Study of air pollution with the use of MODIS data, LIDAR and sun photometers in Cyprus

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Abstract In the frame of 'AIRSPACE' project, ground-based measurements were conducted in the four main cities of Cyprus. Limassol, comprises the main test site as Lidar and CIMEL sun photometer (NASA/AERONET network) are located at the premises of CUT, while the other cities (Nicosia, Larnaca and Paphos) are used as validation sites. During data collection campaign, measurements from handheld sun-photometers, DustTrak (PM_{10}), Lidar and meteorological stations were used to extract an algorithm for relating satellite MODIS AOD retrievals and ground-based PM_{10} data for different types of geographical areas. For this purpose, the vertical distribution of atmosphere after the processing of daily lidar signals and meteorological parameters such as relative humidity, wind speed and direction were used.

1 Introduction

Over the last decades a great number of studies (Nicolantonio and Cacciari 2011, Boyouk et al. 2010) have focused their interest on remote sensing for monitoring air pollution. Aerosol Optical Depth (AOD) is defined as a measure of the extinction of light from the ground to the top of the atmosphere. Particulate matter (PM) is another expression of aerosols loading within the atmosphere and is a crucial parameter due to its direct effect on public health. Exposure to $PM_{2.5}$ and PM_{10} has

been associated with mortality and morbidity (Slama et al. 2007, Gent et al. 2003). Numerous studies have attempted to establish the relationship between columnar AOD and ground-based PM by using linear model (Pelletier et al. 2007, Koelemeijer et al. 2006). This relationship depends strongly on auxiliary parameters such as height of Planetary Boundary Layer (HPBL), Relative Humidity (RH), wind speed and direction (Ws, Wd) (Gupta et al. 2006). In this paper, the first systematic observations performed during the AIRSPACE project at the four urban areas in Cyprus, Limassol, Nicosia, Larnaca and Paphos, are presented. The data in Nicosia and Paphos were retrieved in July 2011, for Larnaca in August 2011 and for Limassol, which is the main study area, the data covered the period of March 2011 and July to September 2011 due to the availability of data for all the instruments used in the study. For each site, the PM_{10} readings in conjunction with MODerate resolution Imaging Spectro radiometer (MODIS) AOD data and sun-photometer measurements were analyzed.

2 Data and Methodology

2.1 Data

In order to retrieve AOD values at 500nm, two Microtops II hand-held sun-photometers were used and measurements performed in Nicosia, Larnaca and Paphos. In Limassol the AOD values were retrieved from both Microtops II and CIMEL sun photometer. The CIMEL comprise part of the AErosol RObotic NETwork (AERONET) and the aerosol data are acquired during daylight and in clear sky conditions. In this study level 2 (March 2011) and level 1.5 (July-September 2011) data were used. Additionally, MODIS AOD data at 550nm were retrieved from both EOS-Terra and EOS-Aqua satellites. Both instruments acquire data daily during daytime when they cross Europe near 1030h and 1330h local solar time. The spatial resolution for both instruments is 10x10 km^2 and two different algorithms over land and sea surfaces are used due to the different radiative properties of water and land.

The TSI DustTrak (model 8533 and 8520) 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. In each site, it is located near the Microtops II sun photometer in the roof of a building chosen according to restrictions in order to avoid the local sources of pollution which may affect the measurements.

In order to examine the origin of air masses ending over Cyprus the HYSPLIT (Hybrid Single Particle Lagrangian Integrated Trajectory Model) model was used (Draxel and Hess 2004). The 2-day back trajectories of the air parcels arriving over Cyprus up to an altitude of 3km were simulated. The simulation concerns three different height regions: 500, 1500, 3000 m a.s.l. (fig.1).

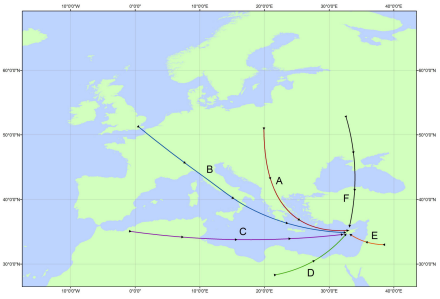


Fig. 1. Main trajectories ending over Cyprus

Meteorological data consist of HPBL, RH at the ground at 08.00 LST, hourly Ws and Wd. The Ws, Wd and RH obtained from the Cyprus Meteorological Services. HPBL has been estimated by using the first derivative of the Range Corrected Signal (RCS) (Menut et al. 1999) from lidar. The backscatter lidar provides aerosol or cloud backscatter measurements from a height beginning from 200m up to tropopause height.

2.2 Methodology

Ground-based AOD data from CIMEL and Microtops II sun photometers and satellite AOD data are used in conjunction with PM_{10} measurements in order to retrieve a relationship between AOD and PM_{10} for the four main cities of Cyprus. 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^2, this allows for the measurement of the vertical profile of aerosols using the lidar signals when available, as well as meteorological data in order to increase the correlation between two study parameters. Lidar, sun photometer and DustTrak measurements were held daily during the Terra and Aqua MODIS overpass (06:00-11:00 UTC).

