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Particulate matter (PM_{10} and $PM_{2.5}$) concentrations during a Saharan dust episode in Istanbul

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Abstract

Istanbul, the biggest city of Turkey, is in a common route for air parcels. Air pollutants are carried over the city from Asian, African, and European continents. Sahara Desert, the largest dust source on earth, affects Turkey's air qualities substantially due to millions of tons of mineral dust being transported from the African continent towards Turkey every year. Although the effect of Saharan dust transportation on PM_{10} concentrations in Turkey was examined many times, its effect on $PM_{2.5}$ concentrations has not been studied yet sufficiently. In February 2015, Istanbul experienced a Saharan dust episode and during this event the concentrations of particulate matter rose to very high levels. This study focuses on particulate matter concentrations (PM_{10} and $PM_{2.5}$) during this Saharan dust episode to better understand the effect of dust transportation on Istanbul's air quality. HYSPLIT trajectory model, satellite products, and air quality monitoring data from ground observations were utilized. We show that the PM_{10} concentrations increased significantly during the dust episode while $PM_{2.5}$ concentrations didn't increase considerably. There was only a slight rise in the values of $PM_{2.5}$. The significant increase for the PM_{10} values can be explained by the higher gravitational settling velocities of coarse particles in the atmosphere.

Keywords Air quality · Turkey · Saharan dust episode · Remote sensing · Particulate matter (PM_{10} and $PM_{2.5}$)

Introduction

The air pollution and its health impacts have attracted worldwide attention during the last decades. Various studies showed that all types of air pollution, at high concentrations, can affect the airways. On the other hand, low-level air pollution is as dangerous as high-level ones once the long-term exposure is in account. Even within the limits of the current air quality standards, the negative health effect of air pollutants can still be observed and measured (Vedal et al. 2003).

Particulate matter is a complex mixture of particles of various sizes and chemical composition originating from various sources. Sahara desert, which produces about half of the annual mineral dust in the world, is the largest dust source of atmospheric mineral dust (Karanasiou et al. 2012). The impact of dust storms can be observed many hundreds of kilometers downwind from the emission source. Large amounts of dust from Sahara desert substantially affect particulate matter concentrations around the world (Carlson and Prospero 1972; Griffin et al. 2001; Cadelis et al. 2014; Stafoggia et al. 2016).

Turkey's largest city, Istanbul, is in a common route for air parcels. Air pollutants are carried over European continent crossing over the city to the Asian and Mediterranean regions. Air masses arriving to Istanbul are seasonally dependent and include air pollution originating in European and Black Sea countries during winter and desert dust–loaded air originating in northern Mediterranean (Saharan) and Arabian countries during spring (Karaca et al. 2009; Özdemir 2019). Particulate matter concentrations can reach very high values during the dust episodes. Because of that, Saharan dust events have an important effect on the air quality levels of Turkey.

In this study, we examined the Saharan dust particulate matter episode on Istanbul in February 2015 by using air quality and meteorological data with NASA satellite images and Aqua/Modis Satellite aerosol products. Our study area was selected as the Sahara desert and the eastern Mediterranean while focusing on Istanbul, where an intense dust event occurred during the period of 01–02 February 2015. The synoptic analysis and NASA satellite maps showed Sahara desert as dust source region. The dust plumes hovered off from the coasts of Egypt and Libya on the date of 01 February and

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spanned Aegean Sea and finally reached as far north as Istanbul. The stations of air quality monitoring network in Istanbul captured these high values which were good matched with the NASA satellite images and MODIS on Aqua/Modis Aerosol Optical Depth values. The results suggest a significant contribution of Sahara dust to high levels of PM_{10} in Istanbul.

Methodology

Study area

Located between Black Sea and Sea of Marmara, Istanbul is the largest urban area of Turkey with 5 400 km^2 area. With a population of 16 million, the city forms one of the largest urban agglomerations in Europe. Istanbul is separated as Asian and European parts by Bosphorus strait which is approximately 30 km in length. The city has a Mediterranean climate. Nowadays, Istanbul is facing especially particulate matter and NO_2 pollution depending on the emission sources (İncecik and İm 2012). The major emission sources in the city are motor vehicles, industrial processes, residential heating, and the ship emissions (Unal et al. 2011). Additionally, the trans-boundary pollutant transport significantly affects the air quality of Istanbul. According to the sensitivity analysis results, the response of Istanbul background PM_{10} concentrations can be as much as 26%, when anthropogenic emissions throughout Europe are changed by 50% (Kindap et al. 2006). Istanbul also experiences dust transport especially in the spring months coming mainly from the Sahara (Karaca et al. 2009; Özdemir 2019).

Ground-based data

Hourly air pollution data (PM_{10} and $PM_{2.5}$) were used from the database of the Republic of Turkey Ministry of Environment and Urbanization, the government agency in charge of collection of air pollution data in Turkey. The hourly concentrations for each pollutant were obtained from the 9 fixed-site air quality monitoring stations of Marmara Clean Air Center Monitoring Network (Sile, Silivri, Esenyurt, Basaksehir, Umraniye, Mecidiyekoy, Sirinevler, Uskudar, and Kandilli). To evaluate the weather conditions on the episode days, hourly meteorological data (temperature and relative humidity) were obtained from the Air Quality Monitoring Stations where meteorological measurements are also made. Daily means of the concentrations calculated from the hourly data of the pollutants and weather variables were used to represent the daily reading for Istanbul.

