Spatial distribution of aerosol pollution based on MODIS and in-situ data over Bucharest urban area, Romania

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Abstract. Atmospheric aerosols are one of the most important parameters affecting the Earth's energy balance and hydrological cycle, climate and human health. With the increasing industrialization and urbanization, especially in the metropolis regions, aerosol pollution has highly negative effects on environment. Urbanization is responsible of three major changes that may have impact on the urban atmosphere: replacement of the natural surfaces with buildings and impermeable pavements, heat of anthropogenic origin and air pollution. Remote sensing is a key application in global-change science and urban climatology. The aerosol parameters can be measured directly in situ or derived from satellite remote sensing observations. All these methods are important and complementary. The objective of this work was to document the seasonal and inter-annual patterns of the aerosol pollution in two size fractions (PM10 and PM2.5) loading over the Bucharest metropolitan area in Romania based on in-situ and MODIS (Terra–Moderate Resolution Imaging Spectoradiometer) satellite time series data over 2010-2011 period. Accurate information of urban air pollution is required for environmental and health policy, but also to act as a basis for designing and stratifying future monitoring networks.

Keywords: aerosol pollution, MODIS satellite data, PM10 and PM2.5, Bucharest

1. Introduction

Air quality has become one of the major environmental concerns in Bucharest, Romania due to the country's rapid development after 1989 year, particularly in transport, energy and building/road construction sectors. Emissions from road traffic, such as PM10 and PM2.5 (particles having aerodynamic diameters less than 10 μm and 2.5 μm , respectively) have become a threat to air quality, particularly in metropolitan areas.Very limited available information has indicated that these pollutants may present a challenge if future EU limits are to be met. The major mechanisms contributing to airborne particulate matter in the region (as elsewhere) are highly variable, including natural as well as pollution sources, chemical reactions in the atmosphere, long-range transport effects and meteorological conditions.

Air pollution estimates at high spatial-temporal scales are critically important for climate modeling and enforcing air quality standards in order to protect human health. The limited coverage of air pollution monitoring and conventional methods of monitoring air pollution restrict our ability to do so. Satellite remote sensing techniques of air pollution and particulate matter has shown tremendous potential for air quality monitoring over global regions with advancement in research and application in terms of spatial-temporal coverage. The moderate resolution spectroradiometer (MODIS) onboard Terra and Aqua satellite have a daily global coverage at 250m resolution. In recent years, satellite observations of aerosols and trace gases have shown an increased potential for application to monitor surface air quality over regional to global scales.

Aerosol parameters over the land and ocean have mainly been retrieved using passive optical satellite techniques, but it is a very complex task, because must be separated surface and atmospheric contributions observed signal at the satellite level. The aerosol data derived from the two MODIS sensors are useful for several applications like as: the investigation of the local, regional and global aerosol distribution, air pollution monitoring, radiative forcing and climate response, aerosol interactions with clouds. The data quality is essential for all these applications, while the required accuracy of the retrievals depends on the spatial and temporal resolution.

In this study we exploited the capability of MODIS Terra/Aqua sensors - on NASA platforms - to retrieve tropospheric Aerosol Optical Depth (AOD) and to verify the degree of correlation between satellite AOD at 550 nm and surface-level particles material PM2.5 and PM10 measured in-situ by classical gravimetric methods. However, several factors affect the relationship between columnar AOD and PM. Among these, two of the most important are the aerosol vertical distribution and the relative humidity.

2. Satellite remote sensing for air pollution monitoring

Aerosol products derived from satellite remote sensing have been extensively used to assess their distributions, transport, radiative effects or pollution coverage [1]. The production of satellite derived maps has relied on various observing techniques with different wavebands, from ultraviolet to near-infrared, and different types of observation geometry.

Dedicated missions such as the Moderate Resolution Imaging Spectroradiometer MODIS, have been active in producing a more complete view of the aerosol characteristics (including information on the size distribution) [2].

