AIR POLLUTION ASSESSMENT OVER PO VALLEY (ITALY) USING SATELLITE DATA AND GROUND STATION MEASUREMENTS

Barbara Arvani[1]
Ph.D. Student, Dipartimento di Ingegneria Enzo Ferrari, Università di Modena e Reggio Emilia
Sergio Teggi
Assistant Professor, Dipartimento di Ingegneria Enzo Ferrari, Università di Modena e Reggio Emilia
Grazia Ghermandi
Full Professor, Dipartimento di Ingegneria Enzo Ferrari, Università di Modena e Reggio Emilia
Alessandro Bigi
Research Associate, Dipartimento di Ingegneria Enzo Ferrari, Università di Modena e Reggio Emilia
R. Bradley Pierce
Physical Scientist, NOAA/NESDIS Advanced Satellite Products Branch

Address[1]: strada Vignolese, 905/A – Modena – Italy – 41125 – Tel: (+39-059-2056295) – barbara.arvani@unimore.it

ABSTRACT

Due to their effect on human health, the study of atmospheric pollutants is an important concern in the Po valley – northern Italy – one of the main industrialized and populated areas of the country. Our work focuses on the applicability of satellite Aerosol Optical Depth (AOD) retrievals in support of air quality monitoring and assessment in urban environments within the Po valley. This has been accomplished by using the implementation of the International MODIS/AIRS Processing Package (IMAPP) Air Quality Applications software, IDEA-I (Infusing satellite Data into Environmental Applications-International) over the Po valley study area. IDEA-I is a globally configurable software package that uses either Terra or Aqua MODerate resolution Imaging Spectro-radiometer (MODIS) AOD product retrievals to identify local domains of high values of aerosol. For our specific analyses, IDEA-I has been used over the large European domain, centred over the Po Valley. One year (2012) of MODIS AOD product retrievals from MODIS on board NASA's Terra (MOD04) or Aqua (MYD04) satellite has been considered using IDEA-I in a retrospective study. These retrieved data have been also compared with the Particulate Matter (PM_{10}) measurements from the Italian Agency for Environmental Protection (ARPA) ground-based network stations. The acceptable results obtained by the correlation PM_{10} – AOD suggest the satellite AOD as a good substitute for monitoring air quality over the Po valley domain. Yet the 10 km resolution of MODIS – AOD product is considered too large for air quality studies at urban scale. Recently, a new Multi-Angle Implementation of Atmospheric Correction (MAIAC) algorithm has been developed for MODIS which provides AOD data at 1 km of spatial resolution. We have evaluated ability of MODIS product MOD04 and MAIAC products to characterize the spatial distribution of aerosols in the urban area through comparison with surface PM_{10} measurements. Using MAIAC data at 1 km, we have examined the relationship between PM_{10} concentrations, AOD, and AOD normalized by Planetary Boundary Layer (PBL) depths obtained from NOAA National Center for Environmental Prediction (NCEP) Global Data Assimilation System (GDAS), for the same period of analysis. Results show that the MAIAC retrieval provides a high resolution depiction of the AOD within the Po Valley and performs nearly as well in a statistical sense as the standard MODIS retrieval during the time period considered. Results also highlight that normalization by the analyzed PBL depth to obtain an estimate of the mean boundary layer extinction is needed to capture the seasonal cycle of the observed PM_{10} over the Po Valley.

KEYWORDS: Aerosol Optical Depth, air quality, Po valley, MODIS, Planetary Boundary Layer

1. INTRODUCTION

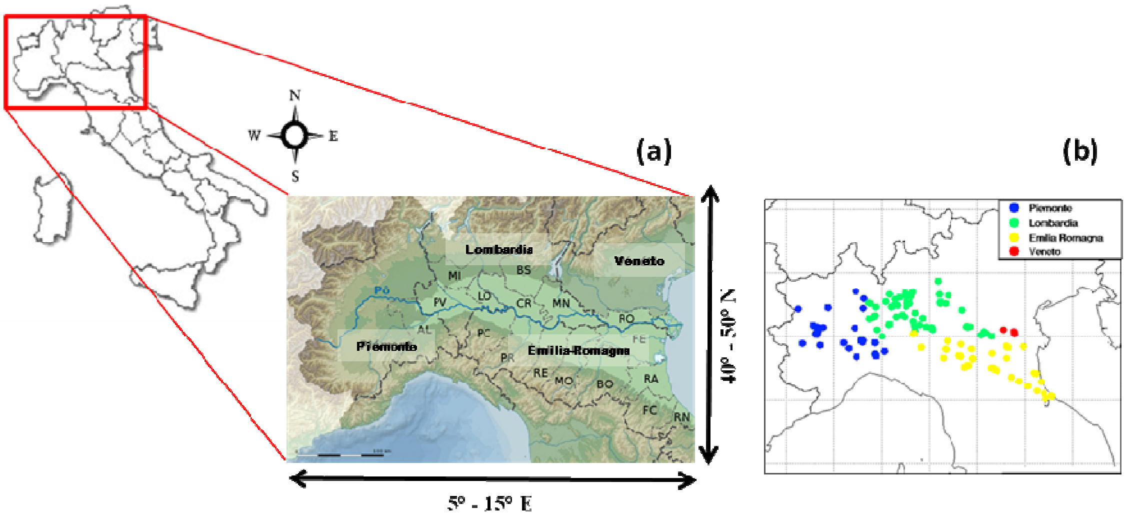

Figure 1: (a) – A map showing the location of the Po valley domain, northern Italy, major industrialized and urbanized regions mentioned in the report. (b) – ARPA network for PM10 measurements over the Po valley. Each colored circle represents the location of a ground-based monitoring station. A different color has been used to distinguish the four different administrative region that cover the Po valley.

