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CORRELATION BETWEEN THE PARTICULATE MATTER (PM_{10}) MASS CONCENTRATIONS AND AEROSOL OPTICAL DEPTH IN BUCHAREST, ROMANIA

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Abstract. The relationship between AOD (Aerosol Optical Depth) computed using OPAC (Optical Properties of Aerosols and Clouds) software and AOD retrieved from satellite was examined, for their reciprocal validation. Then the similar relationship between in situ measurements of PM_{10} mass concentrations near the ground and daily mean AOD values retrieved from satellite was inferred. The couples of data files from the three selected pollution monitoring stations from Bucharest area, during 2008–2009 were statistical analyzed and the correlation coefficients between AOD computed and that from satellite on one hand and between PM_{10} and AOD on the other hand were determined. The correlation coefficients varied between 0.60 and 0.90, depending on the type of station. The results have shown that the regression method can be used to predict the values of PM_{10} or AOD for a time period, knowing the relationship between the two variables and values for one of them for another time period.

Key words: aerosol optical depth, particulate matter, linear regression.

1. INTRODUCTION

Aerosols have strong impact on the atmospheric radiation budget, but these effects still contain considerable uncertainties due to the poor understanding of their radiative properties and their spatial and temporal variation [1]. Space-borne remote sensing of aerosols is best suited to reliably and continuously derive detailed aerosol properties in key locations. Validating aerosol products obtained from various satellite sensors may need ground-based measurements of a variety of optical aerosol characteristics with different data quality requirements [2].

The aerosol loading of the atmosphere takes place mostly in the atmospheric boundary layer because of pollution sources from the ground: thermal power stations, various fuel-driven consumers, traffic, etc. Intrusions of Saharan dust, ash and/or dust from volcanic eruptions or forest fires take place at high altitudes (2000–4000 m), contributing to aerosol loading into the atmosphere. Dispersion mechanisms of the aerosol, from ground level or higher altitudes, can disrupt the measurements of concentration for a specific place and time so that the results do not entirely reflect reality. For this reason, a better practice for monitoring the mass concentration and optical properties of particles is to have a range of different measurement methods for the same place. Thus, if measurements cannot be performed for specific time periods with *in situ* instruments, alternatives are provided then by satellite data, or by European or global networks (AERONET). A lot of scientists are focused on analyzing and developing methods to improve correlations between satellite-based aerosol optical depth (AOD) values and ground-based Particulate Matter (PM) mass concentration measurements made at continuous ambient monitoring stations on Environmental Protection Agencies [3, 4, 5]. The correlations and improved understanding of the relationships between satellite and ground observations are needed to formulate reliable real-time predictions of air quality using data accessed from the moderate resolution imaging spectroradiometer (MODIS). In the literature, validation of satellite data with ground measurements or validation of integrated air column (AERONET) with data from the ground [6, 7, 8] has been questioned, and the results were favorable towards replacing some types of measurements with others.

In this paper, we seek to determine a relationship between the mass concentration of PM_{10} for two urban stations and a regional background station, and aerosol optical depth (AOD). AOD is the aerosol optical parameter of aerosol loading of the atmosphere and is directly proportional to the mass concentration [9]. AOD is also a product of the MODIS Aqua and Terra satellites [10, 11, 12, 4] and it can also be determined using the OPAC software [13].

Therefore, the data we have used in this study, along with methods to achieve the AOD and other optical parameters by means of OPAC, knowing the PM_{10} mass concentration and type, are presented in Section 2.

The results, related to correlations between AOD values obtained from satellite and those obtained from modeling, as well as correlations between the AOD values obtained from satellites and the mass concentrations are presented and discussed in section 3. The conclusions end the paper.