Satellite data

Atmospheric remote sensing is one of the methods that can be used to measure levels of air pollutants. Remote sensing data come from satellites which can be used in combination with ground-based data to help us to get a better understanding when and where air pollution is being happened. In this study, Hybrid Single-Particle Lagrangian Integrated Trajectory Model developed by Air Resources Laboratory of National Oceanic and Atmospheric Administration (NOAA) was used. Region coordinates are marked on the map in the HYSPLIT model and past trajectories showing dust transportation on the maps are obtained. In order to visually examine the high particulate matter concentrations during the episode days, NASA Earth Data satellite images were also used in the study.

Results

On 01 February 2015, a cyclone centered on Adriatic Sea with a 990-hPa low pressure center caused a southerly wind event on the eastern Mediterranean (Fig. 1). Desert sands lifted by strong winds hovered off the coasts of North Africa and spanned the Aegean Sea, passing over Istanbul and reaching as far north as the Black Sea. The dust storm hit the Marmara, Aegean, Black Sea, and Mediterranean Sea regions of Turkey. Dust-laden weather was accompanied by low atmospheric pressure, warm air, and strong winds during the episode (Figs. 2 and 3). The daily average air temperature on the day of the event was 17.4 °C which is well above the average (6.1 °C) and maximum temperature (9 °C) values of February of Istanbul. The daily average wind speed (6.5 m/s) was also very high compared with the average wind speed value (2.6 m/s) of the city.

Spatial distribution of MODIS/Aqua AOD values for the area of Northeastern African coast, Aegean Sea, and Western Turkey between 30 January and 04 February 2015 are shown in Fig. 4. In white areas, data is not available due to the cloud presence. From January 30 to January 31, AOD values were very low (≤ 0.2). On 01 February, very high AOD values (> 1.0) were observed due to atmospheric dust transportation starting from the northern part of Libya, passing through the Aegean Sea and reaching to Black Sea over Istanbul (Fig. 4).

In Fig. 5, dust load transport and its path can be seen well on NASA Earth Data imaginary as a continuous dust flow from North Africa to the Black Sea.

In order to see AOD observation values numerically, the times series of area-averaged aerosol optical depth values between 29 January and 04 February 2015 are presented in Fig. 6. The daily average value of AOD before the dust episode was between 0.1 and 0.2 from January 29 to 31. This value rose to 1.2 on 01 February due to the dust transportation event.

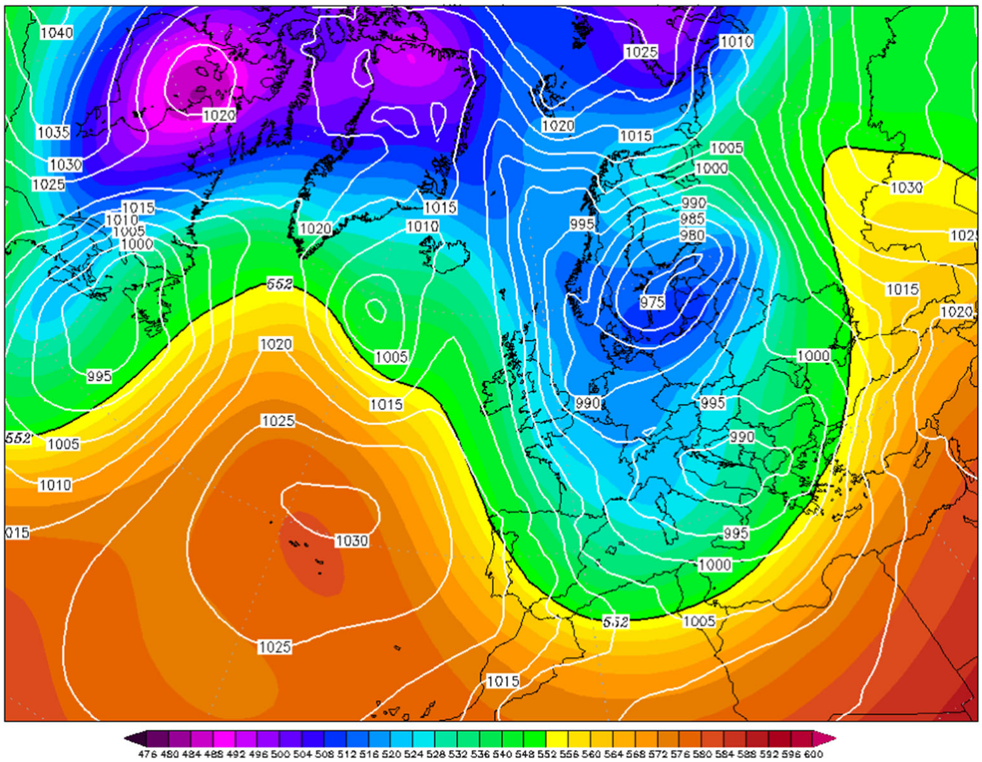

Fig. 1 500 hpa geopotential (gpdam) and mean sea-level pressure (hPa) map of Europe at 06:00 UTC on 01 February 2015 (wetterzentrale 2020)

The AOD value decreased during the next days after the dust episode.