Particulate matter (PM), the dry mass of atmospheric aerosols, measured at ground level at a specific geographic location, is one of the major pollutants studied and monitored as it affects air quality in urban and rural areas worldwide. PM is the general term used to define a complex mixture of solid and liquid particles. These particles vary in size and composition, and remain suspended in the air for different periods of time. The source of the atmospheric aerosol include both natural source, such as fire, sea salt, volcanic eruptions and windblown dust, and anthropogenic source, such as combustion, traffic and industrial activity. PM with aerodynamic diameter of 10µm or less (PM_{10}) leads to serious human health effects. They can be inhaled into the respiratory system and so cause respiratory lung diseases and even premature death (Forastiere, et al., 2005; Brunekreef & Forsberg B, 2005). The Po valley, in the northern part of Italy (Fig.1 (a)), is the area with the most severe air pollution problems in the country as it is the largest industrial, trading and agricultural area with a high population density. The Po River, Italy's longest river, flows from the southwestern Alps to the Adriatic Sea crossing Torino and passing South of Milano. Torino has one of the main industrial centers in Italy, within a heavily urbanized metropolitan area, and pollutants often cloud the skies overhead. The Alpine chain at the North and West sides of the valley, and the Apennines to the South, act as a barrier to winds blowing from Northern Europe and the Mediterranean (Mazzola et al., 2010), favoring the stagnation of pollutants. Due to the serious problems related to the urban air pollution in the area, regional environmental protection agencies have been developing capabilities for a continuous monitoring and assessment of air quality not only from ground-based monitoring stations measurements and an under development combination with satellite remote sensing air quality assessment (Gupta et al., 2006; Gupta et al., 2008). Moreover, they have been working to improve sampling techniques to figure out possible ways to reduce and limit the air pollution problem, especially during the winter when the meteorological conditions favor the near-surface pollutants buildup (Mazzola et al., 2010). Ground-based observations represent point measurements and do not have the necessary coverage to map the distribution of aerosols. Looking at the Po valley domain (Fig. 1(b)), the area present a significant coverage of ground-based stations; they are able to give us a good assessment of the air quality condition. Yet, the development of the use of satellite aerosols products since the launch of the Moderate Resolution Imaging SpectroRadiometer (MODIS) has permitted the exploration of new and under investigation research techniques for monitoring air quality over the area of interest (Gupta et al., 2006).This alternative approach for the air quality assessment provides an estimate of the atmospheric aerosol distribution over the studied area and provides air quality data where the ground-based station measurements are not available giving a complete coverage of the area under investigation. The potential for monitoring air quality by space-based sensors has been demonstrated using Aerosol Optical Depth (AOD) data (Chu et al., 2003). The satellite AOD represents total columnar loading of all aerosols particles from Earth surface to the top of the atmosphere averaged over a specific spatial area. The importance to understand the meaning of AOD is connected with the fact that the AOD data can be used in combination with the PM ground-based stations data for the air quality assessment (Gupta et al., 2008). The new point of the research in this field is to study and analyze the exiting correlation between a measurement of air quality that is limited to the first layer of the surface, and a measurement that represent the integral of the entire atmosphere. As it will become clearer later, the use of satellite data to determine the air quality condition over the area of interest has an important application under development. As presented in Sec.4.1, the Terra (or Aqua) MODIS aerosol MOD(MYD)04 product is integrated into an under development software to identify local domains of bad air quality condition and from them the aerosol trajectories are initialized.

In the present study, AOD at 0.55 μm, retrieved from the MODIS (MODerate resolution Imaging Spectroradiometer) sensor on board NASA's Terra satellite, is compared with the several ground-based PM_{10} mass concentration (μgm^{-3}) measurements spread over the Po valley in northern Italy. The whole year 2012 of data was considered. A retrospective study using IDEA-International has been conducted to investigate anomalous points of PM_{10} – AOD on the scatter plot that correspond to unique air quality conditions.

2. DATA AND METHODS

The region of interest, Po Valley domain, is shown in Fig. 1(a), a specific geographic domain over northern Italy- approximately 40◦ - 50◦ N and 5◦ - 15◦ E. The whole Po Valley domain is divided into four administrative divisions (regions) from west to east, Piemonte, Lombardia, Emilia Romagna and Veneto. Although the study area is small compared to, for example, a United States domain, it is possible to identify specific features for each of the four administrative regions within the Po Valley. Piemonte is characterized by major urban centers and industrialized, including the capital city of Turin. Turin has one of the main industrial centers in Italy, within a heavily urbanized metropolitan area, and pollutants often cloud the skies overhead. Most of the ground stations sites of the regional Italian Regional Agency for Environmental Protection (ARPA) network in Piemonte are located near the Alps chain. Lombardia is the most populated region. It has the major industrial sites, including the area of the capital city of Milan. Emilia Romagna, similar to Piemonte, is characterized by major urban centers. Some of the ARPA sites of this region are located close to the mountain chains of the Apennines (south) and near the coast of the Adriatic Sea to the east. The stations of Veneto have no particular features to mention due to its small sample size of PM ARPA sites. We will consider statistics for the Po Valley as a whole as well as each administrative district.