2. DATA AND METHODS

In our analysis, the datasets consist of daily averages of PM_{10} and AOD. The PM_{10} data is provided by local, Romanian environmental agencies (http://www.calitateaer.ro/index.php) [14]. In this study, data were used originating from three representative stations in the pollution monitoring network in the city of

Bucharest (Fig. 1). The three stations were selected by taking into account the results obtained from the analysis of PM_{10} mass concentration values for 24 hours, at all monitoring stations (Fig. 2), in 2008 and 2009. In addition, these stations have had the longest concurrent satellite datasets with PM_{10} datasets [15]. As such, the following stations were selected: Mihai Bravu for the traffic zone, Berceni for the industrial zone and Balotesti as the background station (Fig. 1).

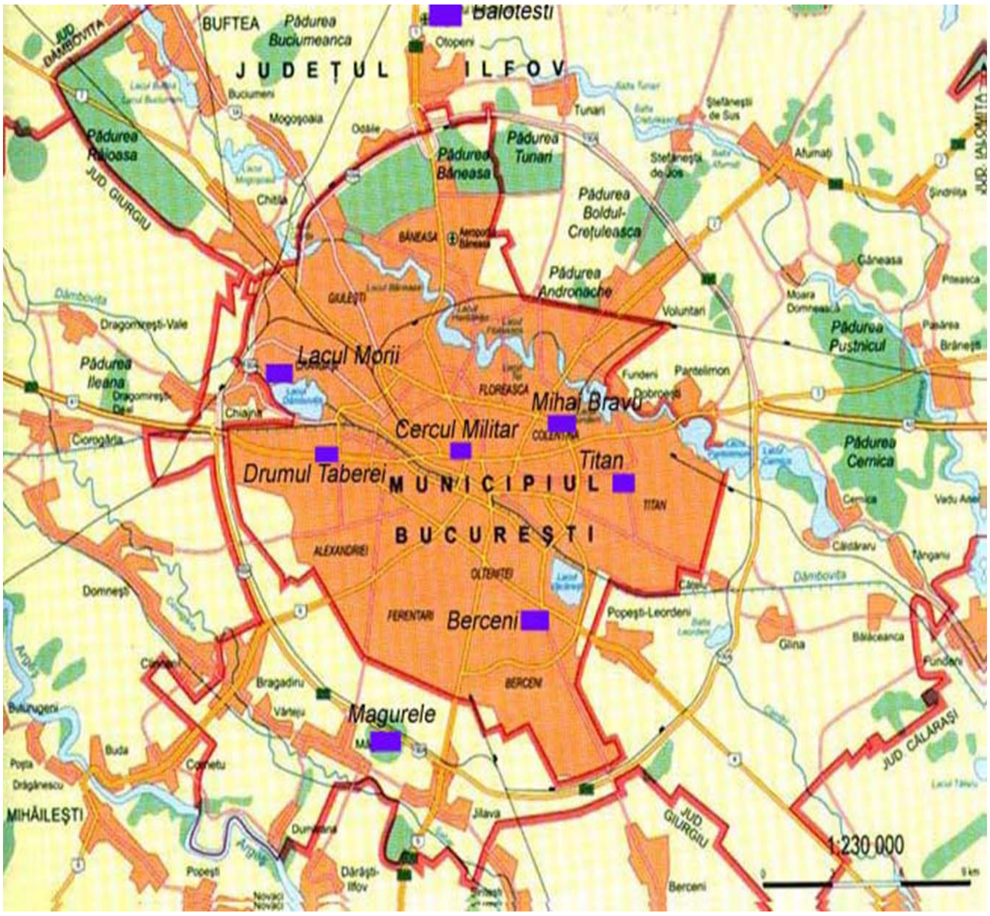


Fig. 1 –Air quality network stations in Bucharest (http://www.apmb.ro).

PM_{10} mass concentrations were used as input for the OPAC software, in order to determine the optical parameters (AOD) considered for this work, herein referred to as AOD-OPAC. The model input data requires knowledge of aerosol type [13]. In this case study, the composition determined and published by Olaru *et al.*, (2011) [16] was used for each type of PM_{10}; for the PBL (Planetary Boundary Layer) parameters, the HYSPLIT 4 model [17] was used.

