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Study of Saharan dust outbreak episode over the Po valley (northern Italy) using IDEA-international air quality forecast product

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Abstract

Transport of Saharan (northern Africa) dust above the Mediterranean Sea and Europe is widely studied throughout the literature. A plume of African dust may result in an anomalous increase of Aerosol Optical Depth (AOD), often accompanied by increases in surface Particulate Matter (PM) concentrations over the entire Mediterranean basin, including the Po valley in northern Italy. Therefore, it is important for air quality assessment and forecasting to understand how Saharan dust contributes to the increase of the AOD, since AOD is strongly correlated with an increment of the daily legal limit of particulate matter PM_{10} (50 $\mu g/m^3$), set by the European Union on 2008 (2008/50/CE). The present work studies an intense African dust outbreak episode which affected the Po valley in early May, 2013. The approach used in this work includes the use of the International MODIS/AIRS Processing Package (IMAPP) Air Quality Applications software, IDEA-I (Infusing satellite Data into Environmental Applications-International) in order to evaluate the impact of the plume of Sahara dust on the air quality measurements of surface PM_{10} concentrations over the Po valley domain. The satellite (MODIS Terra/Aqua) observations show the intense outbreak of dust from north of Africa over Italy. They also show significant cloud cover over northern Italy during the outbreak. Even though significant outbreak occurred between the end of April and May 2013, the ground based concentrations do not show significant increases, with values of PM_{10} remaining within the daily legal limit.

Keywords: IDEA-International; air quality; MODIS; Po valley; Saharan dust outbreak; PM_{10}.

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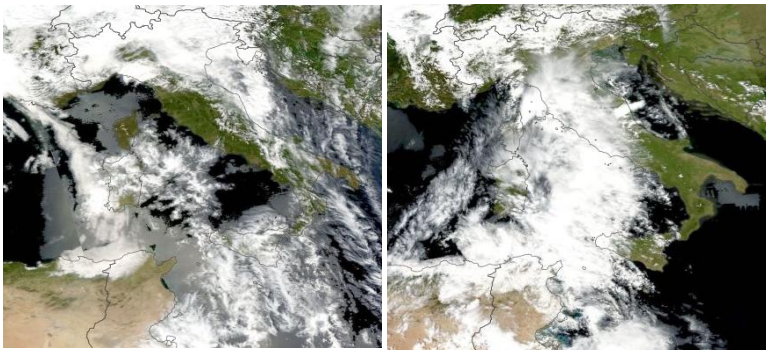
1. Introduction

Desert dust can be transported over long distances from the source regions; the larger particles deposit near the source and the smaller ones can be suspended in the air for few days and be transported long distances from the source (Prospero, 2002). The Sahara desert, in the northern Africa, is the most important dust source region in the world, especially for the Mediterranean basin and south Europe, due to the intense frequency of Saharan dust outbreaks episodes recorded during the year, which show a strong a seasonal cycle (Israelevich, 2012). A plume of African dust is often associated with an anomalous increase of Aerosol Optical Depth (AOD), which is the integral of atmospheric extinction of aerosols from the surface to the top of the atmosphere, and is often accompanied by an increase in surface Particulate Matter (PM) concentrations over the entire Mediterranean basin, including the Po valley domain in northern Italy. Furthermore, Saharan dust outbreaks may affect the human health (Yin, 2005). The health related to air pollution condition is an important issue, especially for the areas characterized by severe pollution problems and which are also affected by dust storms. This is the case of the Po valley area which 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 and often hit by a Saharan dust plumes (Israelevich, 2012). For this reason, it is important for air quality assessment and forecasting to understand how the Sahara dust contributes to the increase of the AOD, since may be strongly correlated with violations of the daily legal limit of PM10 (50 μg/m3), set by the European Union on 2008 (2008/50/CE).

In this work, we examine the effects on air quality in the Po valley during an intense African dust outbreak episode in early May, 2013, using a retrospective analysis with the IDEA-International package.

