Estimating the relationship between aerosol optical depth and PM_{10} using lidar and meteorological data in Limassol, Cyprus

Nisantzi Argyro *, Hadjimitsis G. Diofantos, Alexakis Dimitris
Cyprus University of Technology, Department of Civil Engineering and Geomatics-Remote Sensing Laboratory, Limassol, Cyprus

ABSTRACT

Daily Aerosol Optical Depth (AOD) values from MODIS satellite instrument may be useful to predict Particulate Matter (PM) values in local scale in accordance with vertical profile of the atmosphere and meteorological data. In the frame of 'AIRSPACE' project, correlations between the AOD retrieved from MODIS to sun photometer data from both hand-held MICROTOPS II and ground-based CIMEL from the AERONET network were applied with good correlation coefficients. This permits to use MODIS retrievals as a reliable tool for assessing PM whereas the relationship between these two quantities is not lucid. The main study area is the centre of Limassol in Cyprus. Results concerning the relation between AOD and PM are presented. In cases where high AOD values corresponded to low PM surface values, the vertical distribution of aerosols from lidar allows the AOD to be quantifies within the boundary layer as this fraction best represents the PM measurements in a well-mixed layer.

Keywords: air pollution, AIRSPACE, aerosol optical depth, PM_{10}, CIMEL sun-photometer, Lidar, MODIS

1. INTRODUCTION

Troposheric aerosols consist one of the regulatory parameters in the atmosphere by changing the Earth's radiation budget and thus aerosols have an extensive impact on the environment. Additionally human health is sensitive to aerosols, which is well known as particulate matters (PM) and numerous studies (Gent et al., 2003; Franklin et al., 2007) have reported associations between mortality and morbidity and PM. Aerosol Optical Depth is defined for the entire column of atmosphere and is a measure of the extinction of light from the surface to the top of the atmosphere. It can be measured by satellite sensors like MODIS as well as by ground based instruments (sun photometers) at multiple wavelengths (Holben et al, 1998).Traditionally PM data are retrieved from the ground-based instruments so there is not enough spatial coverage, mainly in the developing world and isolated locations. The last decades remote sensing comes to overcome this gap by correlating aerosol data such as AOD which retrieved from satellite sensors, with PM surface measurements. Worldwide there is a great number of studies which relate these two parameters in order to extract the ground-based PM data using the large spatial and temporal scale of satellite remote sensing techniques (Chu et al., 2003; Wang and Christopher 2003; Vidot et al., 2007; Koelemeijer et al., 2006). Additionally the correlation between ground-based PM and satellite AOD is subject to seasonal differences. Thus several factors, such as Atmospheric Boundary Layer (ABL) height, seasonal meteorological patterns and geographical attributes of study area (coastal, highland) must be taken into account for a better PM-AOD correlation (Liu et al., 2009; Vidot et al., 2007). In this study presents the first results concerning the AIRSPACE project, precisely the correlation retrieved between the AOD from MODIS and Microtops II sun photometer for two years measurements (January 2009- May 2011) as well as the MODIS-derived AOD values with AOD from AERONET data for a year (April 2010- March 2011). Additionally the PM_{10} data retrieved from the TSI DustTrak (8533) for the Limassol area, in the south-west part of Cyprus correlated with the satellite-derived AOD and the AOD retrieved from CIMEL and Microtops II sun photometers. The lidar backscattering soundings comprised the basic parameter for increasing the correlation concerning the relationship between AOD-PM_{10}.

*corresponding authors: argyro.nisantzi@cut.ac.cy tel: +35725002248

2. METHODOLOGY AND DATA SETS

2.1 Methodology

Satellite AOD data from MODIS instruments Terra and Aqua are used in conjunction with ground-based AOD from CIMEL and Microtops II sun photometers and PM_{10} measurements in order to retrieve a relationship between AOD and PM_{10} for Limassol area. Due to the fact that PM_{10} ground measurements are corresponded to a point whereas AOD data refers to the whole column of the atmosphere and MODIS AOD retrievals have spatial scale 10x10km, this lead us to take the vertical profile of aerosols using the lidar signals in the study area so as to gain a better correlation between two parameters. The lidar and sun photometer measurements were held during the MODIS overpass whereas the PM measurements are made from 9:00 to 14:00 local time.