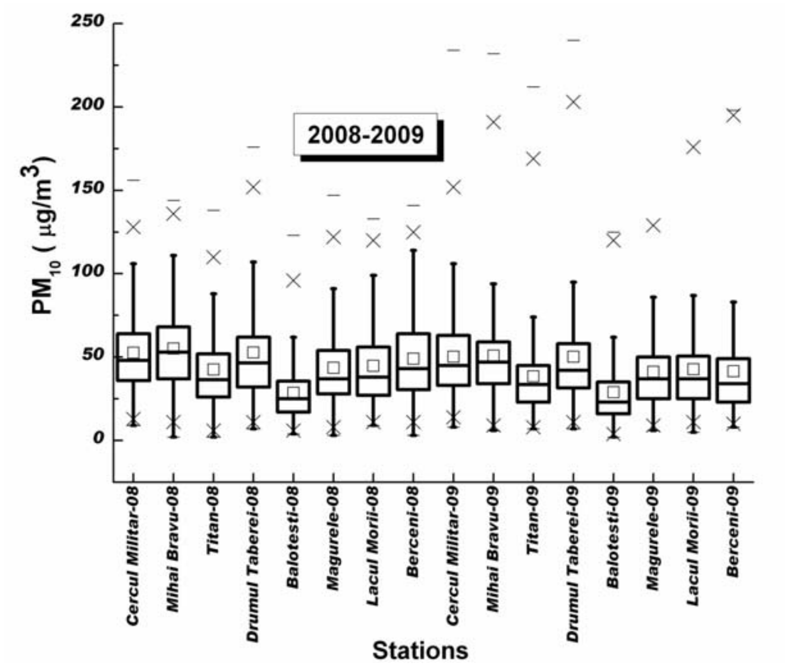


Fig. 2 – Box plots showing distribution of PM_{10} annual concentrations for the eight stations in the 2008 and 2009 years. The statistical data are represented through the box–whiskers method; the upper and the lower sides of the box represent the maximal and minimal values, respectively. The horizontal line of each box is the median. The extended lines from each end of the box represent the confidence percentages of 5% and 95%, respective.

The AOD from satellite data (AOD-Sat, in this paper) corresponding to the three stations was extracted from the MODIS archived data. The MODIS Aerosol Product monitors the ambient aerosol optical thickness over the oceans globally and over a portion of the continents. Further, the aerosol size distribution is derived over the oceans, and the aerosol type is derived over the continents. Daily Level 2 data are produced at the spatial resolution of a 10x10 1-km (at nadir)-pixel array. There are two MODIS Aerosol data product files: MOD04_L2, containing data collected from the Terra platform and MYD04_L2, containing data collected from the Aqua platform (http://modis-atmos.gsfc.nasa.gov/MOD04_L2/). Aerosol optical depth (AOD) is representative of the aerosol loading in the total atmosphere column over the selected location. The uncertainty of AOD retrieved from satellite was around +/–0.05,+/–0.15AOD [18].

In order to properly use the datasets, it was necessary, first time, to select the time intervals on which there are values for both variables of interest (AOD, PM10) and then, to homogenize these datasets by means of a method for filtering the data [19]. For the considered linear correlation, the Pearson method [20] was used for 2009, and the resulted linear regression relationships were verified for 2008.

3. RESULTS AND DISCUSSIONS

3.1. THE CORRELATION BETWEEN THE VALUES OF AOD CALCULATED WITH THE OPAC MODEL AND SATELLITE DATA

After preparing the datasets to be analyzed, the correlation between the AOD-Sat and AOD-OPAC was tested for each of the three stations. The results show that the values are well and very well correlated (Figs. 3 a, b, c).

The variability in time of the two optical parameters is similar, except for the days in April when AOD-OPAC values are smaller. This kind of deviations show up when the humidity at ground level is higher and the chemical composition of the aerosol is changed [21, 22, 23], or when other sources of aerosol appear at higher altitudes, in the satellite's field of view.

