LOCAL - AIR PROJECT: TROPOSPHERIC AEROSOL MONITORING BY CALIPSO LIDAR SATELLITE AND GROUND-BASED OBSERVATIONS

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ABSTRACT

A new method for the detection of the Planetary Boundary Layer (PBL) height from CALIPSO space-borne lidar data was developed and the possibility to infer the sub-micrometric aerosol particle (i.e., PM_1) concentrations at ground level from CALIPSO observations was also explored. The comparison with ground-based lidar measurements from an EARLINET (European Aerosol Research LIdar Network) station showed the reliability of the developed method for the PBL. Moreover, empirical relationships between integrated backscatter values from CALIPSO and PM_1 concentrations were found thanks to the combined use of the retrieved PBL heights, CALIPSO aerosol profiles and typing and PM_1 in-situ measurements.

1. INTRODUCTION

Aerosol monitoring is usually carried out through ground-based monitoring networks that measure the concentration of particulate matter (PM). The main limitation of these networks is their inability to provide wide spatial coverage because of the local character of the measurements. On the other side, satellite remote sensing provides typically a larger spatial coverage but for columnar aerosol parameters. Since 2006, CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) has been providing the vertical distribution of aerosol at global scale. In principle, this could offer the possibility to globally investigate into detail the PBL (Planetary Boundary Layer) region, but limits and uncertainties should be carefully assessed.

In this context, the LOCAL AIR (LOCAL Aerosol monitoring combining In-situ and Remote sensing observations) project aims at the development of a methodology for a synergistic use of data at different resolutions from several platforms for the characterization of tropospheric aerosols on a local scale.

2. DATA AND METHODS

2.1 Satellite observations

Lidar data from CALIPSO were used for taking advantage from its capability of providing vertical aerosol profiles at global scale [1]. CALIPSO is a 2-wavelength elastic backscatter lidar with polarization capability. It provides aerosol and clouds layering and aerosol backscatter and depolarization profiles. Aerosol extinction profiles are also provided through lidar ratio assumptions. In this project, the aerosol optical profiles (Level2 Profile products) and layering and typing information (level2 VFM products) were used.

2.2 Ground-based observations

The study was carried out in correspondence of CALIPSO overpasses at CIAO (CNR-IMAA Atmospheric Observatory) [2], the most advanced atmospheric observatory in the Mediterranean region equipped with active and passive sensors for aerosol, clouds and water vapor observations. In particular, EARLINET (European Aerosol Lidar Network) [3] observations performed at CIAO were found fitting with the scope of the project. EARLINET systems at CIAO are able to provide quality assured profiles of aerosol extinction and backscatter at 2 and 3 wavelengths respectively plus depolarization ratio profiles at 532nm.

In addition, daily concentrations and chemical composition of sub-micrometric aerosol particle (i.e., PM_1) measured at CNR-IMAA from April 2006 to March 2007 were also used [4].

2.3 Methodological approach

The main concept of the project is to use CALIPSO data for providing information about

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local air quality. To this aim, a specific methodology has to be developed and its performance has to be assessed using ground-based measurements as a reference. A first step in this direction was the determination of the PBL top from CALIPSO lidar data. Concerning this, only two methods have been reported in literature up today [5, 6, 7], but one method [5, 6] is limited to cloud free conditions and the other one [7] is unreliable in case of dust advection. Therefore, a new method was developed and investigated. The values obtained were used as input for determining the aerosol backscatter integrated value (IB) into the PBL, an important parameter (under well mixed situation assumption) for the air quality at the surface. Then, the relationship among IB and PM_1 was studied in order to find empirical relationships for inferring PM_1 concentration values from CALIPSO lidar data.

3. RESULTS

For the investigation of PBL top, the study was focused on 2 years, from June 2006-May 2008. During this period, a total of 163 CALIPSO overpasses (daytime and nighttime) occurred within 100 km from CIAO observatory (Figure 1).

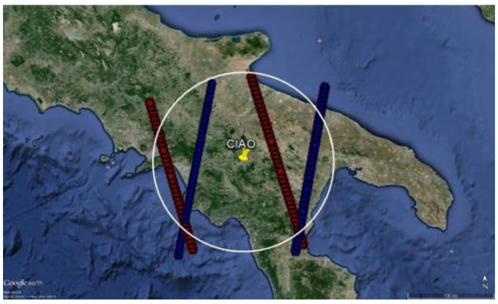

Figure 1. Nighttime (blue) and daytime (red) CALIPSO overpass traces within 100 km from CIAO observatory (white circle). Aerial photography courtesy of Google Earth (http://earth.google.com/).

