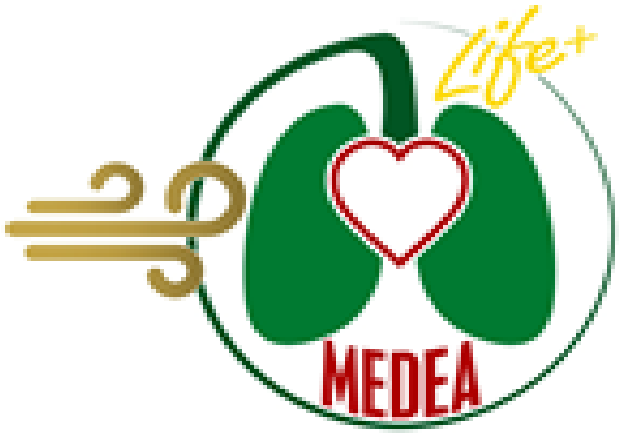

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Dust Storms (DS) events trends over the last 10-years (2007-2016) in Eastern Mediterranean

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Abstract

Studies have shown that characteristics (frequency, intensity) of dust storms are changing in response to climate change and land use. However, there is not constructive solid analyses on dust storms frequency and intensity at the region scale. We applied a common methodology to identify and evaluate the trends of dust storms at three Eastern Mediterranean locations: Crete, Greece; Cyprus; and Israel. From 2007 through 2016, we identified 283, 333, and 483 dust days in Crete, Cyprus, and Israel. We observed a high variability in the frequency and intensity of dust storms during the last decade at the three locations, but no statistically significant trends were observed. However, dust from Syria was more frequent over the last four years in Cyprus and Israel. The highest dust frrequency was observed in 2010 at all three places, but the highest annual PM_{10} net dust contribution (dust day PM_{10} – background PM_{10}) was observed in 2009 in Crete (89.7 $\mu g/m^3$), in 2008 in Cyprus (68.9 $\mu g/m^3$), and in 2015 in Israel (300.2 $\mu g/m^3$).

Introduction

Dust storms (DS) are due naturally occurring events that transport dust particles far from their soil sources. During DS events, which can last for several days, PM_{10} levels are considerably higher than the 2005 EU daily limit value of 50 $\mu g/m^3$ (Achilleos et al. 2014). Daily PM_{10} levels during dust events can exceed 2,000 $\mu g/m^3$ (Krasnov et al. 2014). DS pose a major risk to populations residing in affected areas such as in Mediterranean countries situated at the margins of the global dust belt, extending from West Africa to the Arabian Peninsula (Querol et al. 2009). Several studies have associated dust events with increase in daily mortality, hospital admissions and pregnancy outcomes (birth weight, gestational age at delivery) (Abdo et al. 2016; Crooks et al. 2016; Kwon et al. 2002; Tam et al. 2012; Thalib and Al-Taiar 2012; Vodonos et al. 2014; Yitshak-Sade et al. 2015).

Studies have shown that characteristics (frequency, intensity) of dust storms are changing in response of climate change and land use; therefore their health implications are expected to become more severe (Ganor et al. 2010; Goudie 2014; Krasnov et al. 2016). The frequency of dust storms in the southeastern Mediterranean has increased over the past few decades (Ganor et al. 2010). Krasnov et al. (2016) showed a trend of increase in daily and hourly PM_{10} levels during dust events in the Negev region since 2009. In Cyprus, the number of DS days during 1998–2008 increased at an average rate of 1.7 days/year with a maximum of 30 days in 2008 (Achilleos et al. 2014). In Crete,

during the winter and spring background PM_{10} levels exceeded the daily EU limit in 1 out of 5 days, with 80–100% of the cases linked to DS (Gerasopoulos et al. 2006). However, there is not constructive solid analyses over the last 10 years on DS frequency and intensity at the region scale.

DS have been defined in different ways in the past. For this reason, we will apply a common methodology to identify DS and evaluate the trends of dust related-PM at regional level at the three locations: i) Crete is impacted by long range transport practically only from Africa; ii) Cyprus is impacted by long range transport from both Africa and Middle East; and iii) Israel is impacted by surrounding deserts and long range transport from Africa.

Methods

Study Area

The study is based on three Eastern Mediterranean (EM) stations located: i) at the Island of Crete, Greece (Finokalia background station; 35°20' N, 25°40' E; 250m asl); ii) in Cyprus (Ayia Marina Xyliatou background station; 35°02' N, 33°03' E; 532m asl); and; iii) in Israel (Beer Sheva urban station; 31°15' N, 34°47' E) (Figure 1).