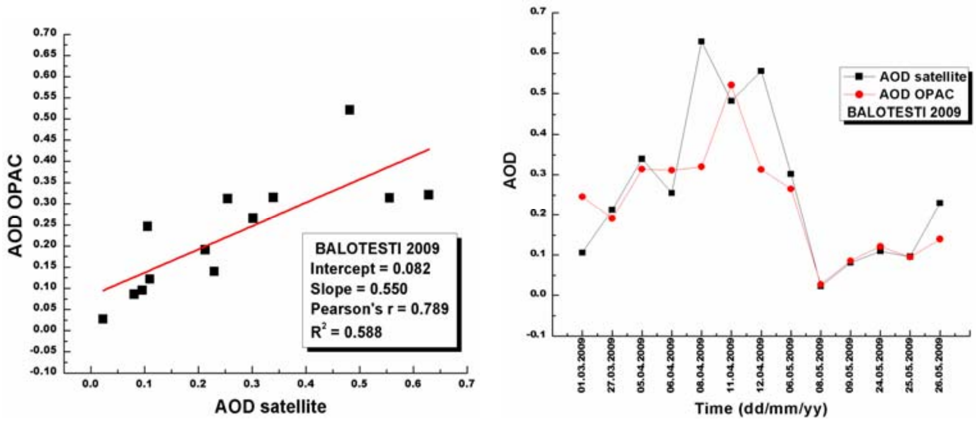


Fig. 3a – Linear regression of the AOD data obtained from satellite data and computed using OPAC soft in Balotesti (regional backgound station), in 2009 and the corresponding temporal representation.

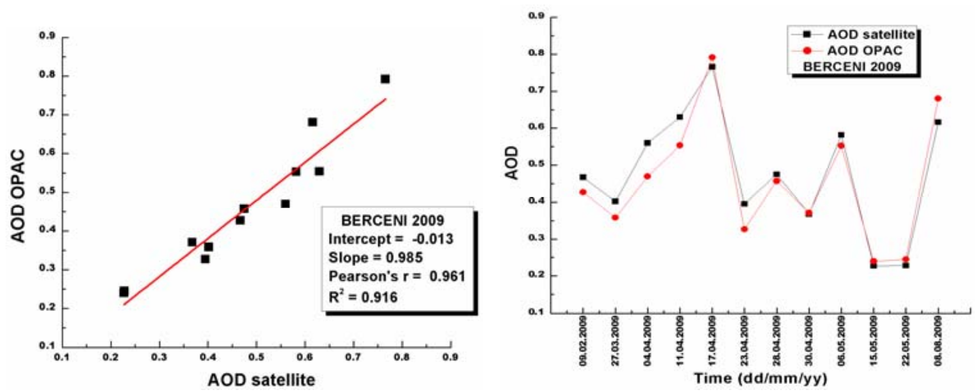


Fig. 3b – The same as in Fig. 3a but for Berceni station.

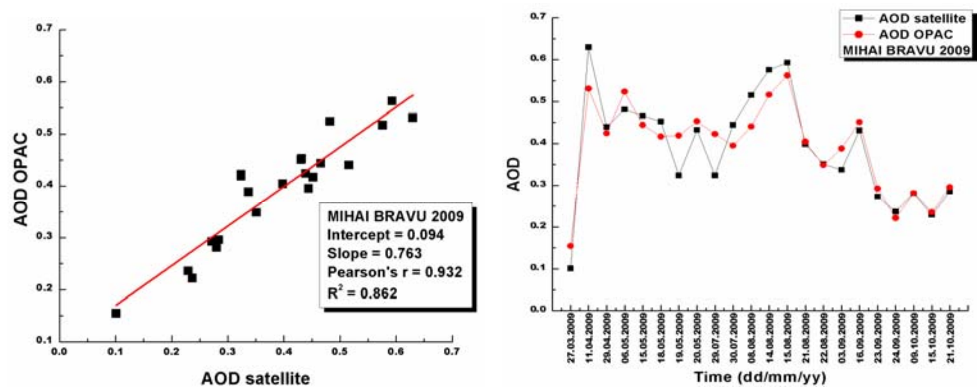


Fig. 3c – The same as in Fig. 3a but for Mihai Bravu station.