2.1. Ground-level PM_{10} data

Twenty-four hour average PM_{10}, mass concentration in μgm^{-3}, has been considered over 126 air quality monitoring stations of the ARPA network, spread over the Po Valley (Fig. 1(b)) during the year 2012. Since each region has its own ARPA network, we considered four different regions covering the Po Valley: Piemonte (27 stations), Lombardia (59 stations), Emilia Romagna (37 stations) and Veneto (3 stations). The distribution of ground-based stations and their location into the Po Valley is highlighted in Fig. 1(b), using different color per each administrative division. In ARPA Piemonte and Veneto the PM_{10} is measured using a Beta Attenuation Monitor (BAM) with an accuracy of 2%. In ARPA Lombardia TEOM, TEOM-FDMS (Tapered Element Oscillating Micro-balance - Filter Dynamics Measurement System), or BAM are used, with an accuracy of ±2.5 μgm^3. In ARPA Emilia Romagna, PM_{10} data have been collected by SWAM 5A, a BAM by FAI Instruments with an uncertainty lower than ±10%. All information relating to the ARPAs stations and instrumentation are available at the ARPA web sites of their respective regions, mentioned above.

2.2. Satellite data

As satellite data we have considered the standard MODIS Aqua Collection 5.1 (MYD04) and MAIAC AOD retrievals from MODIS Aqua retrievals.

The MODIS aerosol MYD04 products collection 5.1, Level 2 (Remer et al., 2006) returns AOD data at 0.55 µm with a spatial resolution of 10X10 km^2 retrieved from MODIS on board of Aqua satellite. The MODIS sensor on board of Aqua satellites has 36 spectral bands that provide information about atmospheric, land and oceanic condition. MODIS gives observations spatially from 250 m – 1 km, every 1 – 2 day in different spectral regions of electromagnetic spectrum. MODIS AOD algorithm uses multi-spectral observed radiances, and pre-computed look-up tables to retrieve AOD over ocean and land (Remer et al., 2005).
MAIAC is a new algorithm that it has been developed to process MODIS land data (Lyapustin et al., 2011(a), Lyapustin et al., 2011(b)). The main difference between the Standard and MAIAC retrieval is that the new algorithm retrieves aerosol parameters over land at 1 km resolution simultaneously with BRDF parameters. This is accomplished by using the time series of MODIS measurements and simultaneous processing of groups of pixels. The MAIAC algorithm guarantees that the number of measurements exceeds the number of unknowns, a necessary condition for solving an inverse problem without empirical assumptions typically used by current operational algorithms. The MODIS time series accumulation also provides multiple (15) view angle coverage for every surface grid cell, which is required for the BRDF retrievals from MODIS data. The aerosol parameters include optical depth, Angstrom exponent from 0.47 and 0.67µm, and aerosol type including background, smoke and dust models (Lyapustin et al., 2012). Moreover, MAIAC incorporates a cloud mask (CM) algorithm based on spatio-temporal analysis which augments traditional pixel-level cloud detection techniques (Lyapustin et al., 2008). The period of MAIAC data over the Po Valley is year 2012. This period is used to determine coincidences between surface PM_{10} mass, MAIAC and MODIS AOD obtained over the Po Valley. Note that the MAIAC data set considered during the analysis covers 4 MODIS standard land tiles (from h18v03 to h19v04, but in smaller area of 1500 × 1500 km^2, divided into 3 × 3 local MAIAC tiles. The MAIAC tiles overlap the standard MODIS tiles. The Po Valley domain is located in the MAIAC tile named h01v02.
A direct comparison between MODIS Collection 5.1, MAIAC retrievals and surface PM_{10} has been done for the year 2012, for each ARPA station considered (126 over the Po Valley). Spatial co-location uses nearest neighbor approaches by calculating the distance between the pixel and PM_{10} station and determining the minimum radius, within a tolerance radius of 0.02° (about 2 – 2.5 km) for MAIAC and 0.20° (about 20 – 25 km) for MODIS Aqua Collection 5.1. But, per a fixed day of analysis, there are more MAIAC coincidences then MODIS Aqua Collection 5.1, due to the overlap of orbit satellite Aqua over the MAIAC local tiles. Because of this, the final MAIAC coincidence is the mean value of all the possible detected coincidences, at a specific day and PM site. The MODIS Collection 5.1 retrieval has already been cloud filtered and is used without additional quality control. The MAIAC AOD retrieval data includes cloud and terrain in masks, incorporated into the AOD Quality Assurance (QA) parameter definition. The MAIAC cloud mask (CM) field has been used to avoid pixels where clouds were detected and the Land-Water-Snow (LWS) mask field has been used to avoid pixels where water or snow is detected.

2.3. Meteorological data

As meteorological data, the 6 hourly 0.5x0.5 degree analysis files from the NOAA National Center for Environmental Prediction (NCEP) Global Data Assimilation System (GDAS) have been considered. The GDAS is the system used by the Global Forecast System (GFS) model to place observations into a gridded model space for the purpose of starting, or initializing, weather forecasts with observed data. The GDAS data are available at http://nomads.ncdc.noaa.gov/, freely downloaded.

