High spatial resolution aerosol retrievals used for daily particulate matter monitoring over Po valley, northern Italy

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Dear Reviewer,
please find here below our replies (indented), and the improvements introduced in the paper, addressing all of the comments received.

Best regards,
The authors

Anonymous Referee #1

ABSTRACT

Why relating AOD at 550 nm to PM10 and not to PM2.5? A discussion on this issue in particular with respect to the size particles compared to the incident wavelength, that is on the variation of the Mie scattering/extinction efficiency as a function of the particle's dimension would have been proper, maybe in the paragraph where the definition of AOD is presented.

> **REPLY**: The reason to relate AOD at 550 nm to PM10 and not to PM2.5 is based on the number of ground-based stations that measure PM10 over the Po Valley domain which have longer records covering the entire year. As mentioned in Chu et al., 2003 (where a case study in northern Italy has been considered), in the paper we are trying to demonstrate MODIS capability for use in monitoring local air pollution using PM10 as particulate matter concentration. In Italy, PM10 measurements are used for regulatory purposes and for use in monitoring human health. Therefore a comparison with PM10 measurements is needed.

Geographical domain of the study is the Po valley and the time period is whole 2012.
Annual correlation. The correlation is not taking into account seasonal or monthly behavior of the investigated phenomenon (e.g. of the mixing layer) and also all the sampling sites located within the domain are mixed: the different kind of particles in the different areas of the domain of interest (i.e. rural, industrial . . .) is neglected.

> **REPLY**: As stated in the abstract, the main aim of this manuscript is to evaluate the ability of AOD at 550 nm, retrieved from two different products with different spatial resolution, to characterize the spatial distribution of aerosols in northern Italy, especially within urban areas. In the second part of the revised Sec. 3.2 we have reported a more specific analysis considering different subsets of sites. The subsets have been chosen by following the administration divisions (Italian regions) mentioned in the Section 2.1. The analysis has been conduct using the standard deviation analysis and the results showed with a barplot approach, reported in Fig. 8. In the conclusions paragraph of the revised manuscript (reported below) we have added a summary of the scope of the present work and a discussion of future work. The new and more

comprehensive study will be presented in a follow-on manuscript (under development). The abstract has been re-written to better specify that in the manuscript we consider an annual analysis.

Therefore part of the **abstract** in the manuscript has been re-written as below:
"[…]. The introduction of the PBL information is needed for AOD to capture the seasonal cycle of the observed PM_{10} over the Po valley over an entire year of data. It significantly improves the PM versus AOD relationship, leading to a correlation of $R^2 = 0.98$ for both retrievals when they are normalized by the PBL depth. […]"

Therefore part of the **conclusions** in the manuscript has been re-written as below:
"[…]. The results reported in this work were obtained but considering just one factor that may affect the relationship between the ground-based and the satellite remote-sensing measurements.

In future studies, we will focus on three aspects, improving the understanding of the satellite-retrieved AOD and PM_{10} relationships. First, we will investigate the possibility to divide the entire domain into areas to study the role of environmental conditions on the PM_{10} – AOD relationship. Because the high level of urbanization affects surface brightness and thus the quality of the aerosol retrieval, our goal will be to demonstrate the performance of MAIAC AOD and the benefit of its high spatial resolution and performance over brighter urban areas if used over urban domain (Lyapustin et al., 2011b). The Po Valley has areas with significant high levels of urbanization. Achieving this goal could lead to a retrieval suitable for a daily monitoring of air pollution within urban areas. As second focus, we will study how the relationship of AOD retrieved in ambient condition and dehumidified PM at surface is affected by relative humidity (RH). Seasonal changes in AOD are more prominent compared to seasonal changes in PM10 mass concentration due to sensitivity of urban aerosols to relative humidity. AOD increases in summer time due to particle growth under humid conditions (Wang and Martin, 2007, Altaratz et al., 2013). Finally, we will investigate the use of higher resolution PBL estimates obtained from regional NWP over Italy (Kukkonen et al., 2012, Baldauf et al., 2011, Barthlott et al., 2010) and explore the relationship for each administrative district over Po valley separately. The aim would be to investigate if the use of finer PBL depth and satellite-retrieved AOD (MAIAC) helps to characterize the spatial variability of aerosol pollution within the Po Valley and study the impact of industrialized regions on PM vs. AOD relationships. "

In the manuscript, the following **references** have been added:

Wang, J., & Martin, S. T. (2007). Satellite characterization of urban aerosols: Importance of including hygroscopicity and mixing state in the retrieval algorithms. *Journal of Geophysical Research: Atmospheres (1984–2012)*, *112*(D17).

Altaratz, O., Bar-Or, R. Z., Wollner, U., & Koren, I. (2013). Relative humidity and its effect on aerosol optical depth in the vicinity of convective clouds. *Environmental Research Letters*, *8*(3), 034025.