The very good correlation coefficient and the variation with time of the two optical parameters show that, for the industrial aerosol, the assumptions in the OPAC model were correctly chosen. It can therefore be said that the values validate each other.

The very good correlation between the values of AOD-OPAC and of AOD-Sat can also be seen from the time variation of the two parameters (right) with small deviations in days from May and June.

The linear regression was verified for the 2008 data, for the same three monitoring stations. AOD-OPAC data were projected for 2008 by using the linear regression relation and AOD-Sat for 2008 for the three stations:

Balotesti (regional background station): $AOD_{OPAC2008}=0.550AOD_{Sat2008}+0.082$

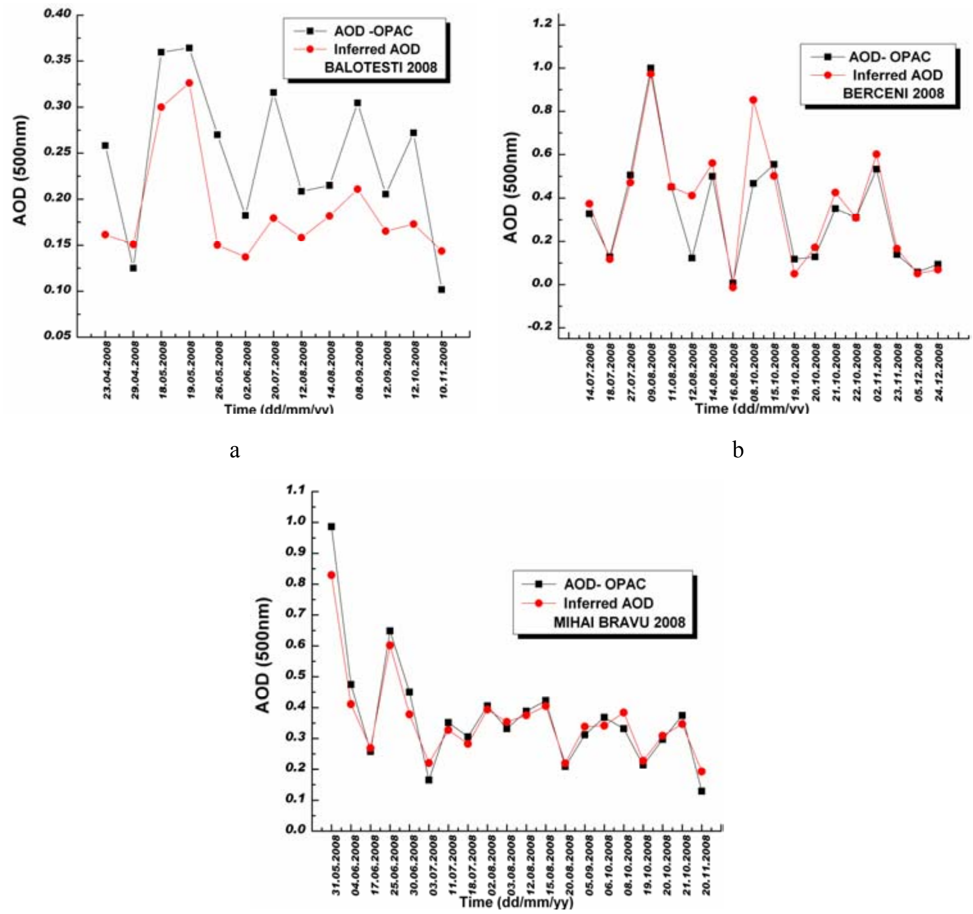
Berceni (industrial station): $AOD_{OPAC2008}=0.985AOD_{Sat\ 2008}-0.013$

Mihai Bravu (traffic station): $AOD_{OPAC2008}=0.763\ AOD_{Sat\ 2008}+0.094$.