Dust transportations from Sahara desert causes great amount of aerosol concentrations in the tropospheric column and often a huge increase of particulate matter at the ground level. Because of that, they have an important effect on the air quality levels on Turkey and Istanbul. In order to see the effects of Saharan dust

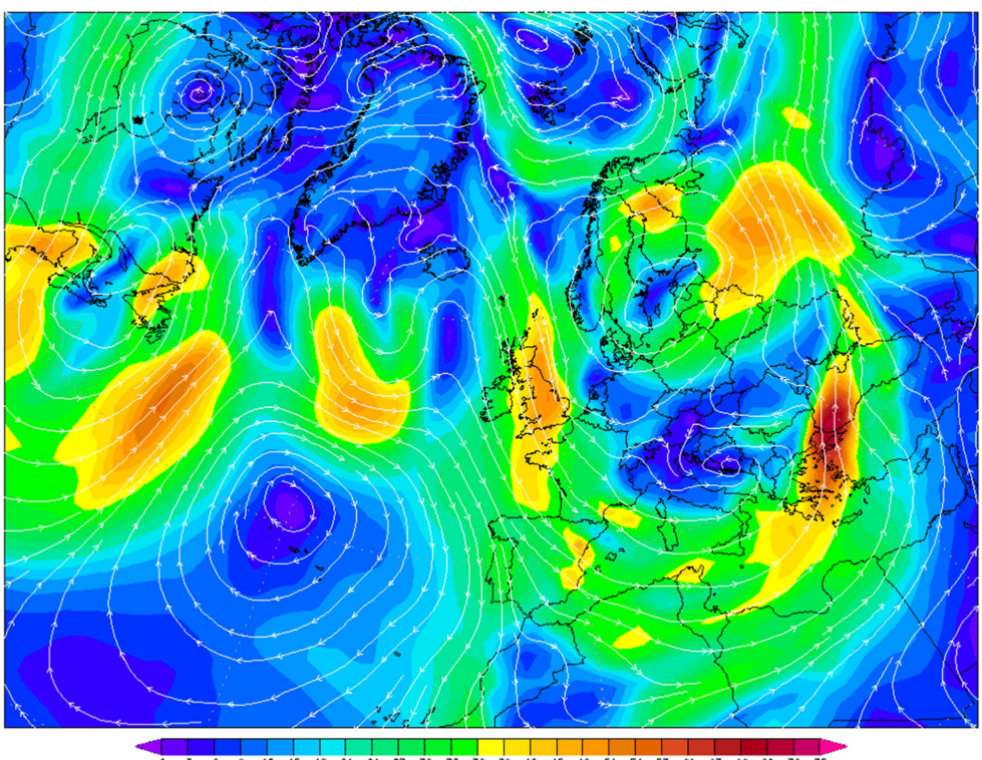

Fig. 2 850 hpa streamlines and wind speed (knots) map of Europe at 06:00 UTC on 01 February 2015 (wetterzentrale 2020)

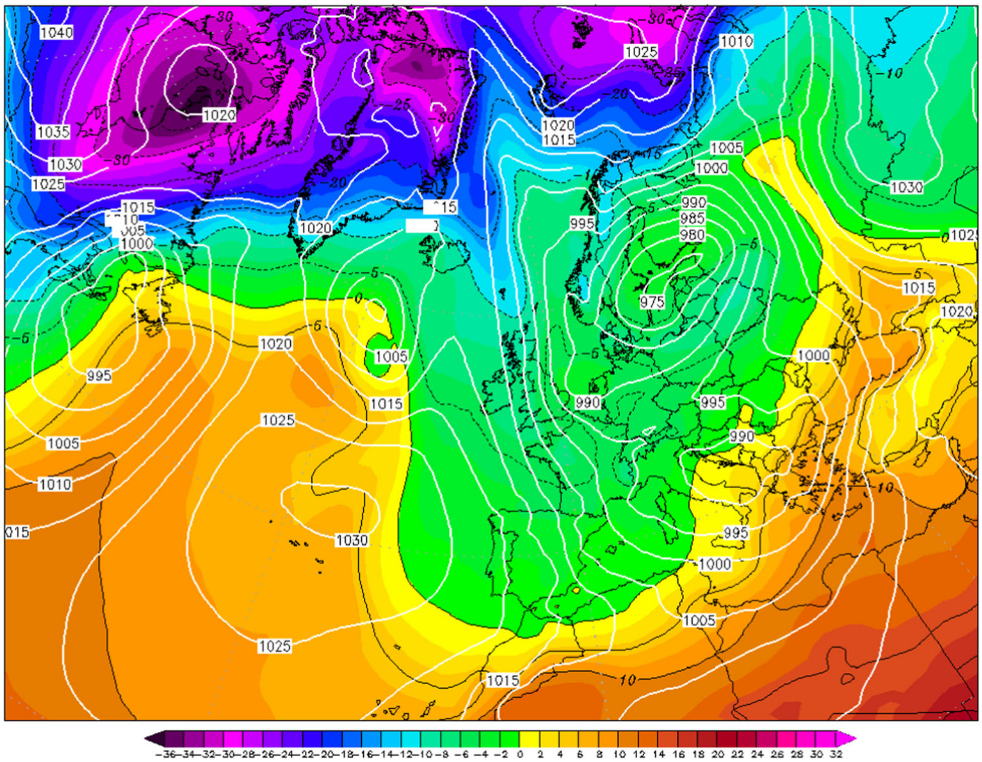

Fig. 3 Mean sea-level pressure (hPa) and 850 hPa temperature (°C) map of Europe at 06:00 UTC on 01 February 2015 (wetterzentrale 2020)