The earth viewing sensor MODerate resolution Imaging Spectroradiometer (MODIS) aboard the NASA Earth Observing System (EOS) Terra and Aqua satellites have 36 spectral bands ranging between 0.44- 15 μm, with different spatial resolution: 250 m (bands 1 and 2), 500 m (bands 3-7) and 1 km (bands 8-36). Among the standard atmosphere products run operationally in the MODAPS (MODIS Adaptive Processing System) at NASA GSFC (Goddard Space Flight Center), the Level 2 aerosol products used in this paper MOD04 (Terra) and MYD04 (Aqua), provide aerosol observations at satellite overpass (available at http://ladsweb.nascom.nasa.gov). This product provides various aerosol optical and physical parameters, such as the AOD and Ångström exponent, over land/ocean at the smoothed spatial resolution of 10 x 10 km2 (i.e.10 x 10 pixels at nadir)[3]. MODIS aerosol retrievals are done separately over land and ocean using two independant algorithms, which provide an abundance of information on atmospheric, terrestrial, and oceanic conditions. MODIS aerosol products are provided in near-real time, which make useful in local and regional studies for monitoring and forecasting of aerosol mass transport. The fine spatial and spectral resolution of this satellite sensor for the seven solar bands (0.47-2.1 μm) used in aerosol retrievals allows providing of standard products for a given grid of 10 x10 km pixels over land and ocean cover. Sensors on board of satellite platforms are able to distinguish fine (submicron) fraction from coarse (supermicron) aerosol fraction over the land and ocean, serving as a signature of the anthropogenic component which can be used to estimate the fraction of anthropogenic aerosols with an uncertainty of ±30%. Application to two years of global MODIS data shows that 21 ± 7% of the aerosol optical thickness over the oceans has an anthropogenic origin [4].Merging information from time series satellite MODIS Terra/Aqua data on aerosol (MODIS Terra records from 2000 year and 2002 year for MODIS Aqua) with ground level based measurements and dynamic models provides scientific and monitoring applications of aerosol in atmospheric sciences [5].

Since Bucharest is an inland area, only land retrievals are used in the results. So, MOD04 and MYD04 products were downloaded in collection versions 5.0 and after 1 January 2009, collection version 5.1. To represent the MODIS AOD over the site location, spatial subsets of

MOD04/MYD04 data were extracted to select all pixels falling within selected metropolitan area of Bucharest (both urban centre and periurban Ilfov county).

3. Aerosol optical properties

Satellite sensors retrievals provide a measure of the abundance of aerosols in terms of aerosol optical depth spectral product (AOD), or aerosol optical thickness (AOT) denoted by τ , as a measure of the integral of aerosol extinction from the ground to the top of atmosphere [6]. Aerosol optical depth (AOD) magnitude is linked to the above aerosol reservoir above each location by the following relationship (1):

$$\tau(\lambda) = \int_0^\infty \beta_{ext}(\lambda, z)dz = \int_0^\infty \rho(z)\sigma_{ext}(\lambda, z)dz \tag{1}$$

where $\beta_{ext}(\lambda, z)$ is the extinction coefficient (m^{-1}), $\rho(z)$ represents the aerosol mass concentration μ g/m^3 at a he3ight z, $\sigma_{ext}(\lambda, z)$ is the aerosol extinction cross-section per unit mass (m^2/μ g), defined for a fixed wavelength λ .

The relation between columnar AOD and particle materials PM ground levels is function of region, season, weather conditions, aerosol type, size distribution as well as vertical profile.

Based on relation (1), for a fixed test site, considering that aerosol mass concentration is mainly suspended and well mixed in the atmospheric Boundary Layer up to a defined height z=H_{mix}, can be express the relationship between ground level PM aerosol mass concentration $\rho(0)$ and columnar AOD as :

$$\tau(\lambda) \cong H_{mix}\rho(0)\sigma_{ext}(\lambda, 0) \tag{2}$$

In general, particle materials PM10 concentration descends following an exponential law in vertical direction, but there is a linear correlation between the aerosol integral concentration and air particular matter concentration near ground. Aerosols near the ground can also be called atmospheric particulate matter (PM) [7]. Ground level measured PM concentrations have to be considered related to dry particles.

Usually for remotely sensed AOD will be considered an existent relative humidity U, and must be defined a humidification factor f(U) as ratio between the scattering coefficient for wet particles and the scattering coefficient for dry particles which is expressed by relation:

$$f(U) = \left(\frac{1 - U(z)}{1 - U_0}\right)^{-\gamma} \tag{3}$$

considered valid for U (z)>U_0. For $U(z) \leq U_0$ it can be assumed f (U) =1. Growth coefficient $\gamma = 1.04$ for urban particles.