3. RESULTS AND DISCUSSIONS

Our air pollution analysis begins with the study of the 2012 monthly mean trend of PM_{10} versus AOD data over the Po Valley domain. The MODIS and MAIAC AOD monthly mean trend has been considered all over the year 2012. The results are reported in Fig. 2. Fig. 2 (a) shows the mean daily value of PM_{10} 24 Hrs mass concentration (black line), for all 126 ARPA stations. The red dots show the monthly mean PM_{10} mass concentration; the blue dots show MODIS Aqua Collection 5.1 AOD monthly mean values. The same analysis has been followed for MAIAC data, represented by blue dots in Fig. 2 (c). As can be seen, the trends in PM and AOD are not comparable during the winter and fall periods when the highest values of atmospheric particles are recorded, especially if we refer to the last two months of the year: the PM monthly mean trend has a positive slope, instead of a negative one of the AOD monthly mean trend. It is noteworthy that PM_{10} and AOD represent two different measurements of atmospheric loading of pollutants, as mentioned in the introduction

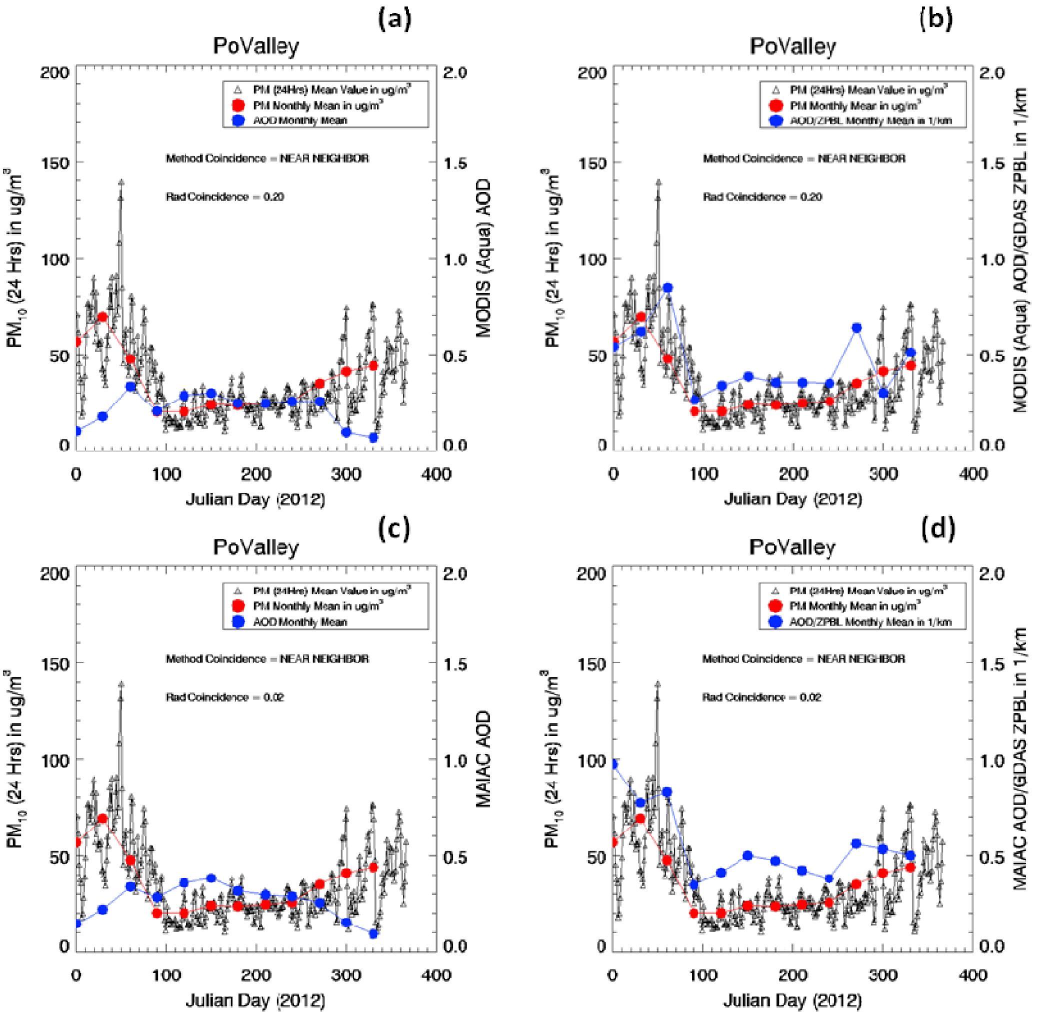

Figure 2: (a) – (c) Trend of PM_{10} (μgm^{-3}) compared to MODIS (Aqua) and MAIAC respectively, over the Po Valley (Italy) domain. (b) – (d) Trend of PM_{10} (μgm^{-3}) compared to MODIS (Aqua) and MAIAC respectively, over the Po Valley (Italy) domain where in this case the MODIS and MAIAC AOD values are normalized by PBL height.

section. As suggested by the literature (Gupta et al., 2006; Tsai et al., 2011), the PM_{10} –AOD correlation may be easily improved. This could be done by considering meteorological data information or vertical distribution of aerosols. For this specific analysis, we have concentrated our attention on vertical distribution of aerosols, by introducing information of Planetary Boundary Layer (PBL) depth over the Po Valley. The PBL values derive from the GDAS analysis files (see Sec. 2.3.). As mentioned previously, the AOD is an integration of the aerosol extinction, from the surface to the top of the atmosphere (Eq. 1):

$$\mathbf{AOD} = \int_0^{\mathbf{TOA}} \boldsymbol{\sigma}^{\mathbf{ext}}_{\mathbf{0.55\mu m}}(\mathbf{z})\mathbf{dz} \qquad \text{equation (1)}$$

The PBL is the lowest part of the atmosphere, directly influenced by its contact with the Earth's surface. We introduce the PBL information over the Po Valley to investigate if the poor PM_{10} – AOD correlation analyzed before might be improved. Under the hypothesis that the aerosols are conned and mixed homogeneously within boundary layer, the values of AOD normalized by PBL height may be regarded as mean PBL extinction in km^{-1}. The normalization has been applied both over MODIS Collection 5:1 and MAIAC AOD retrieval, by following the same procedure. The seasonal trend of PBL heights over Po Valley has low values during the winter and high values during the summer (Arvani et al., 2013a). This characteristic trend is immediately reflected on the AOD monthly mean values normalized by this variable, where the final results are presented in Fig. 2 (b) – (d). The data of monthly average AOD/PBL has a closer correlation with the value of average monthly PM for both MAIAC and MODIS Collection 5.1 even in winter, season in the Po valley characterized by frequent condition of atmosphere stability that favor the near-surface pollutants buildup.