No reference to any relationship between AOD and PM upon which the introduction of the mixing layer height as a normalizing factor is given. The fact that the correlation increases using the normalizing factor is not enough a reference to a method, to a theory should be mentioned and in the following, in a dedicated paragraph, discussed.

REPLY: In the section 2.4 of this manuscript the relationship between AOD and PM with the introduction of the mixing layer height as a normalizing factor is introduced. This section has been revised: new references have been added and the method of normalization followed in the literature by Tsai et al., 2011 has been clearly presented, adding in the section a schematic and a brief discussion.

Therefore part of the **Section 2.4** in the manuscript has been re-written as below:

"[…] As suggested by the literature (Gupta et al., 2006, Barnaba et al., 2010, Boyouk et al., 2010, Tsai et al., 2011, Chu et al., 2013, 2015), the PM - AOD correlation may be improved by considering meteorological data information or vertical distribution of aerosols. […] As mentioned previously, the Aerosol Optical Depth is an integration of the aerosol extinction, from the surface to the top of the atmosphere:

$$AOD = \int_{0}^{TOA} \sigma_{0.55\mu m}^{ext}(z)\,dz \qquad (1)$$

In Tsai et al., 2011, two types of aerosol vertical distributions are discussed. The first type has well-mixed aerosols confined in the PBL; the second type is characterized by two layers of aerosols, one where the aerosols are well-mixed in the PBL and one with an exponential decay of aerosol extinction coefficient with height above the top of the PBL. The first type is assumed in this study. Mathematically it can be illustrate as follows:

$$AOD^{*} = \sigma_{0.55\mu m}^{ZPBL} ZPBL \qquad (2)$$

which is schematically represented in Fig. ??. Under the hypothesis that most of the aerosols are confined and mixed homogeneously within the planetary boundary layer, the values of AOD normalized by PBL depth may be regarded as mean PBL extinction in km^{-1} ($\sigma_{0.55\mu m}^{ZPBL}$)**.** It may be more representative of the surface PM_{10} concentration since variations in the depth of the PBL are accounted for, and the correlation between PM_{10} and AOD/ZPBL would be higher. The normalization was applied both for MYD04 and MAIAC AOD retrievals. […]"

and it has been introduced the following **figure**:

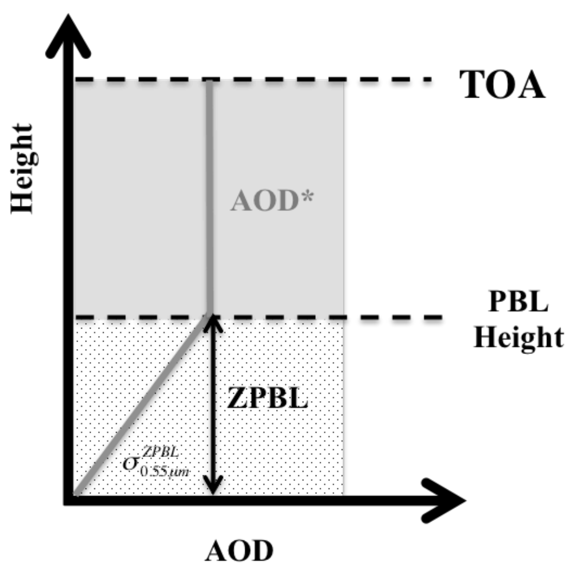

Figure ??. (The correct number of the figure will be defined when it introduced in the revised manuscript) Schematic aerosol vertical profile where the aerosols are considered well-mixed and confined in the PBL height.

In the manuscript, the following **references** have been added:

Barnaba F., Putaud, J.P.,Gruening C., dell'Acqua A., Dos Santos S., 2010. Annual cycle in collocated in situ, total-column, and height-resolved aerosol observations in the Po Valley (Italy): implications for ground-level particulate matter mass concentration estimation from remote sensing, J. Geophys. Res., 115, D19209, doi:10.1029/2009JD013002.

Boyouk, N., J. F. Léon, H. Delbarre, T. Podvin, and C. Deroo, 2010. Impact of themixing boundary layer on the relationship between PM2.5 and aerosol optical thickness, Atmos. Environ., 44, 271-277.

Chu, D. A., Tsai, T. C., Chen, J. P., Chang, S. C., Jeng, Y. J., Chiang, W. L., & Lin, N. H. (2013). Interpreting aerosol lidar profiles to better estimate surface PM 2.5 for columnar AOD measurements. *Atmospheric Environment*, *79*, 172-187.

Chu, D. A., Ferrare, R., Szykman, J., Lewis, J., Scarino, A., Hains, J., Burton, S., Chen, G., Tsai, T., Hostetler, C., Hair, J., Holben, B., Crawford, J., (2015). Regional characteristics of the relationship between columnar AOD and surface PM 2.5: Application of lidar aerosol extinction profiles over Baltimore–Washington Corridor during DISCOVER-AQ. *Atmospheric Environment*, *101*, 338-349.