Finokalia (FKL) is the atmospheric research station of the Environmental Chemical Processes Laboratory at the University of Crete. Finokalia is located 50km east of Heraklion, the biggest city of the island (population: 173,993; 2011 Census). The area is characterized by a dry season (April to September), a wet season (from October to April), and a Sahara dust season during spring (S/SW winds; occurrence up to 20% of the days). The Ayia Marina (AM) station belongs to the air quality monitoring network operated by the Air Quality Section, Department of Labour Inspection. The monitoring site is located in the Nicosia district, 40 km southwest of the city (population: 332,200; 2011 Census). Cyprus has an intense Mediterranean climate with hot and dry summers (May-September), and mild winters (November-March). It is highly affected by dust transport from both the Saharan and Arabian deserts and dust storms are usually occurred during end of winter and spring (February-May). Both FKL and AM stations are included in the network of Co-operative Program for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP).

The city of Beer-Sheva, located in the Negev desert, is one of the main urban areas in Israel (population: 205,810; 2016 Census). Beer-Sheva (BS) monitoring station is located

on the roof of a building at the city center and it is part of the National Air Monitoring Network, operated by the Israel Ministry of Environmental Protection. Beer-Sheva has hot and dry summers, and cool, and wet winters. Dust storms originate from both the Saharan and Arabian region. They occur mostly during the winter, with mild events during spring and fall.

Figure 1.Location of the three monitoring sites in Crete-Greece (Finokalia-FKL), Cyprus (Ayia Marina Xyliatou-AM), and Israel (Beer Sheva-BS).

Environmental Data

PM_{10} data for the period 2007-2016 were collected at each monitoring station. Continuous PM_{10} concentrations were recorded every 2(AM) or 5 (BS) min using a Tapered Element Oscillating Microbalance (TEOM) (AM, BS) and FH 62 I-R Thermo (FKL)

instruments. Hourly measurements of meteorological parameters (temperature, wind speed, relative humidity) were also collected at the monitoring stations (FKL, BS) and from the Cyprus Department of Meteorology (AM). Daily Aerosol Optical Depth (AOD) from MODIS (Moderate Resolution Imaging Spectroradiometer) Aqua platform at a spatial resolution of 1^o x 1^o was obtained. The data was downloaded from the Giovanni online data system, developed and maintained by the NASA GES DISC (https://giovanni.gsfc.nasa.gov/giovanni/).

Daily missing PM_{10} data was replaced by gravimetric measurements (AM, FKL) or by regressing $PM_{2.5}$ data from nearby station (BS) using the following model: $PM_{10}BS$=intercept+$PM_{2.5}$Arad + wind speed-BS + Temperature-BS (R^2=81%). The remaining missing data, after the use of gravimetric measurements and $PM_{2.5}$ data, was 18% in FKL, 1% in AM, and 4.7% in BS.

Dust Events

We followed the following methodology to identify dust events at the three locations:

a) In order to identify PM peaks, a threshold equal to 2 standard deviations above the background (dust free) PM average level was derived at each location. The threshold for BS (71 μg/m^3) was previously estimated based on the daytime PM_{10} concentrations during the dust-free summer months July-August (Krasnov et al. 2014). For FKL and AM, background average was estimated for days with PM_{10} daily concentrations below 50 μg/m^3. From previous investigations, dust events usually exceed the EU PM_{10} daily limit of 50 μg/m^3 at background sites (Achilleos et al. 2014; Gerasopoulos et al. 2006). After excluding the main dust events, PM_{10} levels were 18.2±8.3 μg/m^3 in FKL, and 20.6±8.9 μg/m^3 in AM. Therefore, a cut-off point of 35 and 38 μg/m^3 was used for FKL and AM, respectively, in order to be as inclusive as possible. At this step, all the days with daily average above the background values were assigned as polluted days (by dust or other source).
b) Days with missing or limited PM_{10} data were examined using aerosol maps from BSC-DREAM8b model operated by the Barcelona Supercomputing Center (http://www.bsc.es/ess/bsc-dust-daily-forecast/), and MODIS – Aqua AOD and A (Angstrom exponent). High AOD (>0.3) and low A (<1) implies high load of coarse particles in the atmosphere.

c) All the polluted days derived in the previous steps, were then classified as "dust events" if air masses were originated from known dust sources in this region: Saharan, Arabian, or Syrian desert. Back trajectories of the air masses during five days before the dust event were examined at three altitudes (500,1000, and 1500 m asl) using the HYSPLIT model (Hybrid Single-Practice Lagrangian Integrated Trajectory) (Rolph et al. 2017), and the corrected reflectance images of the MODIS -Terra satellite from the NASA Worldview application (https://worldview.earthdata.nasa.gov/) operated by the NASA/Goddard Space Flight Center Earth Science Data and Information System (ESDIS) project. In case of disagreement between HYSPLIT trajectories and satellite images, further subjective analysis of the prevailing atmospheric conditions was performed, employing surface observations, upper measurements from relevant radiosonde stations as well as analysis of sea level pressure and height patterns at 1000hPa, 925hpa, 850hpa and 500hpa (approximately 100m, 1000m, 1500m and 5500m respectively) in order to identify the originating source of the air mass affecting the stations under investigation.