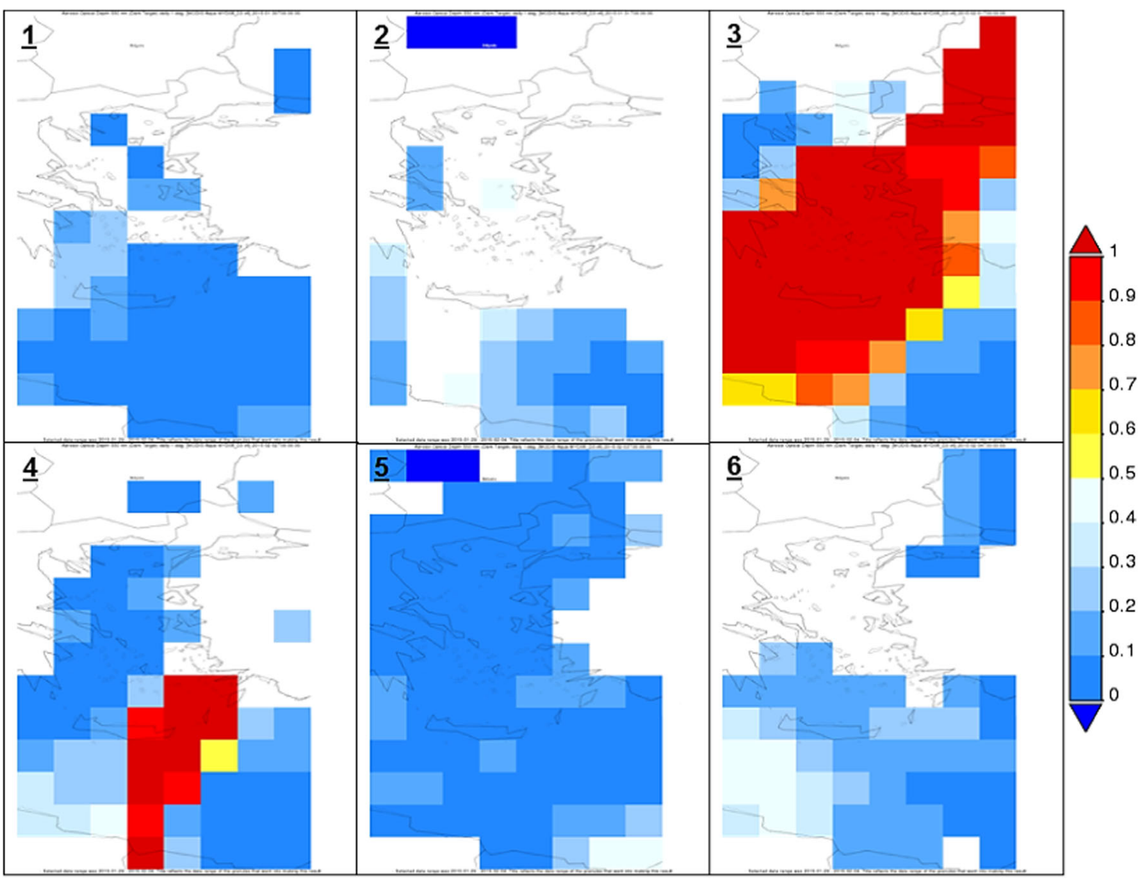

Fig. 4 Spatial distribution of MODIS/Aqua AOD values from top left to bottom right, respectively: (1) January 30, (2) January 31, (3) February 01, (4) February 02, (5) February 03, and (6) February 04