1. INTRODUCTION

The authors underline the importance of the improved spatial resolution of AOD products from 10 to 1 km - on which one completely agrees - but this is then in contrast with the use of meteorological information at the resolution of 0.5 x 0.5 degree which at the latitude of the domain of interest is approximately 55 km
Don't the authors think that it would have been appropriate to fuse meteorological and satellite-derived information of the same order resolution? How the integration of information at 1km resolution and at 55 km resolution could provide reliable information in output? A sensitivity analysis on this has been previously performed? In this case, the results should be presented and if not, it would be highly recommended. Fusing data of so different spatial scale [data coming from different sources (simulations and satellite retrieval) and describing spatially highly variable phenomena] could mask behaviors in the AOD to PM relationship, which cannot be distinguished in this way.

REPLY: The reason for using meteorological information at the resolution of 0.5 x 0.5 degree was determined on the best availability at the time of the analysis.
The use of meteorological information with less resolution than the spatial resolution of AOD products is an issue that is acknowledged in the revised manuscript and we intend to use a new meteorological database with higher resolution meteorology in further research, as discussed in the revised conclusions paragraph.

2. DATA AND METHODS

Fig1 - in the figure legend the acquisition time of the MODIS/Aqua data could be mentioned

REPLY: The acquisition time of the MODIS/Aqua data presented in Fig.1 is 12:55 UTC on 16 March 2012.

Therefore part of the caption of the **Fig.1** in the manuscript has been re-written as below:
"**Figure 1.** Geographic study domain. MODIS (Aqua) satellite True Color RGB image –1km, 16 March 2012, acquired at 12:55 UTC. The blue circle represents the geographic location of the Ispra AERONET station in the Po Valley. "

2.1 Ground-level concentration of PM_{10}

In this section, it could have been mentioned as a reference method the gravimetric technique for measuring PM concentration.

<u>REPLY</u>: As explained in the corresponding section, each regional ARPA network has a unique set of measurements with different uncertainties. All the instruments used are equivalent to the gravimetric technique required by framework of the EC Directive on ambient air quality and cleaner air for Europe (2008/50/EC).

<u>In the manuscript, the following **references** have been added:</u>

"Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on "Ambient air quality and cleaner air for Europe"," *Official J.*, vol. L152, pp. 1–44, Nov. 6, 2008.

Moreover also a discussion should be inserted on how the authors have considered the problems related to the comparison of a dry measure of the PM with respect to the atmospheric-condition of the AOD satellite estimates.

<u>REPLY</u>: We have added an acknowledgement of the role of the relative humidity on AOD measurements in the revised manuscript. It is intention of the authors to investigate the essential role of the relative humidity on the PM-AOD relationship in the future. The results will be presented in the oncoming manuscript, where the main focus will be to extend the annual PM-AOD correlation presented here to daily.

<u>Therefore part of the **Section 2.1** in the manuscript has been re-written as below:</u>
"[…] Again, all the instruments used are equivalent to the gravimetric technique, inserted within the framework of the EC Directive on ambient air quality and cleaner air for Europe (2008/50/EC)."

it has been also introduced in the Section 2.4 to better specify that the only improvement to the PM-AOD relationship considered in the manuscript is the introduction of information on the vertical distribution of aerosols.
<u>Therefore part of the **Section 2.4** in the manuscript has been re-written as below:</u>
"PM_{10} and AOD represent two different measurements of the atmospheric loading of pollutants. The PM_{10} is the dry mass, measured at ground level, at a specific geographic location. On the other hand, the satellite AOD represents total column aerosol loading averaged over a specific spatial area and it depends on the environmental conditions. As suggested by the literature, the PM - AOD correlation may be improved by considering meteorological data information, such as the role of the relative humidity (RH), or the vertical distribution of aerosols (Gupta et al., 2006, Wang and Martin, 2007, Tsai et al., 2011). In this work, variations in the vertical distribution of aerosols are considered by introducing information on the Planetary Boundary Layer (PBL) depth. […]."

<u>In the manuscript, the following **references** have been added:</u>

Wang, J., & Martin, S. T. (2007). Satellite characterization of urban aerosols: Importance of including hygroscopicity and mixing state in the retrieval algorithms. *Journal of Geophysical Research: Atmospheres (1984–2012)*, *112*(D17).

2.3 Satellite data and ground measurements co-location

Fusing meteo and satellite derived data. Is the satellite acquisition-time parameter considered? and how? with respect to the satellite overpass hour, which hour of meteorological analysis has been chosen? isn't the mixing layer height varying during the 6 hours considered? Within this frame, it should be taken also into account that *the satellites derived information could reach the spatial resolution of 1km.*

REPLY: The satellite acquisition-time was considered. As introduced in Section 2.4, the meteorological analysis of this work was based on the 6 hourly 0.5 × 0.5 degree analysis files from the NOAA National Center for Environmental Prediction (NCEP) Global Data Assimilation System (GDAS). For each day four analysis files are available, one per each synoptic hour (00, 06, 12 and 18 UTC). Therefore, these 6 hourly meteorological files were interpolated in time to the satellite overpass hour.
This is discussed in Section 2.4 of the revised manuscript where the meteorological analysis is introduced.