2.2 Datasets description

2.2.1 Sun photometers

In order to retrieve AOD at 500nm two sun photometers were used. The CIMEL sun photometer is an automatic sun-sky scanning radiometer which measures the direct solar irradiance at eight solar spectral bands and sky radiance at four of those wavelengths at the Earth's surface. The aerosol data are acquired during daylight and in clear sky conditions. In this study the cloud screened data are used (level 2). The CIMEL comprise part of the AErosol RObotic NETwork (AERONET) and is calibrated according to program of AERONET specifications (Holben et al., 1998). The Microtops II (solar light Company, USA) hand-held sun photometer measures the attenuation of the direct solar irradiance and the transmittance from which AOD of the atmosphere is derived (Tsanev et al., 2008). For measurements with better accuracy the sun photometer is mounted in a tripod next to the CIMEL sun photometer, in the premises of Cyprus University of Technology, Limassol.

2.2.2 Lidar

In this work the Raymetrics Backscatter Lidar was used which is located in the same building of Cyprus University of Technology where the sun photometers take measurements. The Lidar system provides aerosol or cloud backscatter measurements from a height beginning from 200m up to tropopause height. The Lidar emits a collimated laser beam in the atmosphere and then detects the backscattered laser light from atmospheric aerosols and molecules. The Lidar transmits laser pulses at 532 and co-linearly with a repetition rate of 20 Hz. Two channels are detected at the wavelength of 532 nm. One small, rugged, flash lamp-pumped Nd-YAG laser is used with pulse energies around 25 at 532 nm. The primary mirror has an effective diameter of 200 mm. The overall focal length of the telescope is 1000 mm. The field of view (FOV) of the telescope is 2 mrad. Moreover the lidar system will be used for the detection of clouds and the provision of the ABL and aerosol layer height in near-real time.

2.2.3 MODIS Terra/ Aqua

The MODerate resolution Imaging Spectro radiometer (MODIS) instruments EOS-Terra and EOS-Aqua were launched in 1999 and 2002 respectively. Both instruments perform data daily during daytime when they cross Europe near 10.30 and 13.30 local solar time. Terra and Aqua measures the radiance in 36 spectral bands from visible to infrared (400nm-14500nm) and for retrieving AOD data at 550nm with spatial resolution 10x10km two different algorithms over land and sea surfaces are used due to the different radiative properties of water and land. It is worth mentioning that AOD data obtained only when more than 12 pixels are classified as cloud-free and over surfaces with no high reflectance.

2.2.4 TSI DustTrak

The TSI DustTrak (model 8533) is a light scattering laser photometer that is used to measure PM mass concentrations. Specifically measuring the amount of scattering light which is proportional to volume concentrations of aerosols it could obtain the mass concentration of them. The instrument is placed in the Environmental Enclosure and is mounted to a standard surveyor tripod for allowing reliable and accurate sampling. It is located near the two sun photometers in the roof of a building of Cyprus University of Technology in order to avoid the local sources of pollution which may affect the measurements.

3. RESULTS

Firstly it became a comparison between MODIS AOD at 550nm and AERONET AOD for the first year of measurements where the level 2 AERONET data are available for Limassol area. The number of measurements are 136 and the correlation coefficient according to coefficient of determination ($R^2 = 0.67$) is R=0.822 (fig.1). These results permit us for the future to use with safety MODIS-derived AOD values in case of no AERONET AOD will be available and vice versa. Similarly MODIS AOD compared with Microtops II AOD at 500nm and the retrievals for 141 data shows a better correlation R=0.867 (R^2=0.7525) for more than two years measurements (fig.2).