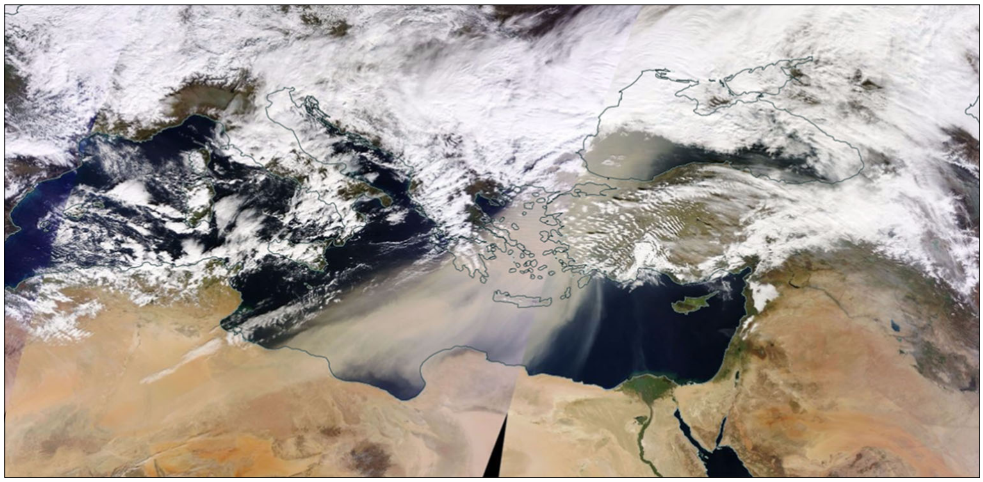

Fig. 5 Saharan dust transport to Istanbul on 1 February 2015 (NASA 2020)

transportation on the air quality of Istanbul and to make a comparison with the AOD values, the daily mean values of PM_{10} and $PM_{2.5}$ measured at the Air Quality Stations in Istanbul between 29 January and 04 February 2015 are given in Fig. 7.

Similarly to AOD values, PM_{10} and $PM_{2.5}$ concentrations were at low concentrations before the dust episode. During the dust transportation event, daily average PM_{10} concentrations rose to very high values in Istanbul (Fig. 4). PM_{10} concentrations climbed to 325.1 μg/m^3 on 01 February. However $PM_{2.5}$ concentrations didn't increase considerably, only a slight increase occurred. After the dust episode, particulate matter concentrations decreased again. According to correlation analysis, AOD values and daily average PM_{10} concentrations were highly correlated during the study period. Very high correlation coefficient value (0.992) shows that there is a strong and positive correlation between the two parameters (Fig. 8). Figure 9 shows that $PM_{2.5}$ concentrations and AOD values were also positively correlated (0.781).

We can clearly see the effect of Saharan dust transportation on PM_{10} concentrations in Fig. 10, which shows the daily mean PM_{10} and $PM_{2.5}$ concentrations in Istanbul during the 2014–2015 winter season. In Istanbul, the daily average PM_{10} and $PM_{2.5}$ concentrations of the 2014–2015 winter season were 63.8 and 37 μg/m^3, respectively. During the dust episode, the daily average maximum PM_{10} concentration was 325.1 μg/m^3 on 01 February 2015. This value is very high compared with the 2014–2015 winter season average of Istanbul (63.8 μg/m^3) and PM_{10} daily limit value of the European Union (50 μg/m^3).

Conclusion

In this study, a Saharan dust transportation event was examined by using satellite images, satellite data, and air quality data between the dates of 29 December 2014 and 04 January 2015. On 01 February, Aqua MODIS shows very high AOD

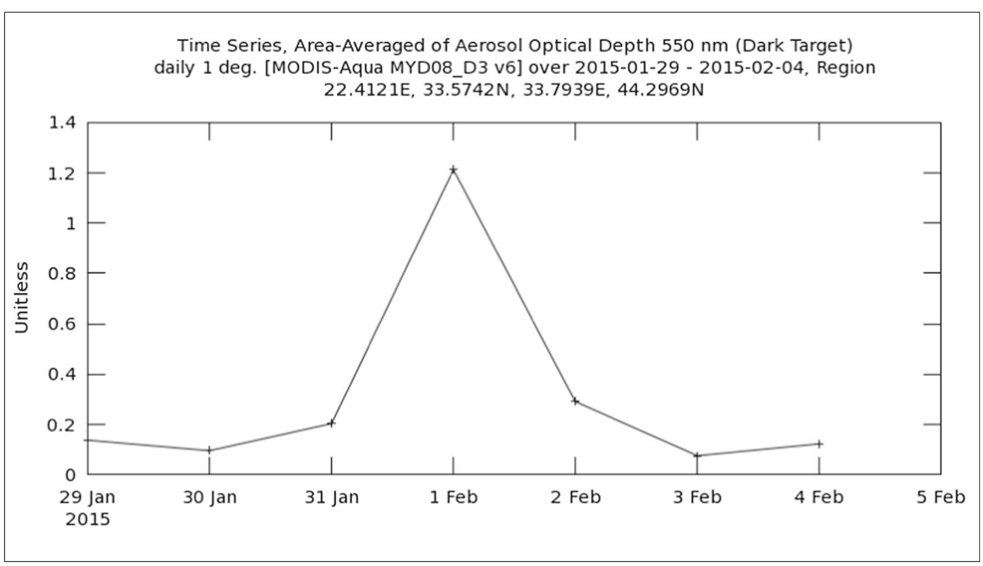

Fig. 6 Area average of aerosol optical depth between 29 January 2015 and 04 February 2015

