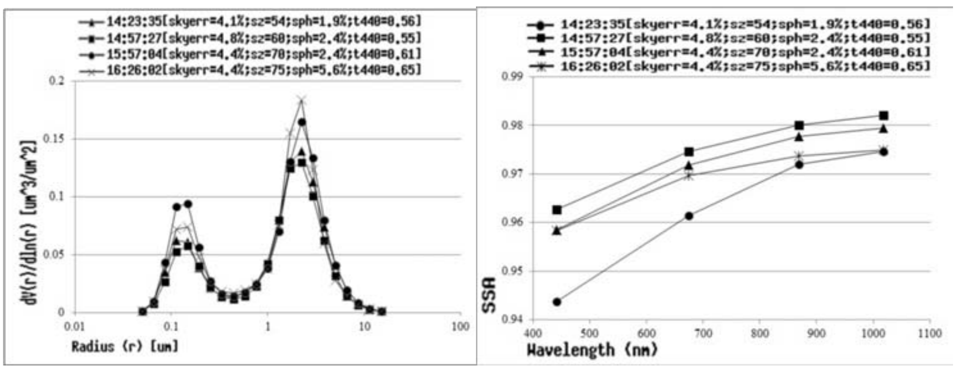

Fig. 7 – Aerosol size distributions (left panel) from sunphotometer data on 12 June 2010, showing dimensional distributions typical for desert dust; right panel – derived single scattering albedo increasing proportional with wavelength.

4. CONCLUSIONS

PM_{10} concentrations exceeded the threshold of 50 μg/m^3 during ten consecutive days in June 2010, as it was highlighted by DREAM – Dust Regional Atmospheric Model. This type of pollution represents a real threat for human health. The origin of the PM_{10} particles in the atmosphere above Romania during 11.06.2010–20.06.2010 has been proved to be Saharan region.

Ground based Lidar measurements at Magurele, confirmed existence of different layers in the troposphere, while the 8-wavelength inversion of sun photometer data measured over south east Romania evidenced values for the microphysical parameters of integrated column aerosol typical for dust particles during several days between 10 and 20 of June 2010.

High AOD values and supra-unitary Å values measured from the ground by sun photometer indicate mixing of local pollution and long-range transported aerosols.

The case presented in this study is just an example on how the synergy of models and ground based instruments can validate and offer complement information about aerosols.

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