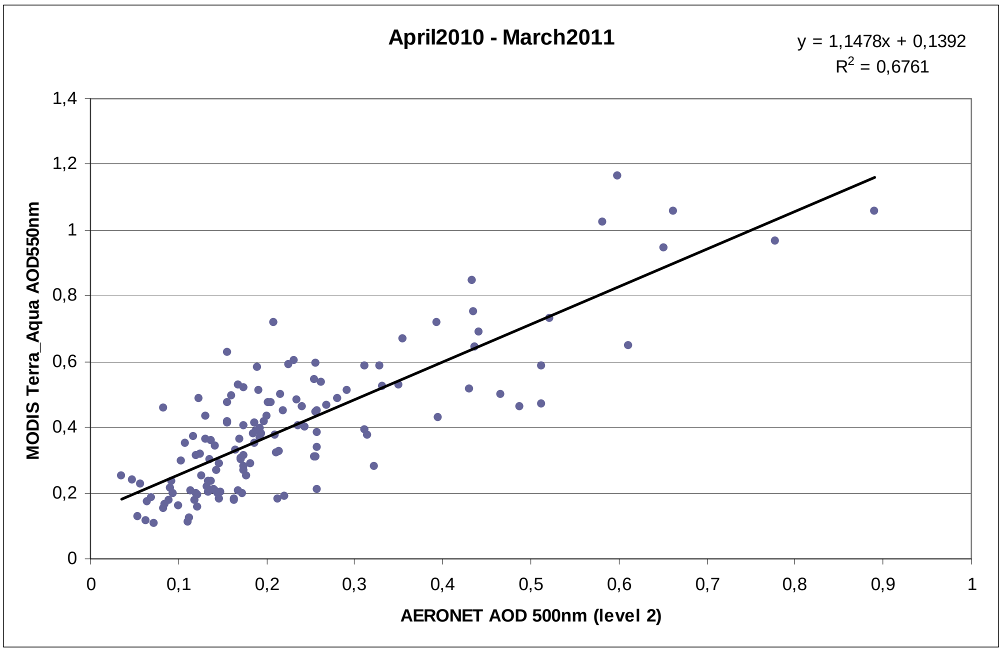


Figure 1. Correlation between MODIS AOD and AERONET AOD (level 2) for Limassol, April 2010 - March 2011.

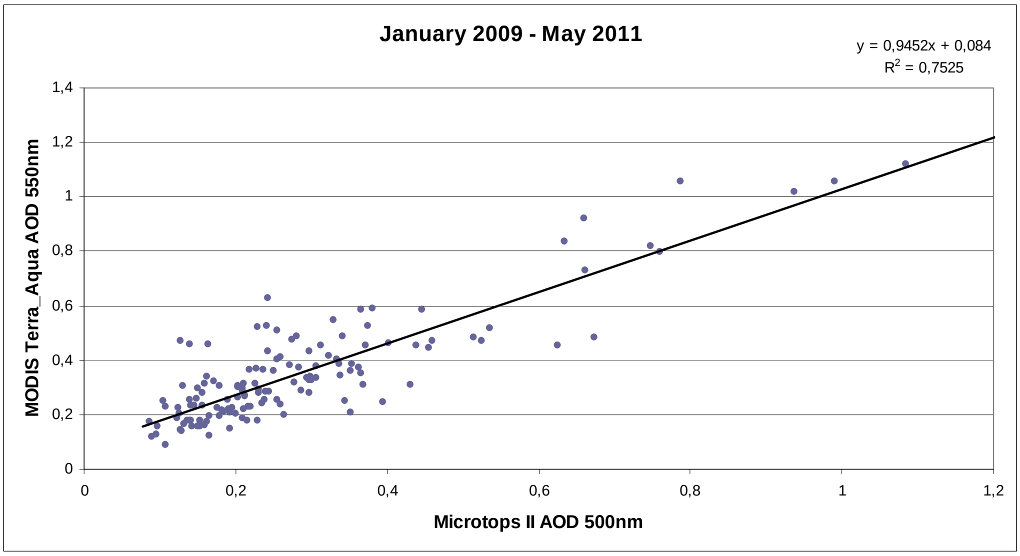


Figure 2. Correlation between MODIS AOD and Microtops AOD for Limassol, January 2009 - May 2011.