3 Results

Figure 2 shows the linear regression concerning AERONET - AOD and PM_{10} for the period March and July - September 2011 (for April to June 2011, the CIMEL sun-photometer had sent for the annually calibration) for Limassol. The following days with dust events occurring were excluded (29-30/3, 25/8, 7/9, 29/9/2011) from the statistical analysis, since no direct relation exists between columnar AOD and ground-based PM_{10} during dust intrusion (Nisantzi et al. 2011). According to the coefficient of determination (R^2=0.2736) the correlation coefficient for 1146 measurements is 0.523 and it is statistical significant in the level of confidence a=0.005. We used AERONET-AOD data instead of MODIS since MODIS-AOD retrievals for Limassol for the study period were limited (n=37). However based on previous study (Nisantzi et al. 2011) the correlation coefficient between AOD derived from MODIS and AERONET is 0.82, so this led us to use AERONET-AOD in case of absent of MODIS-AOD and vice-versa.

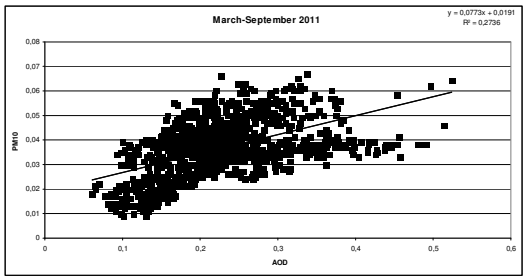


Fig. 2. Relationship between PM_{10} and AERONET - AOD

In order to group the measurements we divide them according to Wd, Ws, HPBL, RH(%) and the 6 main trajectories ending over Cyprus. Table 1 presents the best correlation found for each category.

Table 1. Statistical elements for the best correlation for each study category.

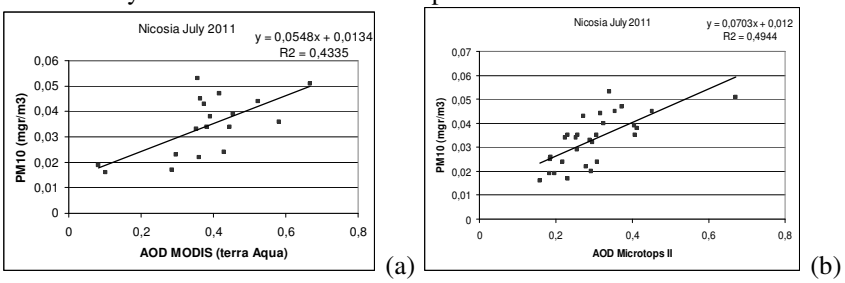
	Slope	Bias	R²	R	n
Wd: North	0.148	0.004	0.596	0.77	108
Ws: 0-4knots	0.159	0.004	0.568	0.75	100
RH: 0-40%	0.134	0.004	0.479	0.69	130
HPBL:650-900m	0.151	0.003	0.524	0.72	263
Trajectory: E	0.131	0.00008	0.786	0.89	66

Regarding Wd and Ws, we noticed that high correlation between PM_{10} and AOD was established when prevailing wind from the north direction and with low speed. When RH is less than 40%, AOD values correlated better with PM_{10} values

as also found in other studies (Gupta et al. 2006). Concerning HPBL it was expected that the higher correlation would happen for lower values (Gupta et al. 2006). This may not present because during the measurements, frequently there was a layer above the PBL in Limassol area in a height of 1500m and this did not permit the usual procedure of PBL evolution. Thus AOD values remained high in contrast with PM_{10} values. While in case of low HPBL without any layer above it, low AOD values correspond to low PM_{10} values. Regarding the analysis of trajectories, it was found that when air masses move from the western part of Asia (see category E, fig. 1), AOD and PM_{10} are better related.

During the one month of measurements for Paphos, Larnaca and Nicosia only the statistical analysis for Nicosia are shown the best correlation between the study parameters. Unfortunately during the one month of measurements for Larnaca and Paphos there were only 2 and 5 retrievals of AOD from MODIS, respectively. This did not allow any conclusion to be drawn about satellite AOD and ground-based PM_{10}. It is worth mentioning that for coastal cities of Limassol, Larnaca and Paphos both Aqua and Terra MODIS retrievals are limited. Additionally, for coastal areas, the relationship between AOD and PM_{10} did not present significant correlation; this may be due to the development of sea breeze during the summer months which diffuses the pollutants within the hinterland (Pokhrel and Lee, 2011).

For the continental area, Nicosia, the first results have shown a well defined relation for both ground-based and satellite derived AOD and PM_{10} (R= 0.7 and R= 0.66 respectively), despite the short period of measurements (fig 3). Using the meteorological data for the three validation sites there was not any clear evidence in order to classify the data due to the limited period of measurements.



(a) (b)

Fig. 3. Linear correlation between PM_{10} and (a) MODIS (Terra – Aqua) – AOD, (b) Microtops II-AOD

4 Conclusions

This paper presented the analysis of the first measurements derived from an ongoing research project (AIRSPACE). It was found that the parameters that regu-

late the correlation in the highest level between PM_{10} and AOD are the north Wd, the low Ws (0-4knots), the low RH value (<40%), the HPBL between 650-900m and the trajectory category E. For the validation sites only Nicosia, possibly due to its geographical position, has given a good correlation between columnar AOD and ground-based $PM_{10.}$ In a latter stage, more measurements are to be implemented using additionally the Harvard Impactors, designed by Pr. Koutrakis that have been installed to the four cities of Cyprus. Thus, $PM_{10,}$ $PM_{2.5}$, EC-OC and Nitrate concentrations will be also available in the next months.

Acknowledgments 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.

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