Therefore part of the **Section 2.4** in the manuscript has been re-written as below:
"[…] The PBL height (ZPBL) values derive from 6 hourly 0.5 × 0.5 degree analysis files from the NOAA National Center for Environmental Prediction (NCEP) Global Data Assimilation System (GDAS), downloaded from *nomads.ncdc.noaa.gov*. For each day, four analysis files are available, one per each synoptic hour (00, 06, 12 and 18 UTC). Therefore, these 6 hourly meteorological files were interpolated in time to the satellite overpass hour over the Po Valley domain. […]"

2.4 AOD normalization

The comparison between mixing layer height (Hmix) derived from GDAS and CALIPSO liar measurements is interesting. Since different studies have been published on the comparison of simulated Hmix and measured Hmix, a reference could be introduced here to better understand the behavior of the GDAS values. Actually, different approximations are employed to calculate mixing layer height in a meteorological model, and several methods used to retrieve Hmix from LIDAR measurements. Which definitions and methods have been chosen and then employed here, and how these choices affect the results?

REPLY: This section has been re-written in the revised manuscript. In the revised manuscript (Section 2.4 – AOD normalization), previous research has been cited to present different studies published on the comparison of simulated and measured Hmix. This helps to complete the section and to underline the fact that more than one method to measure the mixing-layer has been published. Moreover, how the PBL height from the GDAS analysis files is determined is now included.

Therefore part of the **Section 2.4** in the manuscript has been re-written as below:
"[…]. As suggested by the literature (Gupta et al., 2006, Tsai et al., 2011), the PM - AOD correlation may be improved by considering meteorological information or the vertical distribution of aerosols. The use of PBL depth as parameter to improve the determination of PM from AOD measurements may be determined both by measurements (Boyouk et al., 2010, Barnaba et al., 2010, Tsai et al., 2011, Chu et al., 2013) and models simulations (Gupta and Christopher, 2009, Emili et al., 2010). Recently, Chu et al., 2015, have published campaign of measurements for mapping vertical and horizontal distribution of aerosols, over the Baltimore - Washington Corridor. For the current analysis, the variations of the vertical distribution of aerosols are considered by introducing information on the Planetary Boundary Layer (PBL) depth. This parameter is provided by 6 hourly analysis files from the NOAA National Center for Environmental Prediction (NCEP) Global Data Assimilation System (GDAS), downloaded from *nomads.ncdc.noaa.gov*, with a spatial grid resolution of 0.5°x0.5°. For each day, four analysis files are available, one per each synoptic hour (00, 06, 12 and 18 UTC). Therefore, these 6 hourly meteorological files were interpolated in time to the satellite overpass hour over the Po Valley domain. The GDAS PBL height is diagnostically determined and uses the bulk-Richardson approach (Troen and Mahrt, 1986) to iteratively estimate a PBL height starting

from the ground upward (Hong and Pan, 1996). […]. Comparison between the coincident CALIPSO and GDAS PBL depths shows very similar seasonal trends but CALIPSO PBL depths are systematically higher than the GDAS analysis. The bias between the two trends could be due to the two approaches used to determine the PBL height, the first from a Lidar measurement, which is a really measure of the mixing layer depth, and the second from a model implementation.

In the manuscript, the following **references** have been added:

Troen, I. and L. Mahrt, 1986. "A Simple Model of the Atmospheric Boundary Layer: Sensitivity to Surface Evaporation." Boundary Layer Meteorology. Vol. 37, pp. 129-148.

Gupta, P., and S. A. Christopher (2009), Particulate matter air quality assessment using integrated surface, satellite, and meteorological products: Multiple regression approach, J. Geophys. Res., 114, D14205, doi:10.1029/2008JD011496.

Emili, E., Popp, C., Petitta, M., Riffler, M., Wunderle, S., & Zebisch, M. (2010). PM 10 remote sensing from geostationary SEVIRI and polar-orbiting MODIS sensors over the complex terrain of the European Alpine region. *Remote sensing of environment*, *114*(11), 2485-2499.

Hong, S.-Y. and H.-L. Pan, 1996: Nonlocal boundary layer vertical diffusion in a medium-range forecast model. Mon. Wea. Rev., 124, 2322-2339

3 RESULTS AND DISCUSSION

3.1 AERONET validation

It could be interesting here mentioning the values provided by the Aeronet validation made by the official MODIS NASA team and discussing similarities and/or discrepancies.

REPLY: Referring to the Remer et al., 2005 paper, the reported accuracy of MODIS AOD provided by the Aeronet validation has been integrated in the section.