Our analysis followed a second important step: the calculation of the determination coefficient between daily PM_{10} mass and MODIS AOD to estimate quantitatively the linear relationship between the two data sets. The same study approach has been considered on the specific four regions of the domain. We applied the scatter plot linear correlation method on the data set, as mentioned in paper by Gupta et al., 2006 (Gupta et al., 2006). Because of the large spread of PM_{10} and AOD values (Arvani et al., 2013(a)) it is more useful to derive a simple linear regression equation between PM_{10} mass concentration and AOD by dividing the PM_{10} (24 Hrs) into 10 bins of 5 gm^{-3} intervals and comparing with mean AOD within each bin. The value of AOD for each PM_{10} bin was determined by calculating the average value of AOD between the values of AOD retrieved in each class of PM. This set of ten points are reported on the scatter plot as black dots in Fig. 3, in the left panels (a) – (c), along with a solid red line showing the linear regression line between these two data sets. White dots refer to median values of AOD at fixed value of PM_{10}. Yellow symbols represent the 25^{th} and 75^{th} percentile respectively in MODIS AOD for a particular PM_{10} bin. This simple statistical approach gives a robust estimate of the linear regression between the PM_{10} and satellite data. The correlation between bin-averaged AOD and PM_{10} concentration is very high if considered MODIS AOD data product. Instead, the higher spatial resolution MAIAC retrieval algorithm presents a significant lower determination coefficient. The results show a determination coefficient of 0.92 and 0.62 for MODIS Collection 5.1 and MAIAC respectively over the Po Valley domain, for the same period of analysis. This is an interesting result: if we consider a limited time, excluding the winter season – as presented in Arvani et al., 2013 (a) – the determination coefficient for MAIAC data is comparable with MODIS AOD data. Yet, if we consider the entire year of analysis, the determination coefficient decreases. This means that the MAIAC AOD data for the winter season have a significant impact on the final PM – AOD correlation. As we mentioned in the previous subsection, the PM_{10} – AOD correlation may be improved with the introduction of information related to the depth of the aerosol layer. Therefore, we applied the same analysis to the AOD/PBL data. The results related to the Po Valley are summarized in Fig. 3 in the right panels (b), (d). The AOD/PBL results show R^2 of 0.98 for both MODIS Collection 5:1 and MAIAC algorithm retrievals when AOD is normalized by PBL depth.

4. DATA APPLICATIONS

Until this point of our analysis, the use of MODIS aerosol product applied for particulate pollution research has been presented. This has been accomplished demonstrating the significant exiting correlation between ground-based measurements and satellite data. Also, how the spatial resolution of the retrieval algorithm may impact the final correlation result. An interesting followed analysis accomplished was to study how this product – the MODIS retrieval algorithm product – could be used to forecast the air quality over a specific area, for a specific day of the year.

Since years ago, over the Po valley domain, regional Italian Regional Agency for Environmental Protection (ARPA) uses forecasting systems for air quality. Yet such systems do not use satellite data as input of air quality condition. For air quality assessment and forecast, ARPA uses meteorological data applied to atmospheric dispersion modeling including simple Gaussian plume models, and more complex Lagrangian, Eulerian, or Puff models. The use of satellite data, as mentioned above in Sec. 1., allows having a more complete coverage over the studied domain, but most of all having the possibility to have air quality information in near-real time. During September 2003, a team of NASA (National Aeronautics and Space Administration), NOAA (National Oceanic and Atmospheric Administration), and EPA (United States Environmental Protection Agency) researchers demonstrated a prototype for near-real time aerosol forecasting using MODIS AOD retrievals (MOD04 from Terra satellite or MYD04 from Aqua) in daily air quality forecasts known as IDEA (Infusing satellite Data into Environmental Applications) which is a part of the NASA Applied