Taking PM_{10} data every 10 minutes and the AOD measurements for the CIMEL sun photometer at the same time, with a possible deviation 5 minutes, the correlation are shown in fig.3. Unfortunately the data cover only a month due to the fact that the CIMEL sun photometer sent for calibration purpose by April 2011 and the first PM measurements started at the end of February 2011. (n=245, R=0.55)

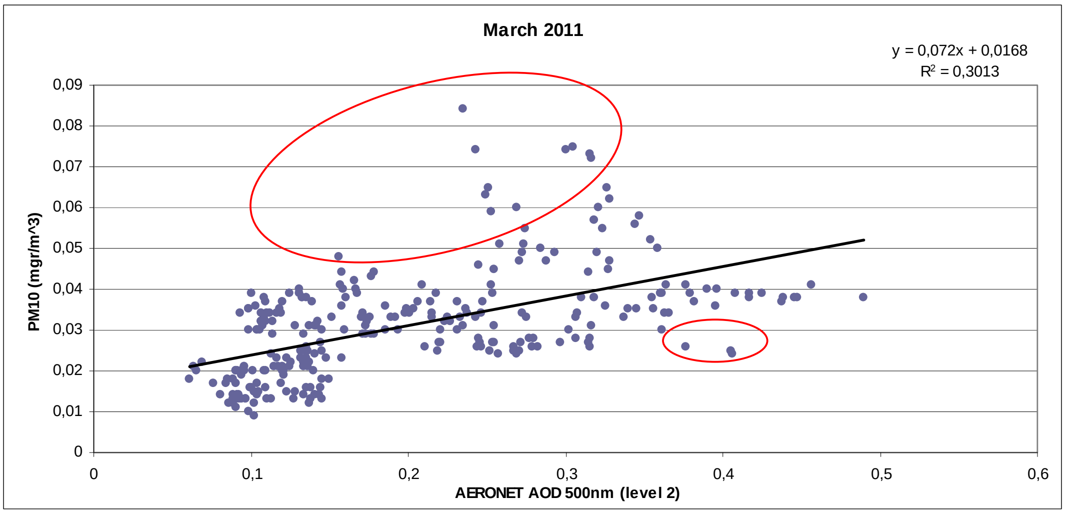


Figure 3. Correlation between PM_{10} and AERONET AOD for Limassol area, March 2011