In case of MODIS overpass measurements over Romania, with the assumption of well mixed aerosol particles up the maximum height of mixing layer (H_{mix}), for $z \leq H_{mix}$, PM2.5 concentration can be assessed from columnar AOD as follows:

$$PM_{2.5} \equiv \rho_{2.5,dry}(0) \cong \frac{1}{\sigma_{ext.2.5,dry}(\lambda, 0)} \frac{\tau_{2.5}(\lambda)}{f(U)H_{mix}} \tag{4}$$

where subscripts are related with dry conditions and particle size $\approx 2.5\,\mu m$.

Based on global validation over both land and ocean for 2000 through 2003, was found that MODIS was comparable to ground truth (e.g.AERONET) within certain expected uncertainties which are expressed by the following relations:

over ocean $\Delta\tau = \pm 0.03 \pm 0.05\tau$ (5)

and

over land $\Delta\tau = \pm 0.05 \pm 0.15\tau$ (6)

The expected errors were designated for the 0.55 μm MODIS channel, but were found to apply in other channels as well.

From extinction Mie theory related with optical and microphysical properties of particle materials PM 2.5 μm have been selected $\lambda = 550nm$ wavelength for MODIS AOD satellite retrieval for fine fraction of particles.

4. Study area and data used

Bucharest urban metropolitan area (Fig.1), is placed in the South – Eastern part of Romania, being bounded by latitudes 44.33 °N and 44.66 °N and longitudes 25.90 °E and 26.20 °E. Its central point is described by coordinates: latitude 44°25′N, longitude 26°06′E. The city is crossed by the Dâmbovita and Colentina rivers and is surrounded by periurban forests (Baneasa, Cernica, etc). Bucharest is one of the most crowded capital in Eastern Europe and maybe the most polluted. Economical development results in traffic increase (presently six times increase in comparison to 1990 year) as well as some industries placed in the surroundings of the city whose activities produce high concentration of heavy metals (sometimes above the acceptable limits).

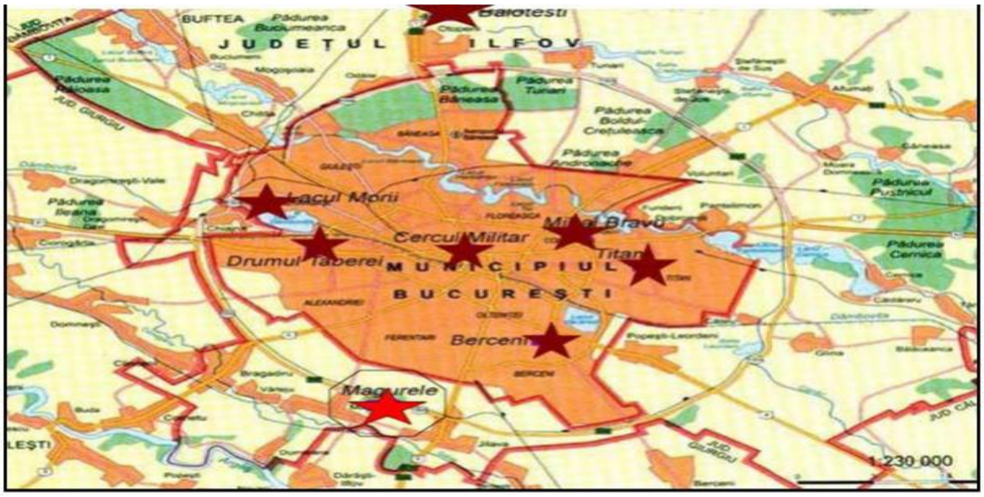

Figure 1. Test site urban Bucharest area and pollution monitoring stations

Investigation of aerosol pollution for Bucharest urban area, Romania was based on MODIS Terra/Aqua, MOD04/MYD04 products over 2010-2011 period, and in-situ monitoring data. Radiometric and geometrically corrected, pan-sharpened, multi-spectral IKONOS sub-scene of 1 m pixel resolution acquired 12/07/2009 was used too. The images have been divided in several sub scenes, chosen as study areas covering different sectors and periurban areas of Bucharest town, namely: Bucharest central area, Baneasa and Magurele periurban areas. In situ-monitoring biogeophysical data as well as ENVI 4.7, IDL 6.3 and ILWIS 3.1 softwares have been also used.