Therefore part of the **Section 3.1** in the manuscript has been re-written as below:

"[…] Moreover, the AERONET data are interpolated in logarithm of wavelength 0.55 μm and 0.47 μm for MYD04 and MAIAC respectively. Scatter plots for the collocated AERONET Level 2.0, MYD04 and MAIAC AOD are shown in Fig. 6. The regression equation and determination coefficient are reported at the top of each plot. For MODIS a determination coefficient equal to R^2 = 0.84 was found. Over land, the reported accuracy of MODIS AOD (τ) is $\Delta\tau = \pm 0.05 \pm 0.15\,\tau$ when compared with several ground-based AERONET measurements. On a global basis, about 68% AOD retrievals fall within expected errors. It indicates that the algorithm is retrieving aerosol optical thickness over land to roughly within the expected accuracy, with an R^2 = 0.64 (Remer et al., 2005). Event thought the value seems to be lower than the one obtained in the analysis of this work, the validation of the AOD parameter was obtained by considering an older collection of MODIS AOD retrieval (a combination of Collection 3 and 4) and over a more extensive range of aerosol types. For MAIAC AOD retrieval a R^2 = 0.69 was obtained. MAIAC (N = 32) provides more data points than Collection 5.1 (N = 25), reflecting the higher spatial resolution of the MAIAC aerosol retrieval algorithm.

In the manuscript, the following **references** have been added:

Remer, L. A., Kaufman, Y. J., Tanre´, D., Mattoo, S., Chu, D. A., Martins, J. V., Li, R.-R., Ichoku, C., Levy, R. C., Kleidman, R. G., Eck, T. F., Vermote, E., and Holben, B. N., 2005:

The MODIS Aerosol Algorithm, Products, and Validation, J. Atmos. Sci., 62, 947–973, doi:http://dx.doi.org/10.1175/JAS3385.110.1175/JAS3385.1

3.2 Time series analysis

The PM10 monthly mean has been calculated for all the 126 stations together - no values of the standard deviations has been reported in the graphics or written in the dedicated text neither for PM10 or AOD. This parameter can provide significant information concerning parameters as AOD or PM; small values of the standard deviation (w.r. to the mean value) could suggest that phenomena is not varying in the time-period considered, on the other hand, values of the standard deviation of the same order of the mean value could suggest that the phenomena is highly variable in the time period in analysis. Has this kind of analysis been carried out? For example also trying to figure out if similarities exists among subsets of the overall 126 sites set. The only one parameter discussed here is the method employed to carry out the co-location with the results that no appreciable difference between the two-colocation methods.

REPLY: This section has been re-written. First, we have changed the title of the subsection 3.2 as "3.2 Seasonality in PM_{10}-AOD relationship". Second, as suggested by the referee, the standard deviations have been reported in the figure (referring to Figure 7 in the manuscript), for the approaches considered. Specifically, the plots have been updated as a box and whisker plot (see new updated figure below). Moreover a new Table (Table 1 see below) has been introduced, which summarizes the PM10 and AOD total available data. A discussion of the new analysis has been added, for both PM10 and AOD variables, highlighting how the seasonal variability compares. In the second part of the section we have reported a more specific analysis considering the entire 126 available ground-based available sites in the Po Valley divided into subsets. The subsets have been chosen by following the administration divisions (Italian region) mentioned in the Section 2.1.

Therefore part of the **Section 3.2** in the manuscript has been re-written as below:
"The AOD - PM_{10} analysis begins with the study of the 2012 monthly mean trend of PM_{10} versus AOD for both the spatial co-location approaches presented in Sec. 2.3. The results are reported in Fig. 7, with a box and whisker plot approach. The top graph of the figure shows the monthly mean value of PM_{10} 24 hour mass concentration (red box), for all 126 ARPA stations. The AOD monthly mean values are represented on the graph by the blue and the green boxes, for MYD04 and MAIAC, respectively. As immediately evident, the trends in PM and AOD are different during the winter and fall periods for the *nearest-neighbor* coincidence approach. For the methods, a radius of coincidence equal to 0.20° was used to allow for a more direct comparison. The disagreement is particularly notable for the two last months of the year, where the PM monthly mean values increase, while AOD values decrease. The highest values of PM are recorded in this period of the year due to the meteorological conditions that favor the buildup of near-surface pollutants, and regional environmental protection agencies are actively trying reducing air pollution problems (Di Nicolantonio et al., 2009, Mazzola et al., 2010). In winter, a larger variation of PM10 is evident compared to summer. For the AOD datasets happen the opposite, with larger variations in the summer. This may be due to the influence of the relative humidity, where in summer it increases the particle size resulting in higher AOD. Therefore, for the same amount of dry PM_{10} mass concentration, the corresponding AOD measure is larger in summer than in winter (Wang and Christopher, 2003). The same analysis was conducted considering the second approach (*average*) and did not show significant differences (results not shown). Other important aspect, especially both in fall and winter periods, is the unavailability of satellite AOD retrievals due to increased clouds and over domains with high reflectivity surfaces, e.g. urban areas or snow, (Gupta and Christopher, 2008). This leads to a different number of data points, if PM or AOD data are considered, as reported in Table 1. The numbers of coincident AOD values represent just the 30% and 39% of

the total possible PM_{10} measurements, for MYD04 and MAIAC retrieval respectively.