It can be seen from the temporal diagrams that the two sets of data (inferred AOD and computed AOD-OPAC) are close to each other and sometimes they even coincide, at Berceni and Mihai Bravu stations. The average relative departure between them (*i.e.* the average of the ratio (inferred AOD – AOD computed by OPAC) / AOD computed by OPAC) being 12% and 10%, respectively. For the Balotesti station (Fig. 4a) the average relative departure of 28% was expected due to the weaker correlation between the two data sets. This can be explained because the AOD values from Balotesti are smaller than the other stations, so the "noise" diminishes the correlation.

By comparison, for Berceni and Mihai Bravu it may also be noted that the inferred values of AOD-OPAC are larger than those computed for Berceni, and contrary for those for Balotesti.

The results that we have obtained for the three stations give us reason to consider the OPAC model as an alternative for non-existent data from satellite, or for a certain PM_{10} monitoring station, and also to assert that when the aerosol (PM_{10}) characteristics are not known, one can use the AOD data from satellite measurements [2].



a b

c

Fig. 4 – Comparison between the AOD-OPAC in 2008, and the corresponding values inferred from the linear regression of data in 2009 for the three monitoring stations: Balotesti (a), Berceni (b) and Mihai Bravu (c).

From these results, one may conclude that the values of the obtained slopes and intercepts of the regression lines can be used with a fairly high degree of confidence for computed AOD using OPAC, when such parameter have not obtained from satellite.

3.2. THE CORRELATION BETWEEN THE AEROSOL (PM_{10}) MASS CONCENTRATION VALUES AND AOD-SAT

For the same three pollution monitoring stations for Bucharest, the statistical correlation procedure has been applied. The correlation was studied for each location, after processing the filtering process. For each dataset, the linear correlation coefficient was computed. Figs. 5a, b, c show the linear regression results and the corresponding temporal variation of normalized AOD-Sat and normalized PM_{10}.

The obtained values of the linear regression slopes and intercepts are indicated for each case on the respective figures. The main observation resulting from the analysis of datasets is that the linear correlations are very good, around 0.80. Good correlation between the six couples of datasets is obvious in the temporal diagrams too, where normalized AOD and PM_{10} values were plotted together against time. As one can see on the temporal diagrams, the major variations of the normalized AOD and PM_{10} plots are synchronized; the discrepancies are in the days when intrusions of Saharan dust were detected over Bucharest [24, 25]. These facts

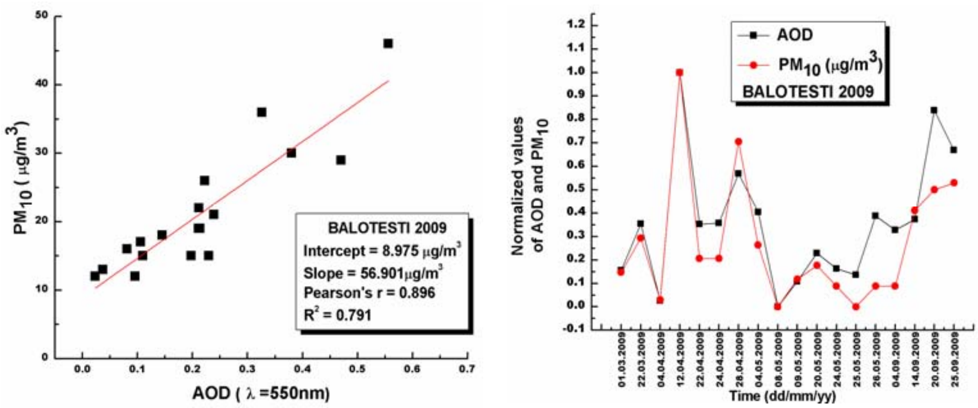


Fig. 5a – Linear regression of the AOD-Sat-PM_{10} data obtained in Balotesti (regional backgound station), in 2009 and the corresponding temporal representation of the normalized AOD-Sat and normalized PM_{10} mass concentrations.