5. Results

During the last 15 years concern on PM concentration values in urban areas led to a number of European studies and European Community actions on PM10 and PM2.5 which have a key role in global climate change in pollution problems and of its potential short-term and/or long-term health impacts. The influence of aerosol particles on climate, and how their properties are perturbed by anthropogenic activity, is one of the key uncertainties in climate change assessments.

In this study has been exploited the capability of MODIS Terra/Aqua sensors - on NASA platforms - to retrieve tropospheric Aerosol Optical Depth (AOD) and to verify the degree of correlation between satellite AOD at 550 nm and surface-level particles material PM2.5 and PM10.

Aerosols are one of the greatest sources of uncertainty in climate modeling having also a great impact on human health and environment. The MODIS aerosol product is used to study aerosol climatology in urban areas, sources and sinks of specific aerosol types (e.g., sulfates and biomass-burning aerosol), interaction of aerosols with clouds, and atmospheric corrections of remotely sensed surface reflectance over the land. Figure 2 shows the mean AOD variation for Bucharest center from 1 January 2010 to 1 January 2011. Also Figure 3 presents the mean AOD variation for Baneasa periurban test site of Bucharest from 1 January 2010 to 1 January 2011. In Figure 4 can be seen the mean AOD variation for Magurele periurban area of Bucharest from 1 January 2010 to 1 January 2011.

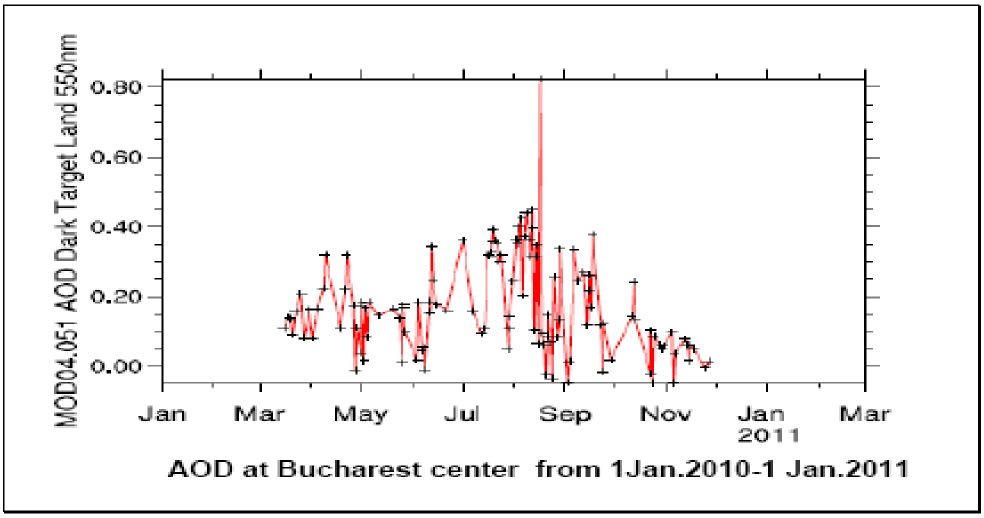

Figure 2. Mean AOD variation for Bucharest center from 1 January 2010 to 1 January 2011

We investigated air quality by monitoring concentrations of ground level particulate matter (PM) with an aerodynamic diameter less than or equal to 10 μm (PM10) and 2.5 μm (PM2.5) for Bucharest-Magurele periurban area.

The predominant recorded component in PM10 was PM2.5 (as can be seen in Figure 5 and Figure 6). Observational results show that recorded yearly average for years 2010-2011 of PM2.5 and PM10 concentrations were 35.96 μg/m3 and 40.91 μg/m3, respectively. The average ratio of PM2.5/PM10 was 87.9 % at Bucharest-Magurele sampling site.