After this step, the polluted days with origin in dust events were separated in order to quantify the net dust load to the daily PM_{10} concentration level. The EU directive 2008/50/EC proposes to subtract background PM_{10} from the PM_{10} concentration levels of each dust day using regional background measurements. Specifically, the directive proposes the use of the monthly moving 40^{th} percentile after excluding the dust days, as an indicator of the background PM_{10} levels. However, the monthly moving 40^{th} percentile is a site specific indicator reproducing well the background level in the Iberian Peninsula (Escudero et al. 2007), but it has not been validated in other countries and, therefore, it was not used in our study. In addition, the directive proposes a more conservative indicator of the background PM_{10} levels; the average of PM_{10} concentrations during 15 days before and 15 days after the dust episodes. But, sometimes the dust events are closer in time and could not be used. To overcome this, we used season- and year-specific background PM_{10} averages, which we subtracted from the dust storm daily PM_{10} concentration for a given season and year.

Results and Discussion

We identified 283(FKL), 333(AM), and 483(BS) dust days in the Eastern Mediterranean region during the ten-year study period, from 2007 through 2016. These, corresponded to 151 (FKL), 155 (AM), and 218 (BS) dust episodes. Each episode lasted from one day to

seven (AM), eight (FKL), or even thirteen days (BS). Dust originated mostly from Sahara and to a lesser extend from Arabian Peninsula deserts in AM and BS. Dust days and events with African source were almost double in number for both AM (Sahara source: 217 days and 109 episodes) and BS (Sahara source: 306 days and 137 episodes). FKL is influenced mainly from Sahara desert and rarely from Middle East deserts (Sahara source: 149 events).

Table 1 presents summary statistics of PM_{10} levels, AOD, and meteorology. PM_{10} concentration and AOD were much higher in BS than in AM and FKL. During dust storms, the mean PM_{10} level was up to six times higher than the non-dust average. The increase was smaller in AM, approximately four times higher concentrations during dust days. A two-fold increase was observed for AOD during dust storms as well. We had fifty dust dates overlapping at the three EM sites (PM_{10}: 113.5±128.6 μg/m^3). AM and BS experienced another 132 common dust days (PM_{10}: 138.5±171.7 μg/m^3), BS and FKL another 37 days (PM_{10}: 89.3±56.1 μg/m^3), and AM and FKL another 34 days (PM_{10}: 70.7±42.9 μg/m^3).

Table 1. Summary statistics for the study period 2007-2016 at Finokalia (FKL), Ayia-Marina Nicosia (AM), and Beer Sheva (BS) stations. (NDS=Number of Dust Days, NDE=Number of Dust Events).

Variable (mean ± sd)	FKL		AM		BS	
	Dust	Non Dust	Dust	Non Dust	Dust	Non Dust
PM_{10} (μg/m^3)	71.8±58.3	17.3±7.3	77.6±65.4	20.3±9.0	178.1±241.2	37.2±16.1
AOD	0.42±0.34	0.19±0.10	0.50±0.41	0.20±0.11	0.55±0.55	0.24±0.12
Temperature (°C)	20.0±5.2	18.1±5.6	20.5±6.1	19.7±7.4	19.9±5.7	19.8±5.8
Relative Humidity (%)	58.7±19.9	73.4±16.2	59.2±15.3	60.5±14.1	50.5±17.5	63.8±13.0
Wind Speed (m/s)	5.9±4.0	6.1±3.0	1.8±0.7	1.8±0.8	3.3±1.4	2.6±0.8
Precipitation (mm)			3.1±8.0	2.2±5.3	0.43±2.51	0.29±1.85

Figure 2 illustrates the annual total number of dust days and episodes. We observed a high variability in the frequency of dust storms during the last decade, and the pattern is the same for both dust days and episodes. The occurrence of dust storms was highest in 2010 and 2013 at FKL, whereas the lowest frequency was observed right before these years (2009,2011, 2012). In AM, dust days and events are decreasing from 2007 to 2012, except a maxima observed in 2010, and it starts increasing again in 2013. In BS, the frequnecy seems to increase from 2007 to 2012, following a downtrend until 2016. In order to assess the trends of dust days and episodes, we applied the Theil-Sen estimator and Mann-Kendall test of significance (a nonparametric method to test and model trends). We found no statistically significant trend at any of the three stations. Specifically, FKL showed no trend for dust days (0 days/year) and a positive non-

significant trend for dust episodes (0.2 episodes/year, p-value=0.42). Dust days and episodes gave a negative non-statistically significant trend in both AM (DD: -3.3 days/year, p-value=0.11; DE: -0.6 episodes/years, p-value=0.37) and BS (DD: -2.6 days/year, p-value=0.28; DE: -0.6 episodes/years, p-value=0.47). No statistically significant trends were found when dust days and episodes were stratified by dust source (Figures S1-S2). However, it seems that dust from Syria is more present over the last four years in AM and BS.