2. Data analysis



(a) (b)

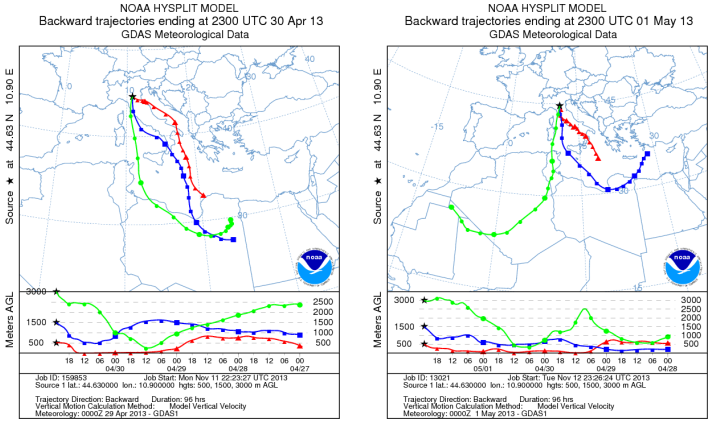
Fig .1. Satellite True Color images Aqua/MODIS on April 30th, 2013 (a) and May 1st, 2013 (b). Source: (EOSDIS Worldview (Alpha) - NASA).

The Saharan dust episode that occurred between April 30th, 2013 and May 1st, 2013 over Po valley area in northern Italy (40° - 50° N and 5° - 15° E), was analyzed using satellite remote sensing retrievals compared to ground-based PM measurements and the application of the air quality forecasts using the IDEA-I software.

In Fig. 1.(a), the satellite True Color image from MODIS (MODerate resolution Imaging Spectroradiometer) Aqua satellite on April 30th, 2013 highlights the spatial distribution of the Saharan dust outbreak from the east side of northern Africa to Po valley in northern Italy (grey colors on the left side of Fig. 1.(a)). Due to the intense cloud cover, it is more difficult to identify the exact spatial distribution of dust plume on May 1st, 2013, but it is still evident in the cloud free part of the image (Fig. 1.(b)).

Twenty-four hour average PM_{10}, mass concentration in μgm^{-3}, was analyzed for 114 air quality monitoring stations of the ARPA (Italian Regional Agency for Environmental Protection) network. The black and red dots in the lower panels of Fig. 4.(b) show the locations of the ARPA stations in the Po valley domain. All information regarding to the ARPA stations and instrumentations are available at ARPA web sites of their respective regions (Arpa Piemonte, 2014), (Arpa Lombardia, 2014), (Arpa Emilia Romagna).

AOD measurements from the NASA Aqua satellite were retrieved using the standard MODIS Collection 5.1 Level 2 (MYD04_L2) with a nominal spatial resolution of 10 km at nadir that increases to roughly four-fold this resolution at the edges of the swath. Further details of the MODIS aerosol algorithm, products and validation are presented in Remer et al. (Remer, 2005). The MODIS AOD measurements and surface PM_{10} concentration were collocated in space for a comparative and quantitative analysis, where one year (2013) of coincidences data over the Po valley was considered to establish and study the relationship between the ground measurements and the satellite aerosol retrievals.



(a) **(b)**

Fig. 2. Air mass back trajectories at 500m, 1500m and 3000m on April 30th, 2013 (a) and May 1st, 2013 (b), both ending at Modena (10.90E, 44,63 N).
Source: NOAA HYSPLIT (http://ready.arl.noaa.gov/HYSPLIT.php).

The 84-hour back trajectories for the Saharan dust episode were calculated using the HYSPLIT-4 model of Air Resources Laboratory of NOAA (NOAA Air Resources Laboratory) and confirm the origin of air masses over the Po Valley came from African Saharan regions. The HYSPLIT backward trajectories were computed for three distinct levels, 500 m, 1500 m, and 3000 m to give representative origins of air masses near the surface, boundary layer and upper free troposphere, respectively. As shown in Fig. 2, the main Saharan dust transport was driven by mid-troposphere path (green trajectory line, 3000 m as ending point).