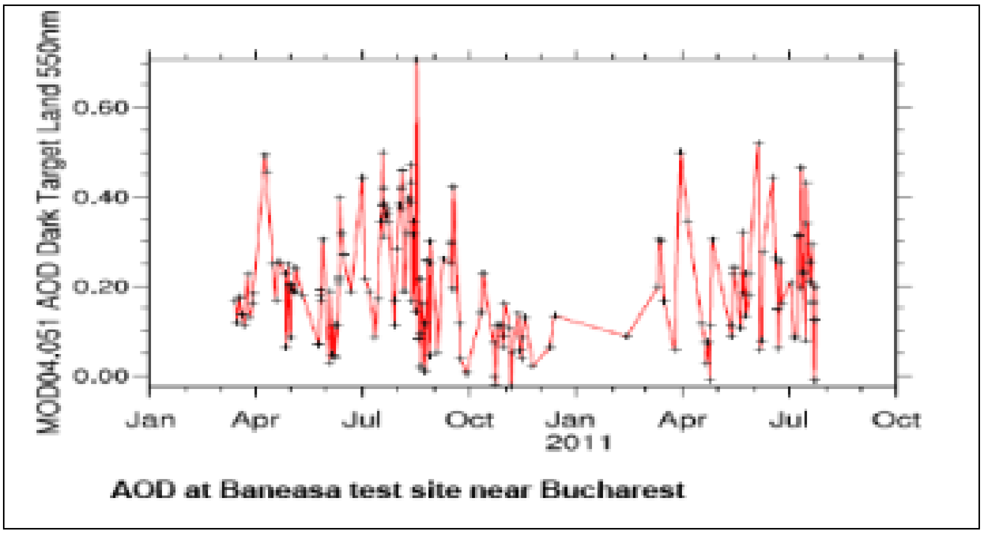

Figure 3. Mean AOD variation for Banes periurban test site of Bucharest from 1 January 2010 to 1 January 2011

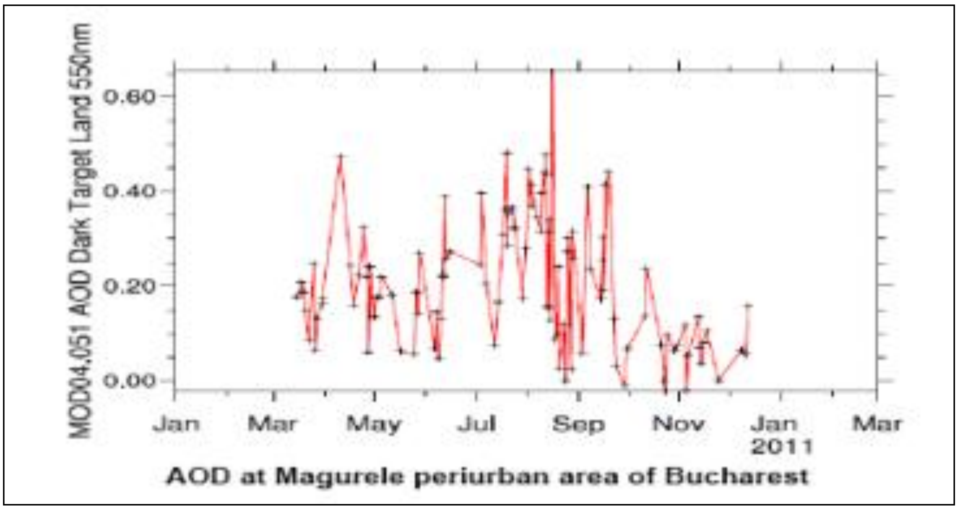

Figure 4. Mean AOD for Magurele periurban area of Bucharest from 1 January 2010 to 1 January 2011

However, in densely populated Bucharest urban and suburban areas the mean daily EC limit values for PM10, PM2.5 are frequently exceeded leading to serious public concern during the last years. The ambient air pollution measurements like as PM10 and PM2.5 levels are used as a proxy for personal exposure levels. Have been investigated also meteorological effects on the temporal patterns of particle matter.

Preliminary comparison, in the case of warm season (August month) and cold season (November month) between satellite-based and ground-based PM10 and PM2.5 measurements have shown a good agreement.