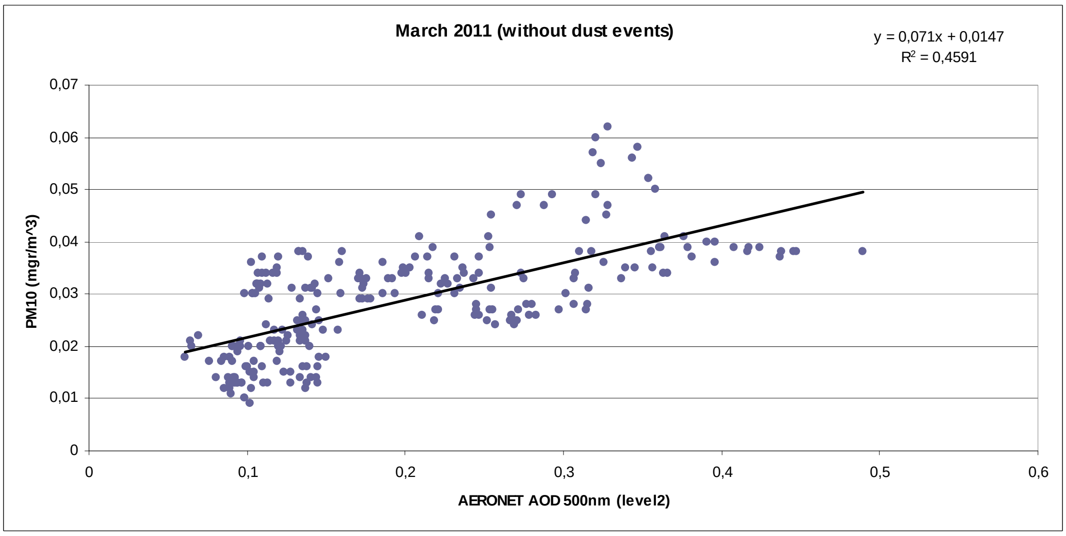
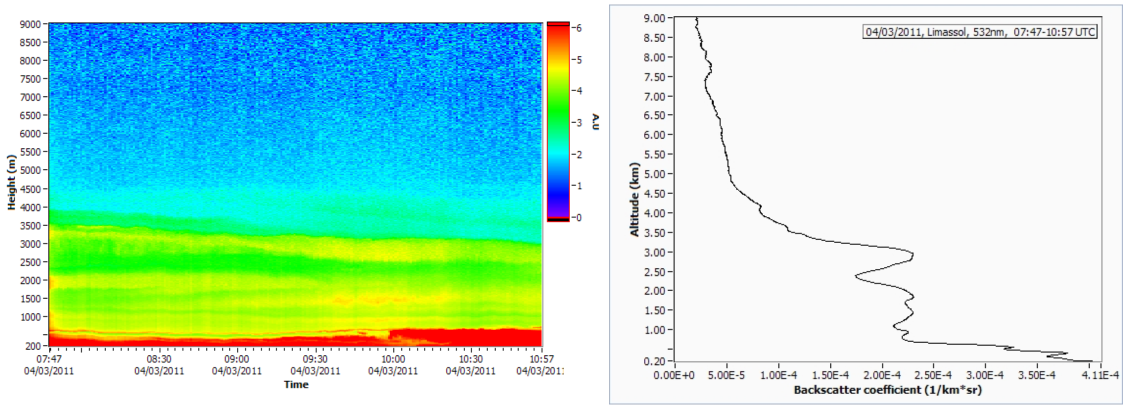


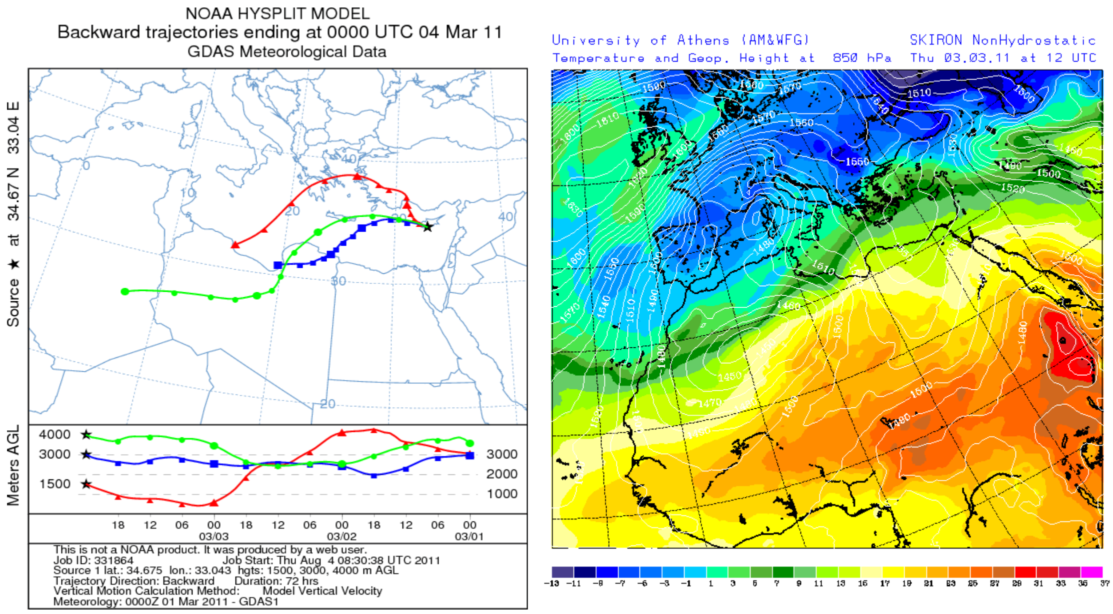
Figure 4. Correlation between PM_{10} and AERONET AOD (level 2) for Limassol area for March 2011 after excluding days with dust layers