In order to estimate the PBL top, the maximum variance technique was borrowed from [5, 6] and applied to the profile of the total aerosol backscatter at 532 nm reported in CALIPSO Level 2 Aerosol Profile (APro) products. This allowed to overcomes the problem of cloud presence in [5, 6] method. On the other hand, searching for the maximum variance, the new method could also overcome the problem of unreliable PBL values in [7] for dust intrusion.

The new method (indicated as APro from the data product on which it is applied) was compared with the existing ones (TAB [5, 6] and ALay [7]) and with ground-based collocated measurements for checking its performances.

As Table 1 shows, the application of the maximum variance technique to TAB and APro allowed the PBL detection in most of the cases (i.e., 108 and 103 out of 163 cases, respectively).

Method	Night	Day	Total
TAB	75	33	108
ALay	43	33	76
APro	57	46	103

Table 1. Number of PBL heights detected by applying the three methods to CALIPSO aerosol data products.

The retrieved PBL heights over the nearest point of CALIPSO overpasses from CIAO were compared with the corresponding PBL heights as determined by Potenza EARLINET station (Figure 2).

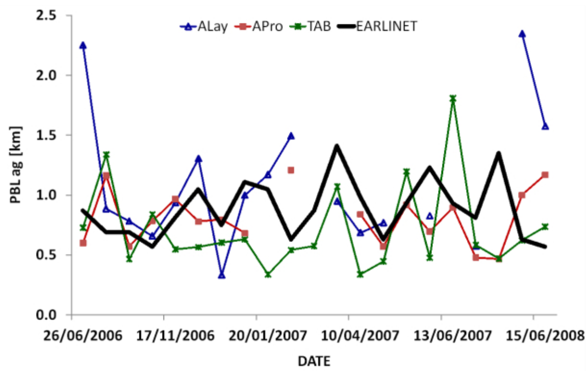

Figure 2. Temporal series of CALIPSO retrieved and EARLINET derived PBL heights.

As Figure 2 shows, the PBL heights detected by applying the maximum variance technique to APro were found to be more consistent with the ground-lidar derived ones with an associated Root Mean Square Error (RMSE) of 0.45 compared to 0.55 and 0.65 for TAB and ALay methods, respectively.

The analyses of the daily and seasonal variability of the PBL heights retrieved using the three methods confirmed the higher capability of the algorithm developed in this study to reconstruct the expected daily and seasonal variations of the

PBL top over the different areas observed (figures not shown).

In order to find empirical relationships able to infer PM_1 concentration values from CALIPSO lidar data, the existing correlations between CALIPSO observations and in-situ PM_1 data were explored. To this aim, at the nearest point of CALIPSO overpasses to CIAO, the IB values were calculated by integrating the CALIPSO total backscatter coefficient at 532 nm profiles within the PBL as estimated by the method developed in this study. Then, the resulting IB values were compared with the PM_1 daily concentrations measured on the same day of the satellite acquisition.

Regression analysis results showed no significant correlation when the entire dataset was considered. This could be due to the fact that different aerosol types have different scattering efficiency, so that the PM-IB relation could be strongly typing dependent.

Low correlation values were observed (R^2<0.5) also by classifying the dataset on the basis of the CALIPSO derived aerosol typing (i.e., Clean Marine - CM, Dust - D, Polluted Continental - PC, Clean Continental - CC, Polluted Dust - PD and Smoke - S.) The low correlations found could be related to some limitations in the CALIPSO aerosol typing, especially in the low troposphere [8].

A significant improvement in the correlations was observed when the dataset was classified according to the ratio between natural (N) and anthropogenic (A) contributions (i.e., N/A) to the PM_1 measured at ground level. In particular, these contributions were calculated starting from the PM_1 trace element composition by applying a methodological approach based on the combined use of the enrichment factor and the chemical mass closure techniques [9].

As Figure 3 shows, two linear relationships between PM_1 concentrations and IB values were found. The first (f1) corresponds to N/A≥0.3 and is characterized by R^2 value of 0.6. The second (f2) corresponds to N/A<0.3 and is characterized by R^2 value of 0.7.