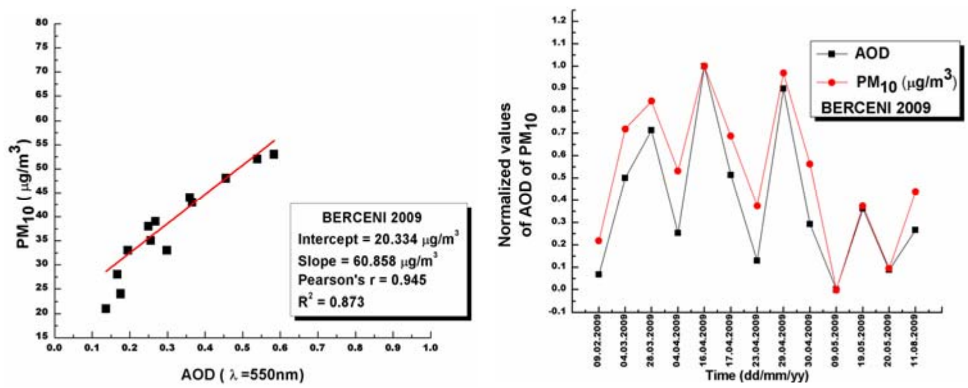


Fig. 5b – The same as in Fig. 5a but for Berceni (industrial station), in spring of 2009.

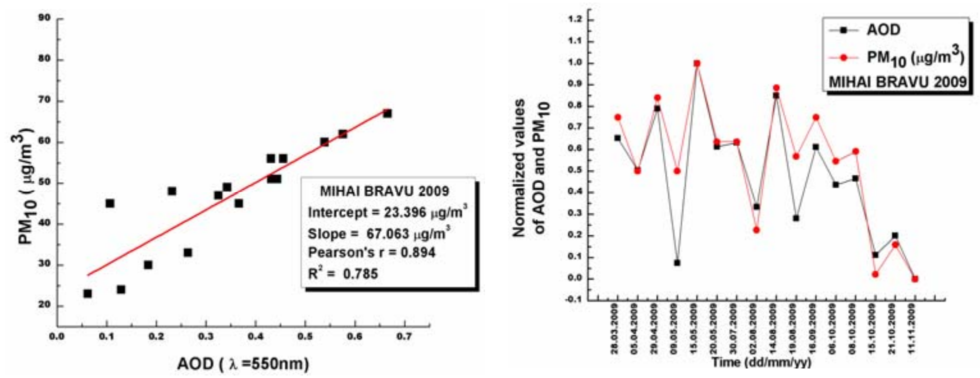


Fig. 5c – The same as in Fig. 5a, but for Mihai Bravu (traffic station), in 2009.

indicate a linear dependence between AOD from satellite and the near-ground concentration of PM_{10}, in accordance to other results reported in the literature [9, 19].

From these results, one may conclude that the values of the obtained slopes and intercepts of the regression lines can be used with a fairly high degree of confidence to estimate near-ground concentrations of PM_{10} during the days when such measurements have not been performed, but AOD-Sat data are available. To prove this assertion, we used the slope and the intercept of the datasets for the three stations in 2009 and the AOD-Sat in 2008, to infer the values of PM_{10} concentrations in 2008. The results can be seen in Fig. 6, where both the inferred and measured mass concentrations of PM_{10} in 2008 have been represented, in absolute values.

The relationships were:

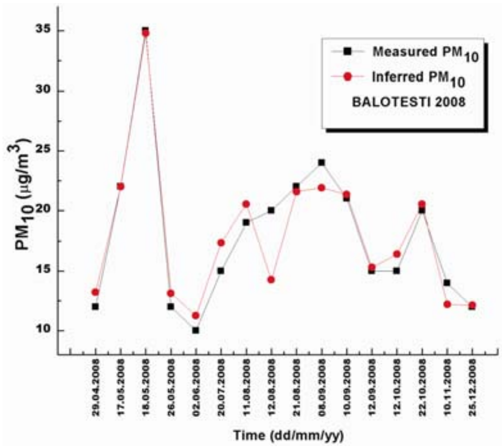
Balotesti: $PM_{10\,(2008)} = 56.901 AOD_{Sat\,2008} + 8.975$;

Berceni: $PM_{10\,(2008)} = 60.858\ AOD_{Sat\,2008} + 20.334$;