Taking into consideration the measurements within the red cycles it observed that these measurements correspond to days with dust layer above the ABL. Precisely according to lidar measurements and using backward trajectories three dust events (3/3/2011-5/3/2011, 16/3/2011-18/3/2011 and 28/3/2011-31/3/2011) occurred within this period. So by excluding the data for these days the correlation increases as shown in fig.4 (n=231, R=0.68). In case of a dust layer the AOD values were high and PM_{10} values remained low and the following day this layer were mixing with the ABL by indicating high PM_{10} as well low AOD values compared with the first day of the plume presence. Suggestively it presents (fig.5a, b) the temporal evolution of dust layers and the vertical distribution of the backscatter coefficient from the analysis of lidar signals only for the first dust event happened during March. This dust intrusion comes from the North Africa as it shown from the back trajectories of HYSPLIT model and from the synoptic map of geopotential height at 850hPa (fig.6a, b). This dust intrusion is the result of Sharav depression which comprises a dominant system of Mediterranean spring (Trigo et al., 1999) and influence Cyprus during this period.



(a) (b)

Figure 5. (a) Temporal evolution of the dust layers over Limassol (b) vertical distribution of the backscatter coefficient on 4 March 2011.



(a) (b)

Figure 6. (a) 72-h air-mass back-trajectories ending over Limassol, Cyprus at 00:0 UT on 4 March 2011 (b)Temperature and Geopotential height over Mediterranean as estimated by SKIRON model on 3 March 2011 12 UTC

Working with the same sense and excluding the measurements with aerosol layer above the ABL from both sun photometer and MODIS data, the correlation between the two variables increases and the final graphs are shown below (fig.7, fig.8). Overall, the correlation coefficient present in Table 1. According to several studies (Koelemeijer et al., 2006; Gupta et al., 2006; Boyouk et al., 2010; Schaap et al., 2009) ABL consists a key issue for retrieving a more precisely relation between AOD and PM_{10}. It is worth mentioning that by taking into consideration the ABL high values from the daily lidar measurements no clear conclusion found in order to extract a safe tool for the relationship between AOD and PM_{10}. This may occur due to the complex topography of the study area. The combination of katabatic winds created from the hill and the developing sea breeze during the measurements (08:00-09:00 UTC) produce a unique air flow that affect the smooth ABL growth.