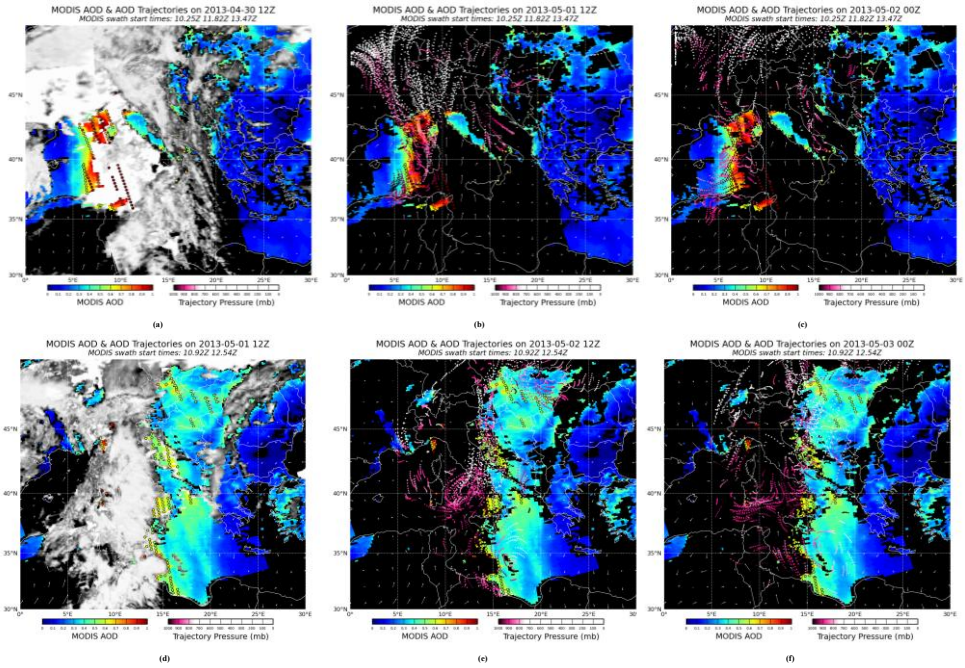


Fig. 3. (Upper panels): IDEA-I 48 hrs forecast for 12 UTC on April 30th, 2013. (Lower panels): IDEA-I 48 hrs forecast for 12 UTC on April 30th, 2013.

3. IMAPP IDEA-International application

Since the launch of MODIS, the use of satellite aerosol products provide an estimate of the atmospheric aerosol distribution where the ground-base station measurements are not available. The use of satellite data provides a more complete coverage and potential near-real time information (Chu, 2003), (Gupta, 2006).

During September 2003, a team of NASA, NOAA, and EPA researchers demonstrated a prototype for real-time aerosol forecasting using MODIS AOD retrievals in daily air quality forecasts known as IDEA (Infusing satellite Data into Environmental Applications) which is a part of the NASA Applied Sciences Program strategy to demonstrate practical uses of NASA-sponsored observations from space and predictions from scientific research. IDEA's goal was to improve air quality assessment, managements, and prediction by infusing satellite measurements from NASA into analyses by EPA and NOAA for public benefit (Al-Saadi, 2005; Huang, 2004). IDEA is now used operationally at NOAA/NESDIS toprovide information to state and local air quality forecasters. Due to its success, an open source version of IDEA, known as IDEA International (IDEA-I), was 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 provides freely distributed software to process MODIS and AIRS satellite data received via direct broadcast antennas. IDEA-I is a globally configurable software package which uses Terra or Aqua MODIS AOD retrievals available daily to identify local domains of high values of aerosol. From these points trajectories are initialized. AOD retrieval is used to initialize the

trajectories which show where the aerosol will move in the next 48 hrs at fixed day, in 3 dimensions. The trajectories are predicted using the NASA Langley trajectory model (Pierce, 1993), combined with the NOAA Global Forecast System (GFS) wind information (IMAPP, 2014).