In addition, we divided the entire 126 ground-based sites over the Po Valley into four subsets, following the criteria of the administration divisions (Italian region) mentioned in the Section 2.1. For this study, the subset of PM10, MYD04 and MAIAC data for days when both retrieval products are available for a given ground-based site was considered. Since MAIAC retrieval provides more data, the limiting factor is the availability of MYD04 product. Again, a standard deviation approach was used and the results in unit of percent (%) are reported in Fig. 8 (1, 2 and 3). Although there are some variations among the four regions in topography and climate conditions (e.g. near the seacoast or the mountain chains or high level of urbanization or land use, and differences on the technique and instruments used to measure the daily particulate matter), the standard deviation analysis does not highlight significant variation in PM10 between the different districts. For winter and fall seasons the % standard deviation has the higher values. The higher values of % standard deviation are for January and October/November months, where the number of satellite retrievals is less. This is also evident if the PBL depth normalization is considered; the % standard deviation increases reflecting higher variability due to variations in the PBL depth."

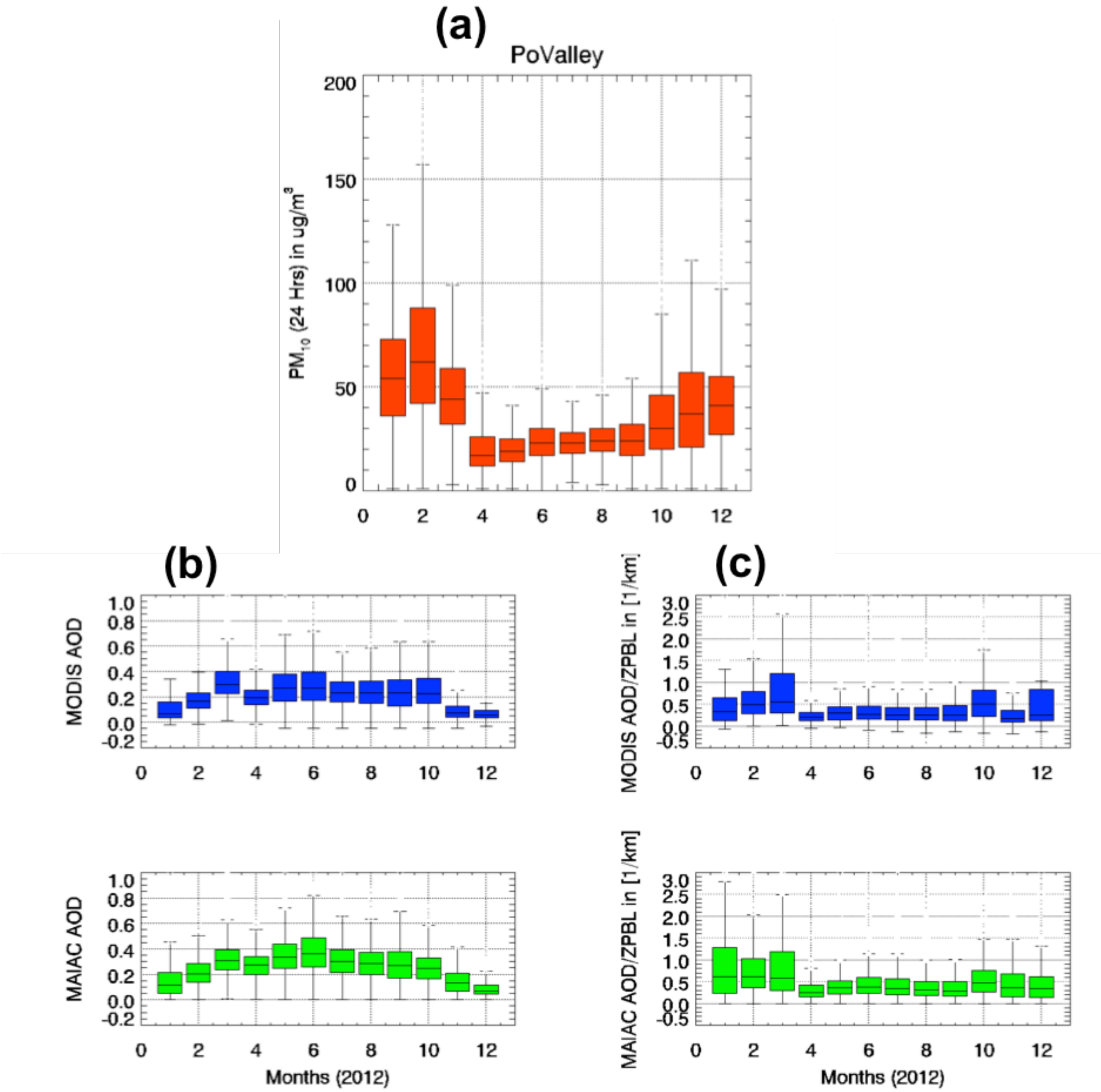

Figure 7. Trend of PM_{10} (μm^{-3}) compared to MYD04 and MAIC respectively. In the panel (b) the relationship PM – AOD is considered, while in the panel (c) is reported the result for PM – AOD/ZPBL relationship. The black line in the box represents the median value, the edges of the box are the 25th and 75th percentiles, and the whiskers should extend out to largest and smallest value within 1.5 times the interquartile range. It was considered a radius of coincidence equal to 0.20°.

and it has been introduced the following **table**:

Table 1. PM_{10} and AOD total available data

Total presumed data (tpd)	N_{tot} = 126 (#stations) * 366(days) = 46116
total PM_{10} retrieved data (trd_PM10)	$N_{PM_{10}}$ = 42798
(trd_PM_{10})/(tpd)	93%
total MYD04 retrieved data (trd_MYD04)	N_{MYD04} = 13603
(trd_MYD04)/(tpd)	30%
total MAIAC retrieved data (trd_MAIAC)	N_{MAIAC} = 18011
(trd_MAIAC)/(tpd)	39%

and it has been introduced the following **figures**:

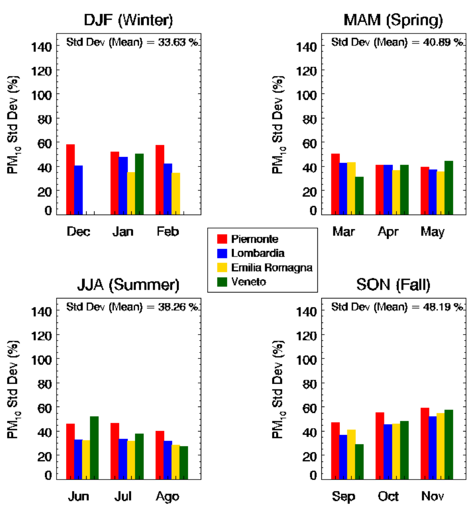

Figure 8 (1). PM_{10} data analysis.

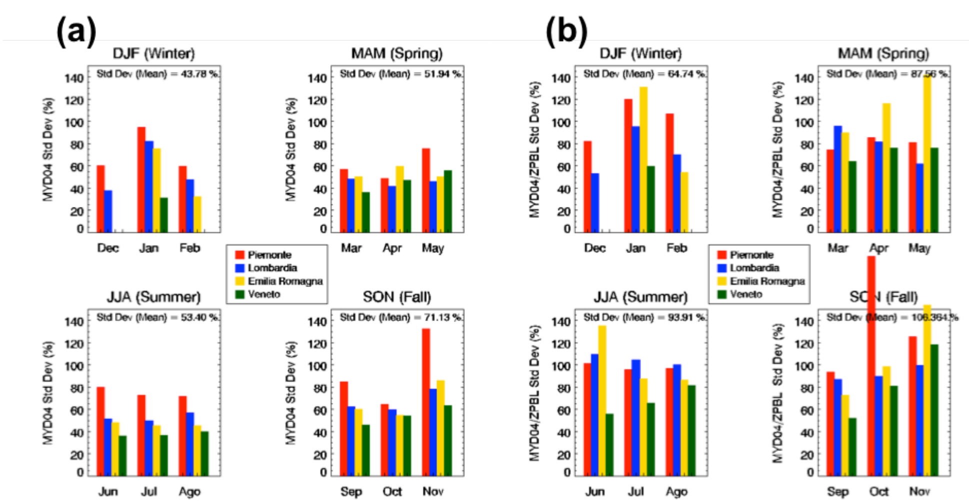

Figure 8 (2). MYD04 data analysis.

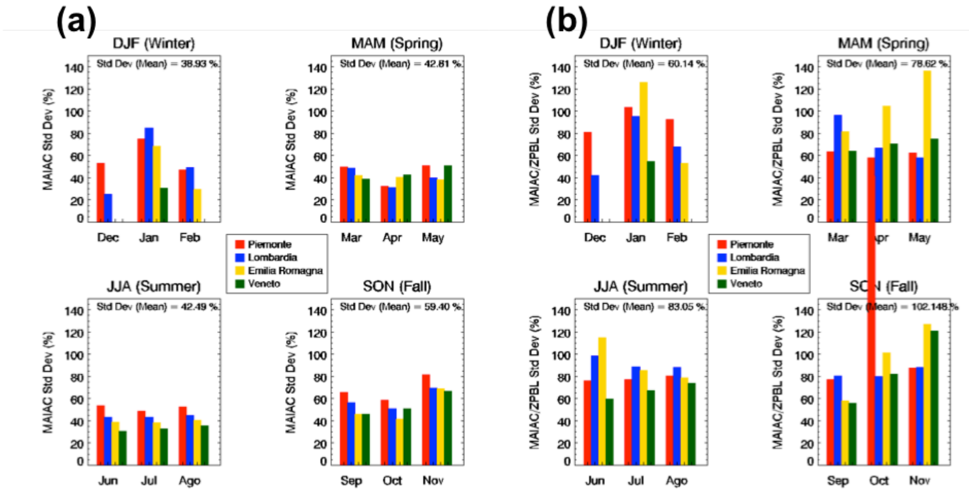

Figure 8 (3). MAIAC data analysis.