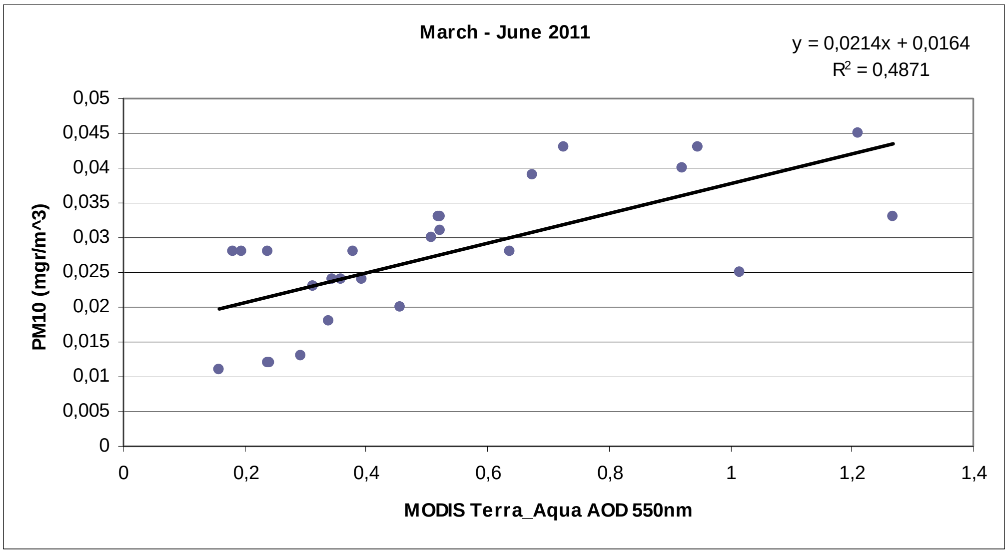


Figure 7. Correlation between PM_{10} and MODIS-derived AOD

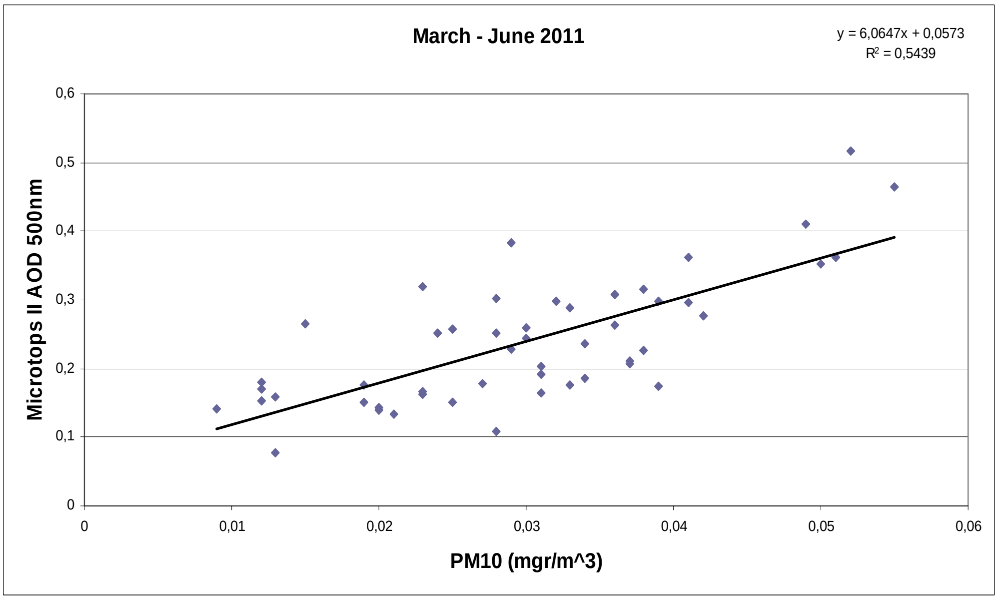


Figure 8. Correlation between PM_{10} and Microtops II-derived AOD

Table1. Correlation study between PM_{10} and AOD

	n (number of measurements)	**R^2**(coefficient of determination)	**R** (correlation coefficient)
PM_{10}-AOD(500nm)_AERONET	231	0.4591	0.68
PM_{10} -AOD(550nm)_MODIS_Terra/Aqua	25	0.4871	0.70
PM_{10}-AOD(500nm)_MicrotopsII	50	0.5439	0.74

4. SUMMARY and CONCLUSIONS

In order to analyze the relationship between the AOD and the PM_{10}, in the frame of AIRSPACE project, we have performed ground based measurements in the South part of Cyprus, in Limassol (34.675ºN, 33.043ºE). Based on two years good correlation (R=0.867) between the Microtops II and MODIS-derived AOD as well as the correlation between the one year AERONET AOD retrievals (level 2) and satellite AOD values (R=0.822) it is obvious that we can safely utilize each of these resources and especially the satellite one to retrieve AOD for the study area. The backscattering lidar soundings in conjunction with ground-based PM_{10} and AOD values from both ground-based and satellite measurements were acquired for the period March to June 2011. The vertical distribution of aerosols could comprise a reliable tool so as to increase the relationship between AOD - PM_{10}. Specifically by knowing the presence of an aerosol layer above the ABL from the lidar signals and excluding these data from the measurements, we obtain a better correlation coefficient compared with the initial results. Unfortunately the daily ABL values in accordance with the AOD-PM_{10} data did not show any clear trend and this may happen due to the complex terrain of Limassol. Katabatic winds and sea breeze affect the micro scale circulation of the study area and reduce the possibility to draw a correlation between ground-based PM_{10} and column average datasets.