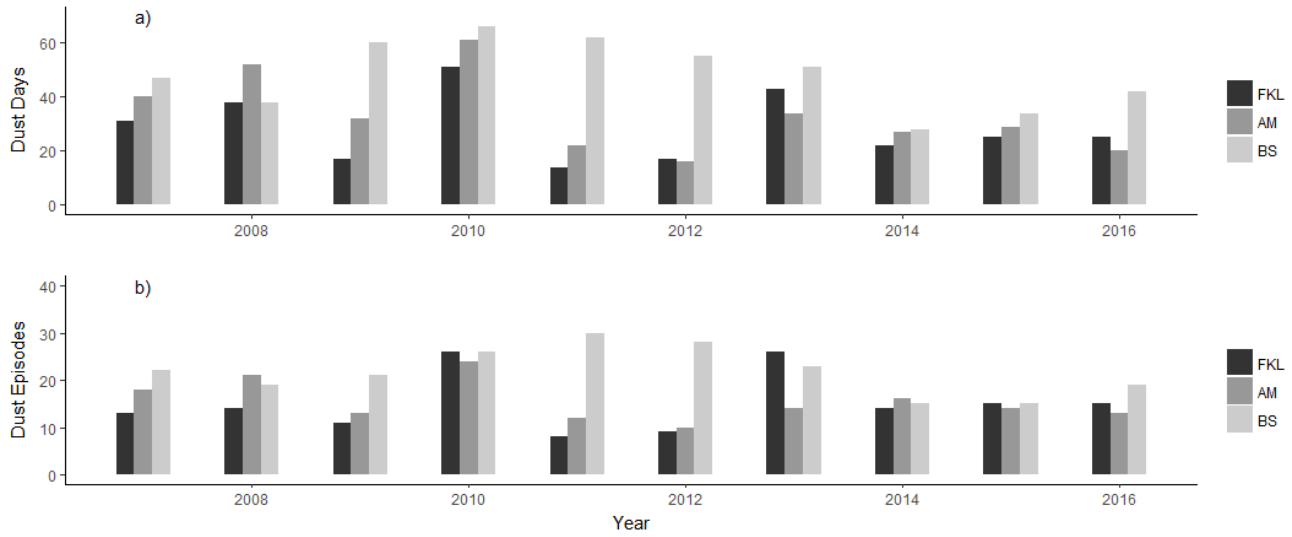

Figure 2. Number of dust days (a) and episodes (b) identified per year at the three stations (FKL, AM, BS)

Table 3 shows the annual contribution of dust days to PM_{10} (total and net) and AOD in FKL, AM, and BS. The intensity of dust storms seem to change over the years but not monotonic. Even if we identified more dust events in 2010, this was not the case for the dust intensity. The annual average dust intensity in FKL reached two maxima in 2009 and 2015, and a minimum in 2014. The AOD value was highest in the same years. Two maxima observed in AM (years 2008, 2013) and BS (years 2010, 2015) as well, but not on the same years. The intensity of dust storms in 2015 in BS was much higher than any other year, even from 2010 peak. AOD in AM reached a maximum in 2012, and in 2015 in BS.

Table 3. Mean (± sd) annual contribution of dust days to PM_{10} ($\mu g/m^3$) (total and net dust contribution) and AOD for the study period 2007-2016.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
FKL										
PM_{10}	46.6±17.1	56.4±26.4	103.9±88.2	74.3±69.6	75.2±38.3	75.2±72.1	74.0±47.2	55.3±14.8	77.4±83.4	63.1±36.3
PM_{10}net	62.2±17.1	38.8±26.7	89.7±88.1	58.0±70.0	54.3±39.1	57.7±73.5	55.7±47.0	39.6±14.5	63.4±83.7	47.8±36.0
AOD	0.46±0.23	0.52±0.28	0.57±0.37	0.44±0.39	0.47±0.28	0.36±0.23	0.30±0.23	0.32±0.20	0.43±0.44	0.43±0.36
AM										
PM_{10}	70.6±29.3	93.5±63.8	87.6±82.8	79.6±80.3	58.4±23.7	62.0±35.7	84.9±83.8	70.8±57.0	78.3±80.6	58.3±26.4
PM_{10}net	47.4±31.4	68.9±65.0	68.1±83.1	56.8±81.1	41.0±24.8	43.7±36.1	67.5±84.2	51.4±57.0	61.3±80.4	40.4±26.7
AOD	0.45±0.21	0.49±0.45	0.51±0.36	0.42±0.22	0.56±0.55	0.62±0.32	0.54±0.61	0.54±0.64	0.57±0.60	0.47±0.32
BS										
PM_{10}	149.6±129.7	146.0±73.4	168.6±202.5	251.1±472.0	140.1±131.6	162.2±133.7	147.9±129.7	144.5±115.4	339.3±376.6	149.7±128.4
PM_{10}net	116.3±130.3	112.0±73.7	136.7±202.3	214.0±472.0	100.9±133.3	126.7±134.3	108.7±129.0	102.9±115.4	300.2±375.9	111.3±129.4
AOD	0.67±0.79	0.54±0.33	0.51±0.45	0.52±0.56	0.49±0.31	0.55±0.40	0.51±0.54	0.63±0.69	0.89±0.98	0.36±0.20