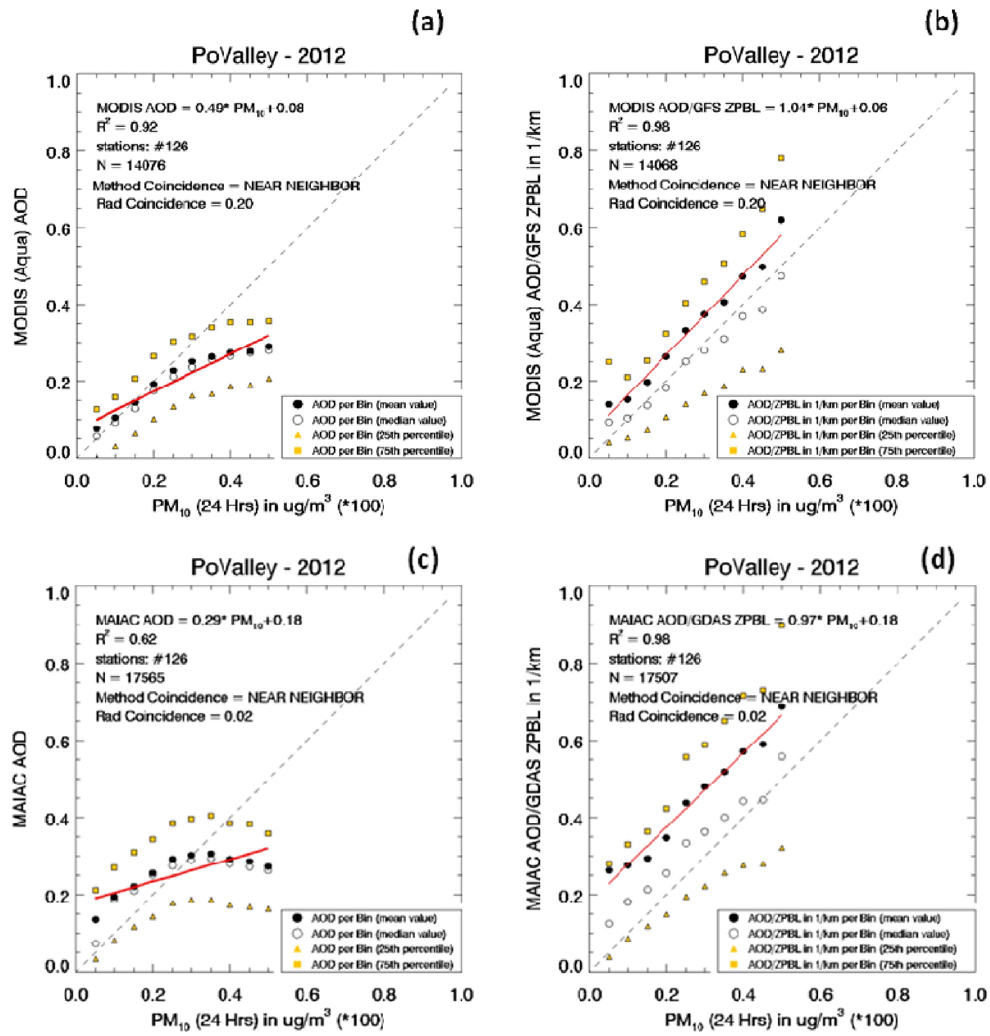

Figure 3: Bin scatter plots results for the Po Valley domain. In the upper side of the panel, (a) and (b), the MODIS Collection 5.1 results are shown. In the lower side, (c) and (d), the comparison with the MAIAC results is presented. N is the number of coincidences detected.

Sciences Program strategy to demonstrate practical uses of NASA-sponsored observations from space and predictions from scientific research. IDEA's goal is to improve air quality assessment, managements, and prediction by infusing satellite measurements from NASA into analyses by EPA and NOAA for health public benefit (Al-Saadi et al., 2005). IDEA is now used operationally at NOAA/NESDIS to provide information to state and local air quality forecasters. After its success, an open source version of IDEA, known as IDEA International (IDEA-I), has now been released. The vehicle for IDEA-I release is the International MODIS and AIRS (Atmospheric Infrared Sounder) Processing Package (IMAPP), developed at Space Science and Engineering Center of University of Wisconsin-Madison (SSEC/UW-Madison). IMAPP allows ground stations, able to receive direct broadcast data from Terra and Aqua satellite to produce a suite of environmental products. The IMAPP software is a free software package (Huang et al., 2004). In particular, IDEA-I is a globally configurable software package that uses MODIS sensor, aboard of Terra and Aqua satellites, aerosol MOD(MYD)04_L2 product, visually used as background basemap – Fig. 4 (a) (Sec. 2.2) to identify local domains of high values of aerosol. From these points, pressure trajectories are initialized and a trajectory model

is then run which provides a forecast of the horizontal and vertical movement of the aerosols over the next 48 hours. The package includes both a netCDF output product as well as hourly trajectory forecast images (Al-Saadi et al., 2005; Davies et al.). As Terra or Aqua MODIS AOD retrievals are available daily, the use of this products by IDEA-I permits near-real time air quality forecasts. This is the strength point: the use of IDEA-I software permits to forecast the air quality condition in a specific area and in a specific day of the year. Yet, using IDEA-I it is also possible to identify and understand the cause of bad air quality condition which is not possible with just an air quality assessment from ground-based stations. This is the case example reported in Fig. 4 (b) a big event of dust from Sahara desert impacted over the Po valley on May 1st, 2013. As evident, over the northern Italy, the trajectories are characterized by low pressure levels and so they may not had a significant impact on the lowest layers of the atmosphere, near the atmosphere, important aspect to study and investigate (at this time of the paper, it is under studying).
As mentioned before, MODIS provides a suite of information about aerosol properties, including AOD, used for climate goals. As known, the standard MODIS aerosol Collection 5.1 product has a nominal spatial resolution of 10x10 km^2 and has a particular used for air quality applications due to the broad swath of MODIS instrument. Yet, the 10 km resolution of this aerosol product is too large if applied for study in urban scale. To resolve this spatial scale product issue, the MODIS aerosol team is introducing a 3 km product as part of their Collection 6 delivery (Remer et al., 2013; Munchak et al., 2013). Since January 1st, 2014, the Level 2 Collection 6 – 3 km product became public available. In relation to this, the main goals of IMAPP team group at Cooperative Institute for Meteorological Satellite Studies (CIMSS) of University of Wisconsin-Madison – USA is to implement in the future the new MODIS aerosol product into IDEA-I software algorithm. Using MODIS aerosol product with a higher spatial resolution means to have a product much more suitable to urban area, as the Po valley domain. Again it is possible to pretend to have a much better air quality forecast over the area.
For our specific purpose, at the end of 2012 IDEA-I was installed at University of Modena and Reggio Emilia, (Italy). Even if the studied area is the Po valley in Italy, the larger European area was chosen as domain for the IDEA-I run. This choice was motivated by the need to look for regional transport patterns that could influence the Po valley (as the example mentioned above).