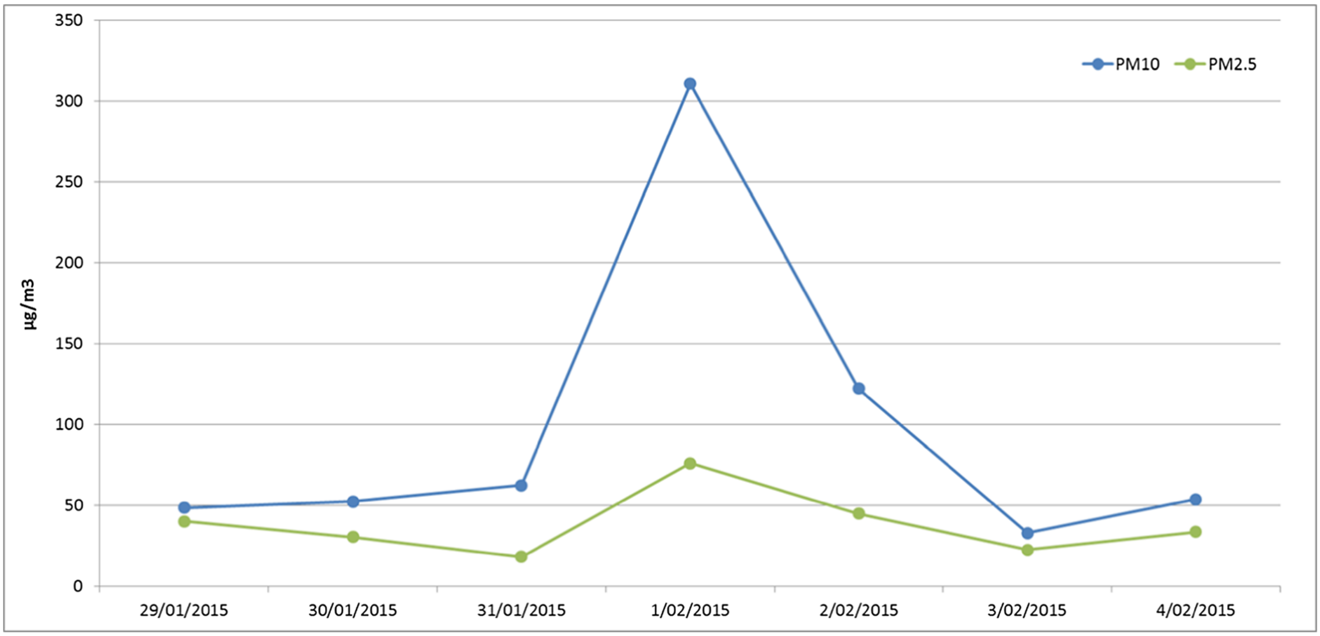

Fig. 7 Daily mean values of PM_{10} and $PM_{2.5}$ measured in Istanbul between 29 January 2015 and 04 February 2015

values starting from the coasts of Libya moving over the Aegean Sea and Western Turkey and finally reaching to the Black Sea. The daily average PM_{10} concentration of Istanbul rose to 325.1 µg/m^3 on 01 February, showing the significant contribution of Saharan dust to high levels of PM_{10}. The AOD and ground level PM_{10} data sets are found to be in agreement with a correlation of 0.992. In a similar study, Chatoutsidou et al. investigated the impact of African dust episodes on the measured PM_{10} levels with two campaigns in Crete in the eastern Mediterranean between April 2017 and March 2018. The daily PM_{10} concentrations of 547 and 234 µg/m^3 were measured during the first and the second campaigns, respectively, both of them associated with severe African dust storms (Chatoutsidou et al. 2019). The significant increase for the PM_{10} values can be explained by the higher gravitational settling velocities of coarse particles in the atmosphere. Barragan et al. found that travelling over the Mediterranean Basin, the geometrical and optical properties of a Saharan dust layer changed in the west-east direction; the columnar AOD was higher over Spain with higher presence of coarse particles while dust particles reached higher altitude over Italy with correspondingly lower presence of coarse particles (Barragan et al. 2017).

Saharan dust contribution to particulate matter concentrations in Turkey has been proven by different studies implementing remote sensing data, air quality models, and

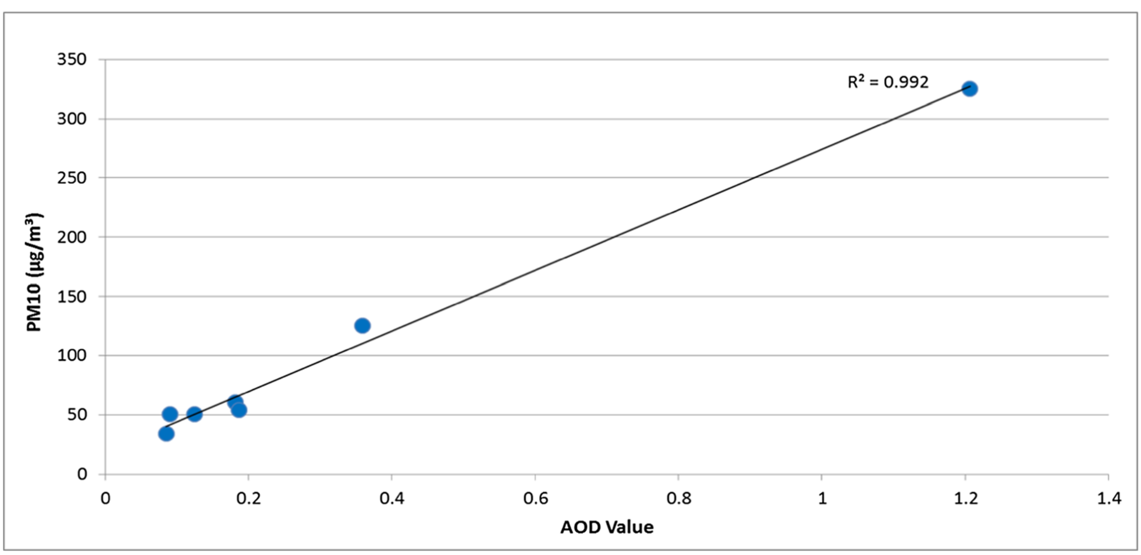

Fig. 8 Correlation between the AOD values and daily average PM_{10} concentrations measured between 29 January 2015 and 04 February 2015