*PM_{10net} = PM_{10}-background PM_{10}

Figure 3 shows the daily average of PM_{10} measured during dust days. At FKL and AM, PM_{10} levels were usually below 100 µg/m^3, with some much higher concentrations during 2008-2011, 2013, and 2015. The maximum daily PM_{10} average at FKL was observed in 2015 (1/2/2015, PM_{10}=421.8 µg/m^3), and in 2010 at AM (28/5/2010, PM_{10}=626.8 µg/m^3). In BS, PM_{10} during dust events are usually 200 µg/m^3 or less, and much higher concentrations were observed in 2010, 2011, and 2015-2016. The maximum daily average was observed in 2010 at BS (12/12/2010, PM_{10}=3,210.9 µg/m^3).

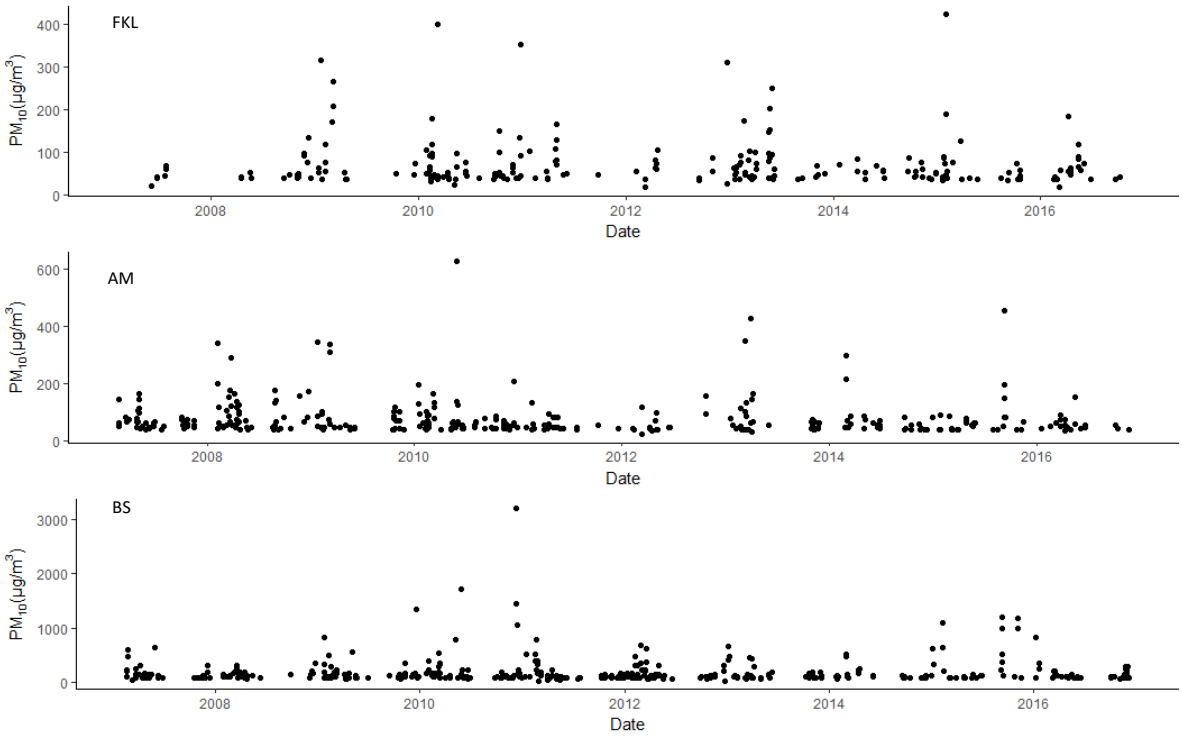

Figure 3. PM_{10} concentrations (µg/m^3) during dust storm days at the three stations (FKL, AM, BS).