When the CALIPSO derived aerosol type was associated to each IB-PM_1 couple, it was observed that only Polluted Continental (PC) and Polluted Dust (PD) cases corresponded both to N/A≥0.3 and N/A<0.3 (Table 2).

N/A	CM	D	PC	CC	PD	S
TOT	1	2	7	-	10	3
≥ 0.3	0%	100%	43%	-	50%	100%
< 0.3	100%	0%	57%	-	50%	0%

Table 2. Correspondence between data grouped by N/A ratio and CALIPSO derived aerosol types.

In particular, the points corresponding to PD and PC followed the regression line of the first relationship if PM_1 > 8.5 μgm^{-3} and the second relationship if PM_1 < 4.5 μgm^{-3} (Figure 3).

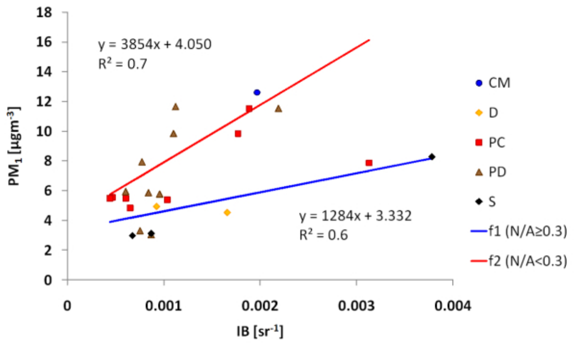

Figure 3. Scatter plot between PM_1 daily concentrations and IB values. The regression lines (f1 and f2) obtained by dividing the IB-PM_1 dataset as a function of the N/A ratio are also reported. Moreover, each IB-PM_1 couple is classified according to the corresponding CALIPSO aerosol type.

Therefore, the reconstruction of the PM_1 concentrations from CALIPSO IB values was obtained as follows. If CALIPSO derived aerosol types were dust or smoke, then f1 was applied. If, polluted dust or polluted continental types prevailed, a further analysis was performed. In particular, PM_1 concentrations were estimated by CALIPSO IB values using both f1 and f2. If the estimated value of the PM_1 concentration by f1 exceeded the value of 8.5 μgm^{-3} or the estimated value of the PM_1 concentration by f2 was lower than 4.5 μgm^{-3}, than the obtained estimate was retained. Otherwise, the PM_1 concentrations were estimated by applying f1 and f2 and averaging the obtained values. For clean marine cases, the same procedure used for polluted dust or polluted continental types was adopted because of the well-known problems for the typing of this category [10]. As Figure 4 shows, a good agreement between retrieved and measured PM_1 concentrations was observed in most of the cases.

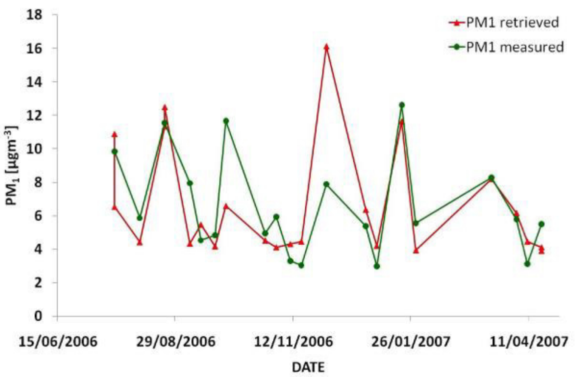

Figure 4. Comparison between retrieved and measured PM_1 concentrations.

4. CONCLUSIONS

A new algorithm for the PBL height detection from CALIPSO space-borne lidar data was developed. The comparison of the retrieved PBL heights with the the EARLINET reference point at CIAO corresponding ones as well as daily and seasonal variation analyses showed its reliability on the investigated area, also compared with methods reported in literature. The possibility to infer PM_1 values at ground from CALIPSO observations was also explored. Thanks to the combined use of retrieved PBL heights, CALIPSO aerosol profiles and typing and PM_1 in-situ measurements, empirical relationships between IB and PM_1 concentrations were found, representing the starting point for the development of a new methodology for providing PM_1 in-situ concentrations from CALIPSO aerosol data. Further work needs to be conducted in order to better understand the empirical relationships obtained and to evaluate the possibility of their transfer to different locations.

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