Figure 8. Seasonal Standard Deviation (SD) - in % - analysis using PM_{10}, MYD04 and MAIAC data. The total 126 ground-based stations were divided following the administration criteria, obtaining four regions: Piemonte, Lombardia, Emilia Romagna and Veneto. In the panels (b) of Figure 8 (2) - (3) the AOD data were considered normalized by the PBL depth.

In the manuscript, the following **references** have been added:

Gupta, P., & Christopher, S. A. (2008). An evaluation of Terra-MODIS sampling for monthly and annual particulate matter air quality assessment over the Southeastern United States. *Atmospheric Environment*, *42*(26), 6465-6471.

3.3 Scatter plot and bin analysis: PM10 vs. AOD relationship. Comparison of different method of coincidence

In grouping the pm data only on the basis of the concentration values some information concerning aerosol type (anthropic/natural, mixed . . .), seasonality, and other features as hygroscopic behavior and meteorological conditions of the domain are completely neglected. Any analysis concerning these features have been previously performed? With which results?

REPLY: Any analysis regarding seasonality, aerosol type or other features have not been considered yet. But, as mentioned in the previous comments (second comment in the abstract section), as future work, it is intention of the authors to conduct a seasonal and monthly behavior study of the investigated phenomena. Preliminary results have been reported in the conclusions paragraph (see comments above).

4. CONCLUSION

The published results can be already found in literature, in several papers, not only on this preliminary relationship between AOD and PM but also in the same geographical domain, with very similar results. Authors should, at least, mention them. Furthermore, no significantly new elements are here introduced with respect to literature on the use of satellite derived aerosol information for monitoring PM at the surface. Actually, the work here presented would have been enriched with sensitivities analysis concerning the spatial resolution of the different kind of information fused together.

REPLY: In the introduction paragraph a literature review on the relationship between AOD and PM in the same geographical domain has been introduced.

Regarding new aspects introduced in the manuscript, one important element was introduced: the evaluation of the MAIAC retrieval within the Po Valley. This has not been done before. One reason is due to the fact that the MAIAC retrieval is not publically available yet. The only work presented using the MAIAC retrieval near the Po Valley domain is presented in Emili et al., 2011 work. There, a study over the mountain region (Alpine chain, northern Italy) is presented, but the entire industrialized Po Valley domain is neglected. Therefore, a key point of this manuscript was to use a new AOD retrieved database, with higher resolution and investigate how this could be used in an industrialized area as the Po Valley.

Therefore part of the **introduction** in the manuscript has been re-written as below:
"[…]. As they point out, correlations between ground measurements and optical thickness are actively used and investigated. In previous work, the Po Valley domain was studied, where the air quality monitoring from satellite measurements was applied (Di Nicolantonio et al., 2007, Di Nicolantonio et al., 2009, Barnaba et al., 2010). These studies pointed to the use of satellite remote sensing observations for monitoring the air pollution over industrialized and urban areas, such as the Po Valley. […]."

In the manuscript, the following **references** have been added:

Putaud, J. P., Cavalli, F., Martins dos Santos, S., & Dell'Acqua, A. (2014). Long-term trends in aerosol optical characteristics in the Po Valley, Italy. *Atmospheric Chemistry and Physics*, *14*(17), 9129-9136.

Bigi, A., & Ghermandi, G. (2014). Long-term trend and variability of atmospheric PM10 concentration in the Po Valley. *Atmospheric Chemistry and Physics*, *14*(10), 4895-4907.

Mélin, F., and G. Zibordi (2005), Aerosol variability in the Po Valley analyzed from automated optical measurements, Geophys. Res. Lett., 32, L03810, doi:10.1029/2004GL021787.

Di Nicolantonio, W., Cacciari, A., & Tomasi, C. (2009). Particulate matter at surface: Northern Italy monitoring based on satellite remote sensing, meteorological fields, and in-situ samplings. *Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal of*, *2*(4), 284-292.

Di Nicolantonio, W., Cacciari, A., Bolzacchini, F., Ferrero, L., Volta, M., & Pisoni, E. (2007). MODIS aerosol optical properties over North Italy for estimating surface-level PM2. 5. In *Proceedings of Envisat Symposium* (pp. 3-27).