We also examined whether there is a significant trend on dust intensity over the years. For FKL, we excluded the first two years when using PM_{10} because of high missing data. A non-statistically significant downtrend was observed for the DS net contribution at all three stations. The DS contribution to PM_{10} followed a non-statistically significant negative trend in FKL and AM, but a positive non-significant trend in BS. Non-statistically significant trend was found for AOD in AM (0.007 units/year, p-value=0.28) and BS (-0.005 units/year, p-value=0.72). The downtrend of AOD observed at FKL was significant at 0.10 significance level (-0.010 units/year, p-value=0.07). Dust intensity was examined for each dust source as well. The intensity showed a non-significant downtrend for all dust sources in AM. The intensity of Sahara dust storms gave a negative non-significant

trend, but the Arabian dust had a positive non-significant trend for BS (Figures S3-S4). In BS, the annual net PM_{10} Sahara dust contribution ranged between 104.0 (year 2008) and 258.4 (year 2010) $\mu g/m^3$, and the Arabian dust between 59.8 (year 2007) and 422.5 (year 2015) $\mu g/m^3$.

A change in the seasonality of dust storms has been noticed (Figure 4). Seasons were defined as winter (November-February), spring (March-May), summer (June-August), and fall (September-November). In BS, dust events were more abundant during winter and spring seasons, but over the last four years they occur more in the fall. Winter and spring frequency was significantly decreased over the years (winter: -1.7 days/year, p-value = 0.07; spring: -1.3 days/year, p-value=0.04), and fall was increased (0.80 days/year, p-value=0.37). Winter and spring season is the most dominant dust season in AM and FKL, and no significant seasonal trends on dust frequency was observed. However, it seems that winter (AM) and summer (FKL) dust occurrence decreased over the years. In AM, a significant decrease of winter PM_{10} net dust contribution was found over the years (-6.2 $\mu g/m^3$/year, p-value=0.03), and two fall peaks were observed in 2012 and 2015 (Figure S5). The net dust PM_{10} was positively correlated with precipitation in AM (correlation coefficient, r = 0.29), and with wind speed in BS (r = 0.33). Significant trends on local climate was found for annual precipitation in BS (0.05 mm/year, p-value = 0.03) increasing from 0.33 mm in 2007 to 0.59 mm in 2016, and wind speed in AM (-0.04 m/s per year, p-value = 0.07).

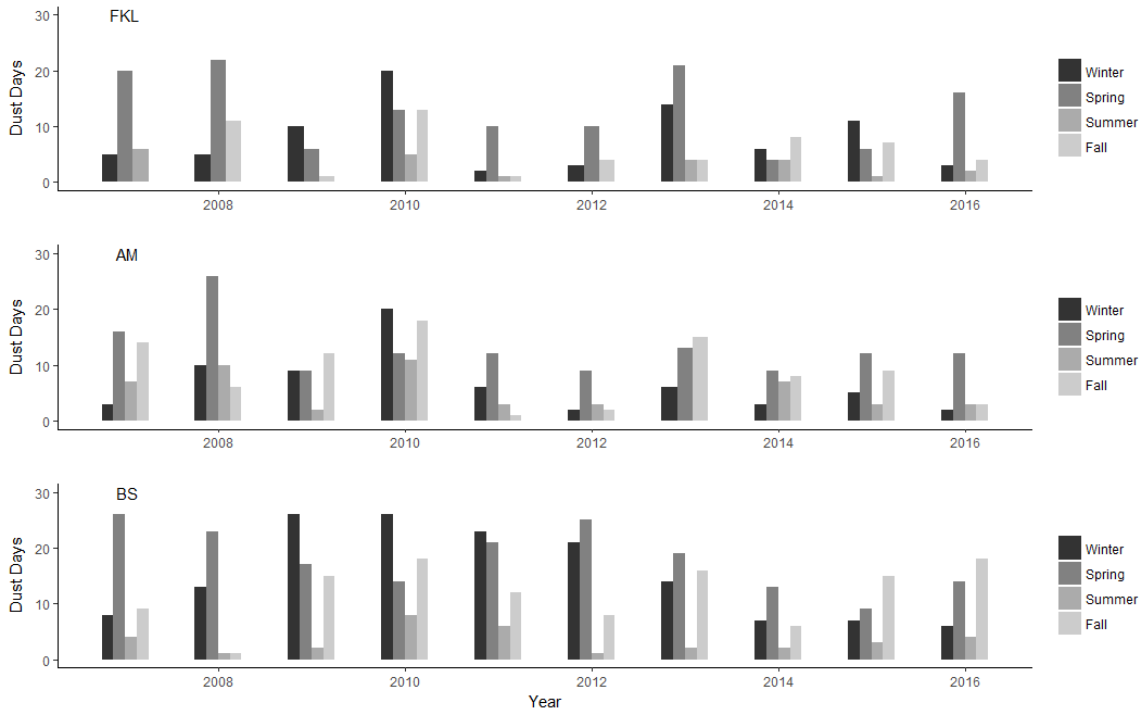

Figure 4. Number of dust days identified per year and season at the three stations (FKL, AM, BS)