In Fig. 3.(a) on April 30th, 2013, the satellite MODIS Aqua retrieval shows an intense outbreak of dust from northern Africa to the west of northern Italy, clearly visible 24 hrs later on May 1st, 2013 (Fig. 3.(b)), despite the significant cloud cover over the northern Italy during the episode. Fig. 3.(c) shows the 48 hr IDEA-I trajectory forecast. Looking over the Po valley, the trajectories (Fig. 3.(b)) are characterized by ascent (white color) especially over the Po Valley, meaning that the Saharan dust intrusion on April 30th, 2013 stayed in the upper atmosphere over the Po valley domain. The lower panels of Fig. 3. show the IDEA-I forecast on May 1st, 2013.

4. Time series analysis

The Saharan dust transport episode occurred on early May, 2013 does not seem to affect the PM_{10} mass concentration at the surface. Fig. 4.(a) shows the time series analysis of both PM_{10} mass concentration and remotely sensed AOD measurements. The scale was chosen so that the AOD values overlay the PM_{10} mass concentration throughout most of the period. This AOD to PM_{10} relationship holds quite well except for the April 30th – May 1st, period, where the AOD increases to approximately 1.0 while the PM_{10} reaches only about 38 $\mu g/m^3$ mass concentration on. Significant cloud cover over northern Italy during the dust episode limited the ability to retrieve AOD over the Po valley area (see MODIS Aqua images in Fig. 1.). As result, a very few coincidences of AOD with the PM data at the ground were detected, represented by the red dots in the lower panels in Fig. 4.(b). Just an 11% of total AOD retrieved data was recorded against an almost total percentage (96%) for the total PM_{10} retrieved data on May 1st, 2013.

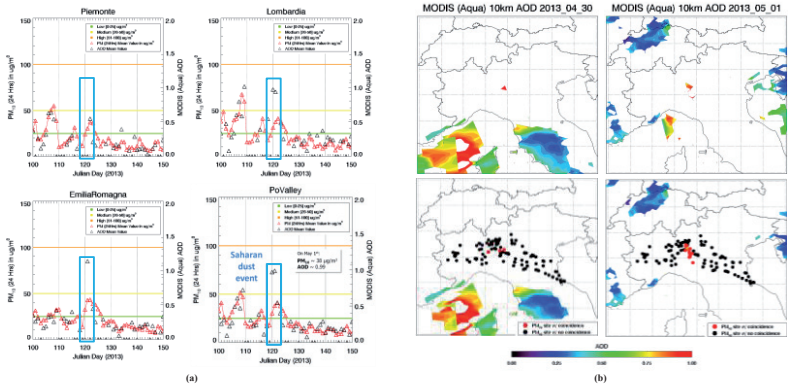


Fig. 4. (a): PM_{10} and AOD trends during the Saharan dust episode for each of the three administrative regions considered as well as for the entire domain Po valley. (b): The upper panels show MODIS Aqua satellite retrieved MYD04_L2 AOD products for the days of Saharan dust episode. The location of the ARPA ground-based stations is shown in the lower panel. The red dots represent ARPA sites which had coincidences with the remotely sensed AOD data, while the black sites had no coincidences.

5. Summary and conclusion

In this study, IDEA-I was used to identify a Sahara dust outbreak episode impacting the Po valley area. Comparing MODIS AOD retrievals with the PM_{10} ground measurements, it is possible to identify that the-re were periods where the AOD (a remotely sensed column measurement) has high values over the Po valley domain while the ground PM_{10} do not exceed the legal threshold level. Both HYSPLIT back-trajectories and IDEA-I AOD trajectories confirm that this is due to the fact that the aerosol plume responsible for the elevated AOD is aloft and not able to effect surface concentrations.

As ongoing work: using meteorological and aerosol analyses from the Real-time Air Quality Modeling System (RAQMS), helps to understand the role of wet deposition on reducing surface PM_{10} concentrations during the episodes studied.

6. Acknowledgements

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