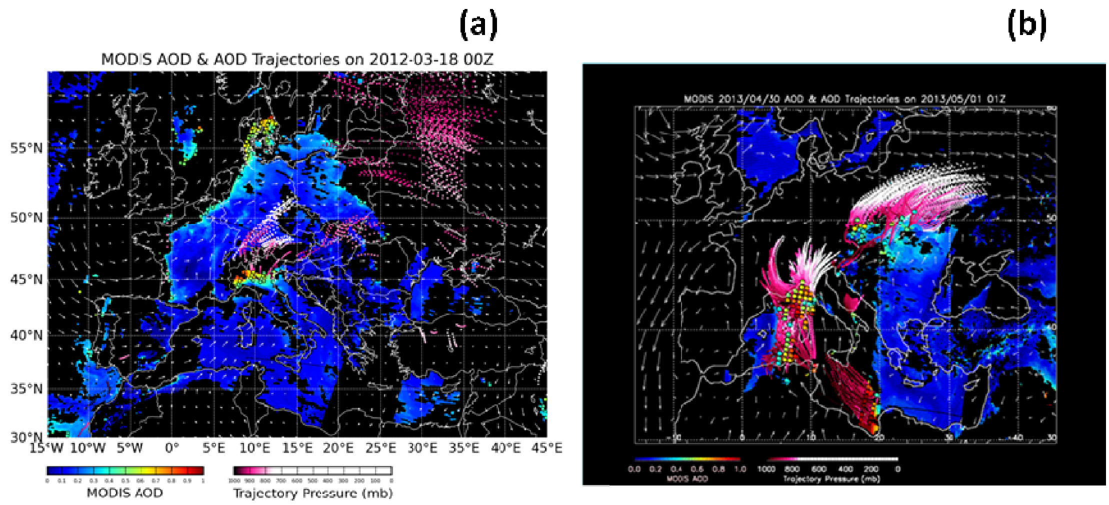

Figure 4: (a) – Example of an IDEA-I domain, centered on Po valley for the day March, 18th 2012, a significant polluted day of the year. IDEA-I run obtained at Università di Modena e Reggio Emilia. The pressure levels of the trajectories are plotted in mb and colored to a magenta-white scale. The color white indicates that the air parcel no longer affects the surface. The background basemap is represented by MODIS MOD(MYD)04_L2 aerosol product (b) – Example of an IDEA-I run for a significant Sahara dust event, which impacted the Po valley air quality on May, 1st .

5. CONCLUSION

Using MODIS derived AOD on NASA's Terra satellites along with co-located ground-based PM_{10} concentration measurements at 126 stations spread over the Po valley in Italy, we examined PM air quality. A regression analysis was used and we derived empirical relationship between 24 hour PM_{10} mass concentration (μgm^{-3}) and MODIS AOD at 0.55 µm. Our preliminary analysis indicates that satellite data can be used for quantitative monitoring of air pollution levels and obtaining air quality indices where PM_{10} measurements are not available. The satellite AOD data are able to return a preliminary and immediate indication of air quality condition over the studied domain. Moreover, IDEA-I simulation, for the considered period and domain, heightens the comprehension of the recorded air quality condition when meteorological data information are not available. Until recently, the MODIS Collection 5.1 satellite AOD data product, with 10 km resolution, was the main source of global satellite aerosol data worldwide. In this paper we examine the new high-resolution (1 km) AOD retrieval from MODIS data based on the MAIAC algorithm. Our analysis suggests that MAIAC 1 km retrieval provides high resolution information on aerosol optical depth within the highly industrialized Po Valley of Northern Italy which is quantitatively similar to the coarser resolution Collection 5.1 retrieval. Furthermore, as often noted by the literature, the link between surface measurements and AOD data alone is limited and often not suitable for quantitative analysis. However, the normalization by the PBL depth generally improves the R^2 due to seasonal changes in the PBL depth over the Po Valley. In the last section of this paper, an application of MODIS AOD product was introduced. We tried to explain the importance to use a software able t use aerosol retrieval algorithms from satellite measurements as input to air quality forecast.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the University of Modena and Reggio Emilia for funding Barbara Arvani's Ph.D. scholarship, as well as partial funding by Ministero dell'Istruzione, dell'Università e della Ricerca under contract PRIN2010-11, 2010WLNFY2. A significant acknowledge to IMAPP team at the Cooperative Institute for Meteorological Satellite Studies (CIMSS) of Space Science and Engineering Center (SSEC) at the University of Wisconsin-Madison. Finally, the authors gratefully acknowledge Alexei I. Lyapustin of NASA Goddard Space Flight Center and his team to permit the use of MAIAC AOD data for the research analysis presented in this work. The views, opinions, and findings contained in this report are those of the author(s) and should not be construed as an official National Oceanic and Atmospheric Administration or U.S. Government position, policy, or decision.