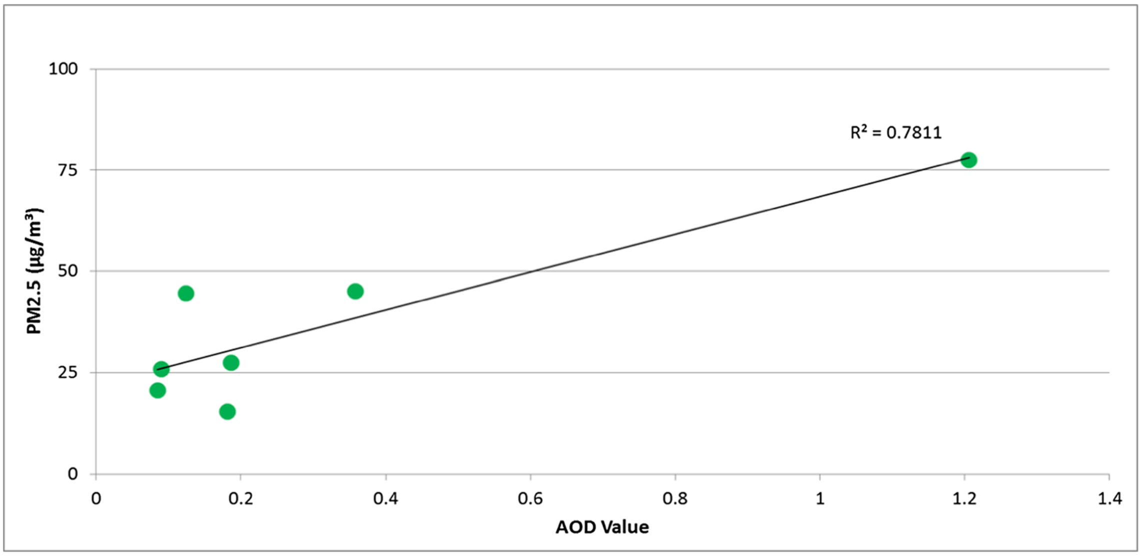

Fig. 9 Correlation between the AOD values and daily average $PM_{2.5}$ concentrations measured between 29 January 2015 and 04 February 2015

ground observations. Kabatas et al. compared Regional Air Quality Modeling System (RAQMS) with 118 air quality stations distributed throughout Turkey (81 cities) for April 2008. Their results suggest a significant contribution of Sahara dust to high levels of PM_{10} in Turkey with RAQMS and in situ time series showing similar patterns (Kabatas et al. 2014). Agacayak et al. investigated a dust transport episode using atmospheric 3D modeling, satellite data, and in situ observations in Turkey. According to their study, during the dust episode affecting Aegean and Marmara Regions intensively, the daily mean PM_{10} was 102.6 µg/m^3 in the Aegean Region and 117.3 µg/m$_3$ in the Marmara Region on 23 March 2008. AOD was 1.11 (at 550 nm) in the Aegean Region and 0.87 in the Marmara Region according to the RegCM4.1 model results on the same day (Ağaçayak et al. 2015).

According to the results, it can be said that the long-range Saharan dust transportation had a significant effect on the PM_{10} concentrations of Turkey. However, $PM_{2.5}$ concentrations didn't rise considerably compared with PM_{10}. Considering the health effects of particulate matter, it is suggested to investigate the effects of dust transport episodes on human health in the future studies.

Compliance with ethical standards

Conflict of interest We wish to confirm that there are no conflicts of interest with this publication and there has been no financial support for this work that could have influenced its outcome.