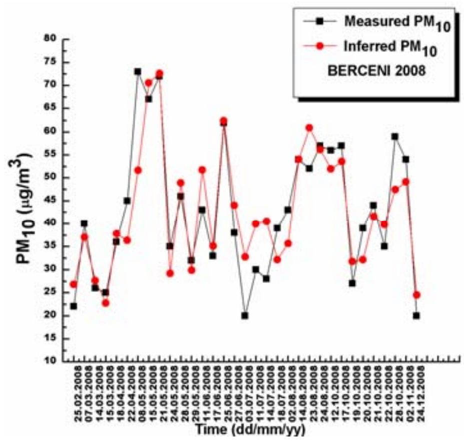
Mihai Bravu: $PM_{10\,(2008)} = 67.063\ AOD_{Sat\,2008} + 23.396$.

It can be seen that the two sets of data are close to each other, sometimes coincident, the average relative error between them being small – Mihai Bravu: 16%, Berceni: 27%, Balotesti: 28%.

Unfortunately, it may also be noted that there is not a rule for the behavior of the inferred and measured values: the inferred values of PM_{10} are sometimes larger than the measured ones, and sometimes they are contrary to those. The explanation consists in the uncertainty of measured PM_{10} values at ground level, that do not represent the entire mass concentration from the air column over that location and because the scarcity in amount of raw data.



a



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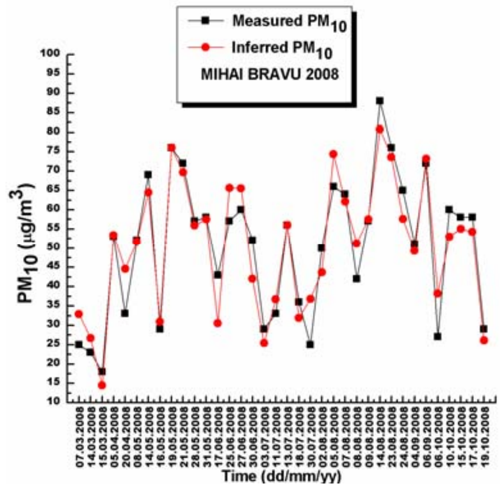

c

Fig. 6 – Comparison between the PM_{10} concentrations measured in 2008 and the corresponding values inferred from the linear regression of data in 2009, for the three stations: Balotesti (a), Berceni (b) and Mihai Bravu (c).

4. CONCLUSIONS

Statistical tools have been used in order to study the expected relationships between the AOD-Sat and AOD-OPAC, and those between the PM_{10} measured at a given ground location and AOD-Sat.

Before proceeding to the statistical analysis, the datasets for the three selected stations in 2009 year were filtered, to eliminate the discrepancies between the values of AOD-Sat and AOD-OPAC, and between AOD-Sat and PM_{10}.

The statistical correlation between the AOD-OPAC and AOD-Sat was very good, with coefficients from 0.588 (Balotesti station) to 0.916 (Berceni station).

The correlation coefficient depends on the type of station, *i.e.* the type of the aerosol (PM composition).

The same statistics for PM_{10} data files and AOD-Sat data files have shown correlation coefficients around 0.80.

The linear regression analysis that was performed for each dataset in 2009 for the three stations in the Bucharest area provides slopes and intercepts of the regression lines which were further used to predict values of AOD-OPAC or PM_{10} mass concentrations for the other time period.

The relationships between the two AOD values were used for each station in the Bucharest area, where AOD-OPAC data in 2008 were inferred from AOD-Sat data in 2009. The comparison between the inferred and computed values has shown that two sets of data are close to each other and sometimes coincident, and that the average relative error between them is small.

The results derived from the comparison of PM_{10} mass concentrations measured in 2009 and the PM_{10} predicted for 2008 emphasize a very good agreement.

One can conclude that the linear regression method can be applied with good results in order to predict AOD-OPAC and/or AOD-Sat, and PM_{10} measured at ground level.

Lengthy raw datasets allow for a more precise construction of the regression line, therefore can improve such a predictive method.

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