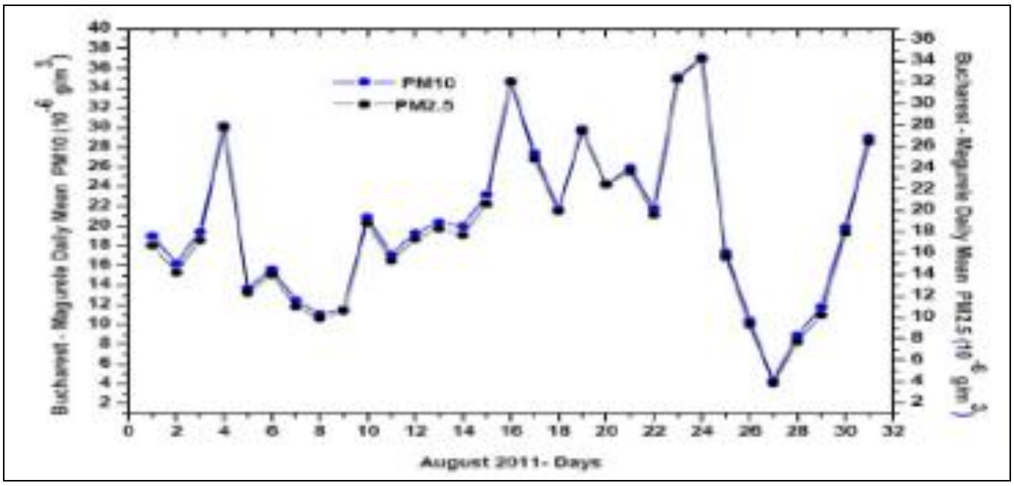

Figure 5. Monthly (August) variation of ground level PM10 and PM2.5 concentrations at Bucharest- Magurele

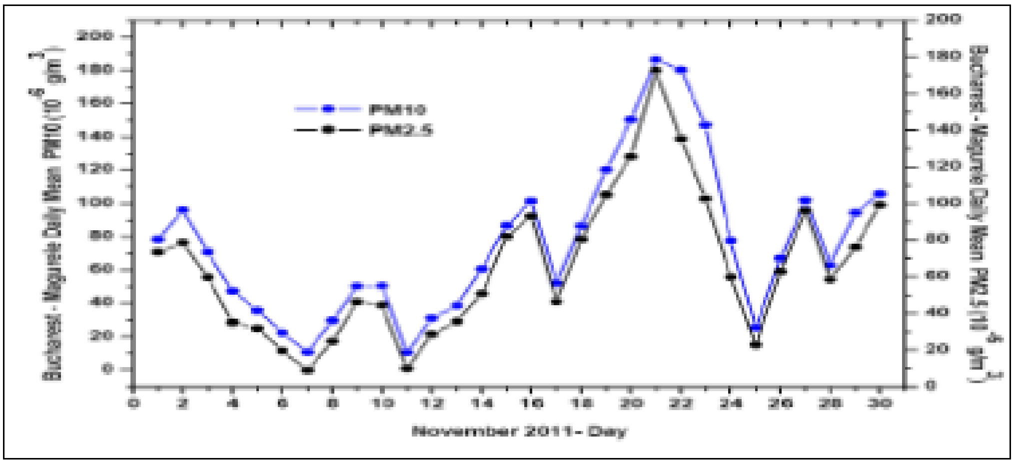

Figure 6. Monthly (November) variation of ground level PM10 and PM2.5 concentrations at Bucharest- Magurele

6. Conclusions

In recent years, satellite observations of aerosols have shown potential for application to monitor surface air quality with high spatial and temporal resolution over local, regional to global scales.

Satellite remote sensing of particulate matter air pollution from MODIS Terra/Aqua satellites has shown tremendous potential for air quality monitoring over metropolitan area of Bucharest with advancement in research and application period of less than a decade.

The potential of satellite remote sensing in a context of air quality monitoring can be recognized. Preliminary comparison, in the case of warm season (August month) and cold season (November month) between satellite-based and ground-based PM10 and PM2.5 measurements have shown a good agreement. As statistical approach, it is necessary a major number of samples for further validation. Despite the feature of high repetition cycle of 1 day of MODIS sensor, missing data is due to clouds'presence. Furthermore, PM2.5 samplings at ground are not routinely performed.

Acknowledgements

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