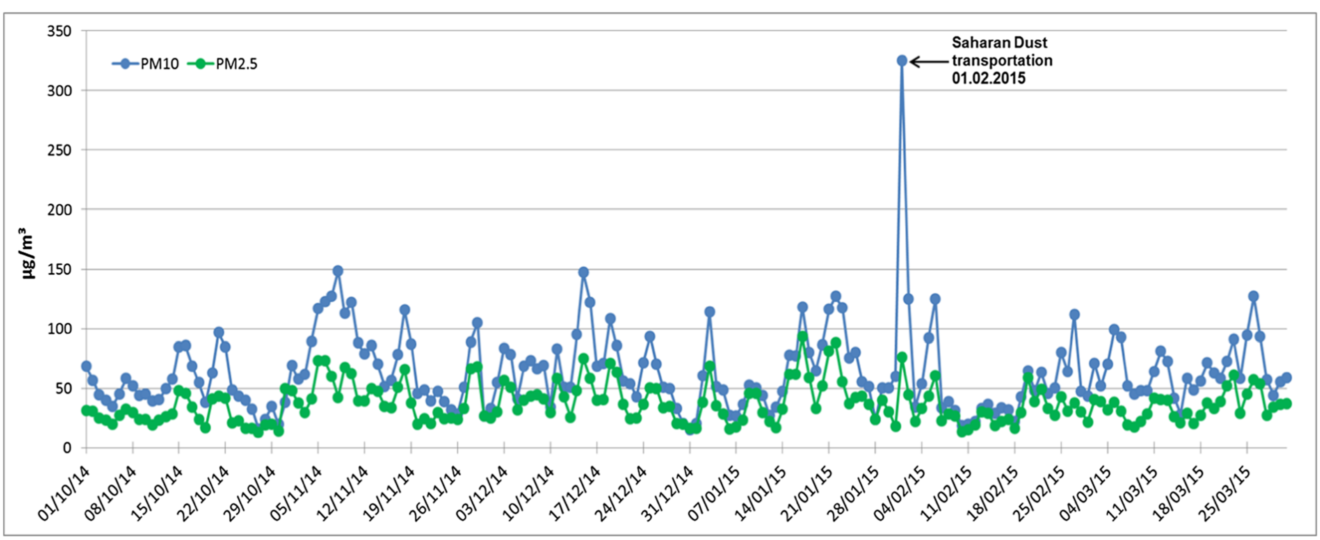

Fig. 10 The daily average PM_{10} and $PM_{2.5}$ concentrations in Istanbul during the 2014–2015 winter season (01 October 2014–31 March 2015)

References

Ağaçayak T, Kindap T, Ünal A, Pozzoli L, Mallet M, Solmon F (2015) A case study for Saharan dust transport over Turkey via RegCM4.1 model. Atmos Res 153:392–403

Barragan R, Sicard M, Totems J et al (2017) Spatio-temporal monitoring by ground-based and air- and space-borne lidars of a moderate Saharan dust event affecting southern Europe in June 2013 in the framework of the ADRIMED/ChArMEx campaign. Air Qual Atmos Health 10:261–285

Cadelis G, Tourres R, Molinie J (2014) Short-term effects of the particulate pollutants contained in Saharan dust on the visits of children to the emergency department due to asthmatic conditions in Guadeloupe (French Archipelago of the Caribbean). PLoS One 9(3):91136

Carlson TN, Prospero JM (1972) The large-scale movement of Saharan air outbreaks over the Northern Equatorial Atlantic. J Appl Meteorol 11(2):283–297

Chatoutsidou SE, Kopanakis I, Lagouvardos K et al (2019) PM_{10} levels at urban, suburban, and background locations in the eastern Mediterranean: local versus regional sources with emphasis on African dust. Air Qual Atmos Health 12:1359–1371

Griffin WD, Kellogg CA, Shinn EA (2001) Dust in the wind: long range transport of dust in the atmosphere and its implications for global public and ecosystem health. Global Change & Human Health 2(1): 20–33

İncecik S, İm U (2012) Air pollution in mega cities: a case study of Istanbul. Air pollution - monitoring, modelling and health. Intech Open Access Publisher, 77-116

Kabatas B, Unal A, Pierce R, Kindap T, Pozzoli L (2014) The contribution of Saharan dust in PM10 concentration levels in Anatolian peninsula of Turkey. Sci Total Environ 488–489:413–421

Karaca F, Anil I, Alagha O (2009) Long-range potential source contributions of episodic aerosol events to PM_{10} profile of a megacity. Atmos Environ 43:5713–5722

Karanasiou A, Moreno N, Moreno T, Viana M (2012) Health effects from Sahara dust episodes in Europe: literature review and research gaps. Environ Int 47:107–114

Kindap T, Unal A, Chen SH, Odman MT, Karaca M (2006) Long-range aerosol transport from Europe to İstanbul, Turkey. Atmos Environ 40:3536–3547

NASA (2020) EOSDIS Worldview, Washington D.C https://worldview.earthdata.nasa.gov/. Accessed 13 Mar 2020

Özdemir T (2019) Investigations of a southerly non-convective high wind event in Turkey and effects on PM10 values: a case study on April 18, 2012. Pure Appl Geophys 176:4599–4622

Stafoggia M, Zauli-Sajani S, Pey J, Samoli E, Alessandrini E, Basagana X et al (2016) Desert dust outbreaks in Southern Europe: contribution to daily PM(1)(0) concentrations and short-term associations with mortality and hospital admissions. Environ Health Perspect 124(4):413–419

Unal YS, Toros H, Deniz A, Incecik S (2011) Influence of meteorological factors and emission sources on spatial and temporal variations of PM_{10} concentrations in İstanbul metropolitan area. Atmos Environ 45:5504–5513

Vedal S, Brauer M, White R, Petkau J (2003) Air pollution and daily mortality in a city with low levels of pollution. Environ Health Perspect 111:45–51

Wetterzentrale (2020) NOAA Reanalysis, Mönchstrassez https://www.wetterzentrale.de/. Accessed 10 Aug 2020