ACKNOWLEDGEMENTS

The project is funded by the Cyprus Research Promotion Foundation in the frameworks of the project “AIRSPACE”. In addition the authors would like to acknowledge the Cyprus University of Technology / Department of Civil Engineering and Geomatics (Remote Sensing Laboratory) for supporting this study.

REFERENCES

[1] Boyouk, N., Leon, J.F., Delbarre, H., Podvin, T. and Deroo, C., “Impact of the mixing boundary layer on the relationship between PM2.5 and aerosol optical thickness,” Atmospheric Environment. 44, 271-277 (2010).
[2] Catrall, C., Reagan, J., Thome, K. and Dubovik, O., “Variability of aerosol and spectral lidar and backscatter and extinction ratios of key aerosol types derived from selected Aerosol Robotic Network Locations,” Journal of Geophysical Research, 110, 1-13 (2005).
[3] Chu, D. A., Kaufman, Y. J., Ichoku, C., Remer, L. A., Tanre, D. and Holben, B. N., “Validation of MODIS aerosol optical depth retrieval over land,” Geophys. Res. Lett., 29, 8007 (2002).
[4] Franklin, M., Zeka, A. and Schwartz, J., “Association between PM2.5 and all-cause and specific-cause mortality in 27 US communities,” J Expo Sci Environ Epidemiol., 17, 279-287 (2007).
[5] Gent, J.F., Triche, E.W., Holford, T.R., Belanger, K., Bracken, M.B. and Beckett, W.S., “Association of low-level ozone and fine particles with respiratory symptoms in children with asthma,” JAMA 290, 1859-1867 (2003).
[6] Gupta, P., Christoper S.A., Wang J., Gehrig, R., Lee, Y. and Kumar, N., “Satellite Remote Sensing of particulate matter and air quality assessment over global cities,” Atmospheric Environment, 40, 5880-5892 (2006).
[7] Holben, B.N., Eck T.F., Slutsker I., Tame D., Buis J.P., Setzer A., Vermote, E., Reagan, J.A., Kaufman, Y., Nakajima, T., Lavenu F., Jankowiak, I. and Smimov, A, “AERONET – A federated instrument network and data archive for aerosol characterization,” Rem. Sens. Environ., 66, 1-16 (1998).
[8] Koelemeijer, R.B., Homan, C.D. and Matthijsen, J., “Comparison of spatial and temporal variations of aerosol optical thickness and particulate matter over Europe,” Atmospheric Environment, 40, 5304−5315 (2006).
[9] Liu, Y., Paciorek, J. C. and Koutrakis, P., “Estimating regional Spatial and Temporal Variability of PM2.5 Concentrations Using Satellite Data, Meteorology, and Land Use Information,” Enviromental Health Perspectives, 117, 886-892 (2009).
[10] Schaap, M., Timmermans, R.M.A., Koelemeijer, R.B.A., de Leeuw, G. and Builtjes, P.J.H., “Evaluation of MODIS aerosol optical thickness over Europe using sun photometer observations,” Atmospheric Environment, 42, 2187-2197(2008).
[11] Tsanev, V. I. and Mather, T. A., “Microtops Inverse Software package for retrieving aerosol columnar size diustributions using Microtops II data”, Users Manual (2008).
[12] Vidot, J., Santer, R. and Ramon, D., “Atmospheric particulate matter (PM) estimation from SeaWiFS imagery,” Remote Sensing of Environment, 111, 1-10 (2007).
[13] Wang, J. and Christopher, S. A., “Intercomparison between satellite-derived aerosol optical thickness and PM2.5 mass: Implications for air quality studies,” Geophys. Res. Lett., 30, 2095, (2003).