Evan et al. (2016) showed that surface wind patterns are responsible for the variation of North Africa dust emissions. A historic re-analysis from 1851 to 2011, from the same authors, gave a statistically significant downtrend in the dust emissions. The downtrend was associated with increase in greenhouse gas emissions. In West Africa Sahel, an increase of dust emissions was observed over the last decades starting from late 1940s and it was related to droughts and to the increase in the threshold wind velocity for dust entrainment (Goudie 2014). In Eastern Mediterranean, studies in Israel found an increasing trend of dust storms during 1958-2006 in association with changing synoptic conditions (Ganor et al. 2010), but a decrease in dust storms frequency during 2001-2015 and higher hourly and daily PM_{10} levels since 2009 (Krasnov et al. 2016). Starting our analyses from 2007, this effect was not visible for Beer Sheva. Pey et al. (2013) study found no significant trend of African dust contribution to PM_{10} over central and southern Mediterranean areas from 2001 to 2011, with sporadic annual peaks. A decreasing trend on PM_{10} contribution was observed from 2006 or 2007 through 2011 in western and central Mediterranean areas. A previous analysis on dust trends in Cyprus, found an increasing trend on dust storms frequency during 1998 and 2008 (Achilleos et al. 2014).

Comparing our results with the findings of these previous studies, dust storms characteristics can change over decades. Studies are suggesting that the future of dust storms will depend on anthropogenic pressure on desert surfaces, natural climatic variability (e.g. in the El Niño Southern Oscillation or the North Atlantic Oscillation); and changes in climate from climate change (Goudie 2014).

Conclusions

In this study, we studied the dust storms frequency and intensity at a region scale using PM_{10} data from monitoring stations in Crete, Cyprus, and Israel for the period 2007-2016. We observed no significant trends of dust frequency and intensity over the last years, with sporadic annual peaks. The observed peak of dust frequency was observed in 2010 at all three stations, however the peak in the dust intensity was observed in different years at each location. The observed variability can be partially explained by natural climatic variability as shown by other studies. Changes in dust seasonality and contribution of dust desert sources have been identified. Nevertheless, in order to get a better understanding of the dust storm situation in the area, we need to expand our analysis to cover more than ten years since changes can occur over decades.

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References

Abdo N, Khader Yousef S, Abdelrahman M, Graboski-Bauer A, Malkawi M, Al-Sharif M, et al. 2016. Respiratory health outcomes and air pollution in the eastern mediterranean region: A systematic review. In: Reviews on Environmental Health, Vol. 31, 259.

Achilleos S, Evans JS, Yiallouros PK, Kleanthous S, Schwartz J, Koutrakis P. 2014. Pm10 concentration levels at an urban and background site in cyprus: The impact of urban sources and dust storms. Journal of the Air & Waste Management Association (1995) 64:1352-1360.

Crooks JL, Cascio WE, Percy MS, Reyes J, Neas LM, Hilborn ED. 2016. The association between dust storms and daily non-accidental mortality in the united states, 1993–2005. Environmental Health Perspectives 124:1735-1743.

Escudero M, Querol X, Pey J, Alastuey A, Perez N, Ferreira F, et al. 2007. A methodology for the quantification of the net african dust load in air quality monitoring networks. Atmospheric Environment 41:5516-5524.

Evan AT, Flamant C, Gaetani M, Guichard F. 2016. The past, present and future of african dust. Nature 531:493.

Ganor E, Osetinsky I, Stupp A, Alpert P. 2010. Increasing trend of african dust, over 49 years, in the eastern mediterranean. Journal of Geophysical Research: Atmospheres 115:n/a-n/a.

Gerasopoulos E, Kouvarakis G, Babasakalis P, Vrekoussis M, Putaud JP, Mihalopoulos N. 2006. Origin and variability of particulate matter (pm10) mass concentrations over the eastern mediterranean. Atmospheric Environment 40:4679-4690.

Goudie AS. 2014. Desert dust and human health disorders. Environment International 63:101-113.

Krasnov H, Katra I, Koutrakis P, Friger MD. 2014. Contribution of dust storms to pm10 levels in an urban arid environment. Journal of the Air & Waste Management Association (1995) 64:89-94.

Krasnov H, Katra I, Friger M. 2016. Increase in dust storm related pm10 concentrations: A time series analysis of 2001–2015. Environmental Pollution 213:36-42.

Kwon HJ, Cho SH, Chun Y, Lagarde F, Pershagen G. 2002. Effects of the asian dust events on daily mortality in seoul, korea. Environmental research 90:1-5.

Pey J, Querol X, Alastuey A, Forastiere F, Stafoggia M. 2013. African dust outbreaks over the mediterranean basin during 2001–2011: Pm₁₀ concentrations, phenomenology and trends, and its relation with synoptic and mesoscale meteorology. Atmos Chem Phys 13:1395-1410.