BIBLIOGRAPHIC REFERENCES

1. Forastiere, F.; Stafoggia, M.; Picciotto, S.; Bellander, T.; D'Ippoliti, D.; Lanki, T.; von Klot, S.; Nyberg, F.; Paatero, P.; Peters, A.; Pekkanen, J.; Sunyer, J. & Perucci, C. A. A Case-Crossover Analysis of Out-of-Hospital Coronary Deaths and Air Pollution in Rome, Italy American Journal of Respiratory and Critical Care Medicine, 2005, 172, 1549-1555
2. Brunekreef, B. & Forsberg, B. Epidemiological evidence of effects of coarse airborne particles on health European Respiratory Journal, 2005, 26, 309-318
3. Gupta, P.; Christopher, S. A.; Wang, J.; Gehrig, R.; Lee, Y. & Kumar, N. Satellite remote sensing of particulate matter and air quality assessment over global cities Atmospheric Environment, 2006, 40, 5880 – 5892
4. Gupta, P. & Christopher, S. A. Seven year particulate matter air quality assessment from surface and satellite measurements Atmospheric Chemistry and Physics, 2008, 8, 3311-3324
5. Mazzola, M.; Lanconelli, C.; Lupi, A.; Busetto, M.; Vitale, V. & Tomasi, C. Columnar aerosol optical properties in the Po Valley, Italy, from MFRSR data Journal of Geophysical Research: Atmospheres, 2010, 115
6. Chu, D. A.; Kaufman, Y. J.; Zibordi, G.; Chern, J. D.; Mao, J.; Li, C. & Holben, B. N. Global monitoring of air pollution over land from the Earth Observing System-Terra Moderate Resolution Imaging Spectroradiometer (MODIS) Journal of Geophysical Research: Atmospheres, 2003, 108

7. Al-Saadi, J.; Szykman, J.; Pierce, R. B.; Kittaka, C.; Neil, D.; Chu, D. A.; Remer, L.; Gumley, L.; Prins, E.; Weinstock, L.; MacDonald, C.; Wayland, R.; Dimmick, F. & Fishman, J. Improving National Air Quality Forecasts with Satellite Aerosol Observations Bull. Amer. Meteor. Soc., Bulletin of the American Meteorological Society, American Meteorological Society, 2005, 86, 1249-1261
8. Huang, H.-L.; Gumley, L. E.; Strabala, K.; Li, J.; Weisz, E.; Rink, T.; Baggett, K. C.; Davies, J. E.; Smith, W. L. & Dodge, J. C. International MODIS and AIRS Processing Package (IMAPP): A Direct Broadcast Software Package for the NASA Earth Observing System Bull. Amer. Meteor. Soc., Bulletin of the American Meteorological Society, American Meteorological Society, 2004, 85, 159-161
9. Davies J., S. K. – IDEA-I: a globally configuble IMAPP MODIS software package in support of air quality forecasts.
10. Lyapustin, A.; Wang, Y.; Laszlo, I.; Kahn, R.; Korkin, S.; Remer, L.; Levy, R. & Reid, J. S. Multiangle implementation of atmospheric correction (MAIAC): 2. Aerosol algorithm Journal of Geophysical Research: Atmospheres, 2011, 116
11. Lyapustin, A.; Wang, Y.; Hsu, C.; Torres, O.; Leptoukh, G.; Kalashnikova, O. & Korkin, S. Analysis of MAIAC dust aerosol retrievals from MODIS over North Africa AAPP | Physical, Mathematical, and Natural Sciences; Vol 89, SUPPLEMENT NO 1 (2011): ELS XIII Conference, 2011
12. Lyapustin, A., Korkin, S., Wang, Y., Quayle, B., and Laszlo, I., Discrimination of biomass burning smoke and clouds in MAIAC algorithm," Atmospheric Chemistry and Physics 12(20), 9679-9686 (2012)
13. Lyapustin, A., Wang, Y., and Frey, R., "An automatic cloud mask algorithm based on time series of MODIS measurements," Journal of Geophysical Research: Atmospheres 113(D16) (2008).
14. Remer, L. A.; Tanre, D.; Kaufman, Y. J.; Levy, R. & Mattoo, S. Algorithm for remote sensing of tropospheric aerosol from MODIS: Collection 005 National Aeronautics and Space Administration, 2006
15. Remer, L. A.; Kaufman, Y. J.; TanrÃ©, 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. & Holben, B. N. The MODIS Aerosol Algorithm, Products, and Validation J. Atmos. Sci., Journal of the Atmospheric Sciences, American Meteorological Society, 2005, 62, 947-973
16. Tsai, T.-C.; Jeng, Y.-J.; Chu, D. A.; Chen, J.-P. & Chang, S.-C. Analysis of the relationship between MODIS aerosol optical depth and particulate matter from 2006 to 2008 Atmospheric Environment , 2011, 45, 4777 - 4788
17. Arvani, B.; Pierce, R. B.; Lyapustin, A. I.; Wang, Y.; Teggi, S. & Ghermandi, G. "Application of MAIAC high spatial resolution aerosol retrievals over Po Valley (Italy)". Proc. SPIE, 2013 (a), 8890, 88900P-88900P-12
18. Arvani, B.; Pierce, R. B.; Teggi, S.; Bigi, A. & Ghermandi, G. "Implementation of IMAPP/IDEA-I over the Po Valley region, northern Italy, for air quality monitoring and forecasting" Proc. Cest, 2013
19. Remer, L.; Mattoo, S.; Levy, R. & Munchak, L. MODIS 3 km aerosol product: algorithm and global perspective *Atmospheric Measurement Techniques Discussions, Copernicus GmbH,* 2013, 6, 69-112
20. Munchak, L.; Levy, R.; Mattoo, S.; Remer, L.; Holben, B.; Schafer, J.; Hostetler, C. & Ferrare, R. MODIS 3 km aerosol product: applications over land in an urban/suburban region *Atmospheric Measurement Techniques Discussions, Copernicus GmbH,* **2013**, *6*, 1683-1716