Querol X, Pey J, Pandolfi M, Alastuey A, Cusack M, Pérez N, et al. 2009. African dust contributions to mean ambient pm10 mass-levels across the mediterranean basin. Atmospheric Environment 43:4266-4277.

Rolph G, Stein A, Stunder B. 2017. Real-time environmental applications and display system: Ready. Environmental Modelling & Software 95:210-228.

Tam WW, Wong TW, Wong AH. 2012. Effect of dust storm events on daily emergency admissions for cardiovascular diseases. Circulation journal : official journal of the Japanese Circulation Society 76:655-660.

Thalib L, Al-Taiar A. 2012. Dust storms and the risk of asthma admissions to hospitals in kuwait. Science of The Total Environment 433:347-351.

Vodonos A, Friger M, Katra I, Avnon L, Krasnov H, Koutrakis P, et al. 2014. The impact of desert dust exposures on hospitalizations due to exacerbation of chronic obstructive pulmonary disease. Air Quality, Atmosphere & Health 7:433-439.

Yitshak-Sade M, Novack V, Katra I, Gorodischer R, Tal A, Novack L. 2015. Non-anthropogenic dust exposure and asthma medication purchase in children. European Respiratory Journal 45:652-660.

Supplementary

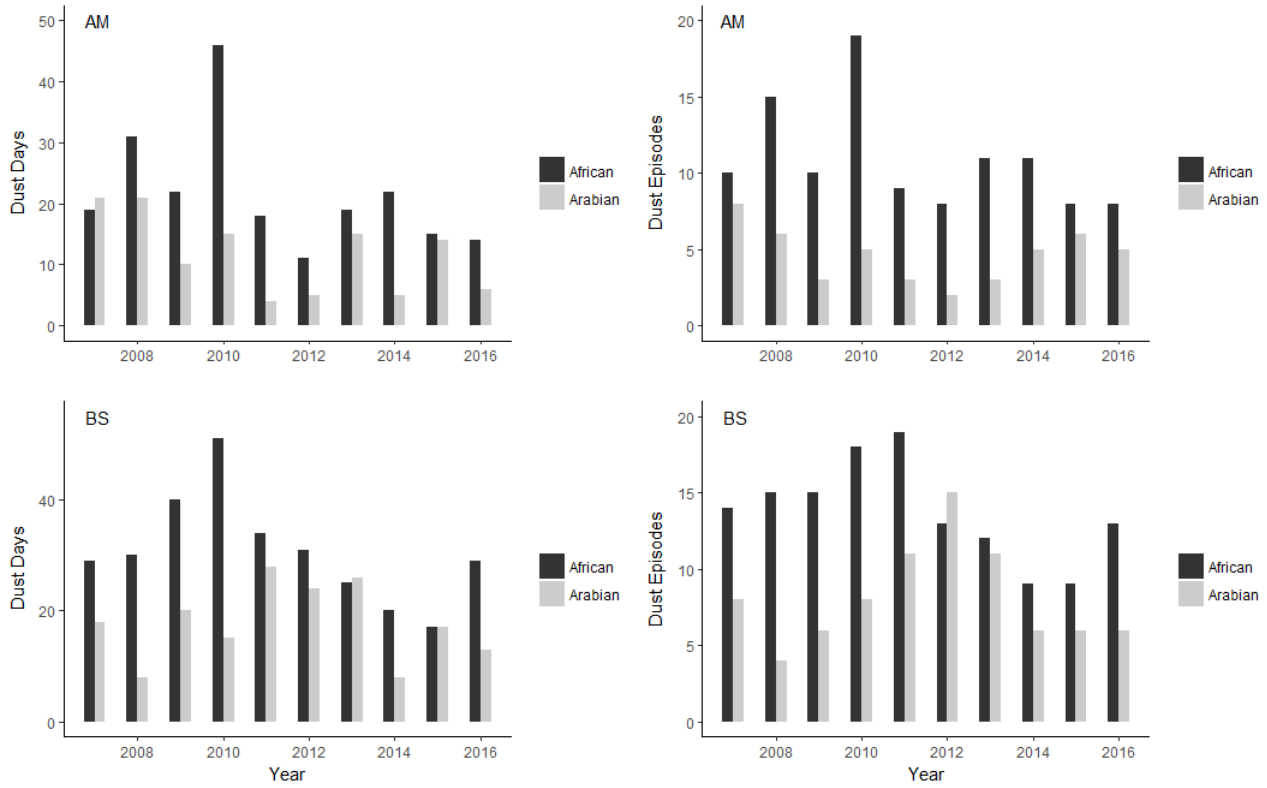

Figure S1. Number of dust days and episodes by desert source (African=Sahara, Arabian= Arabian and Syrian) in AM and BS.

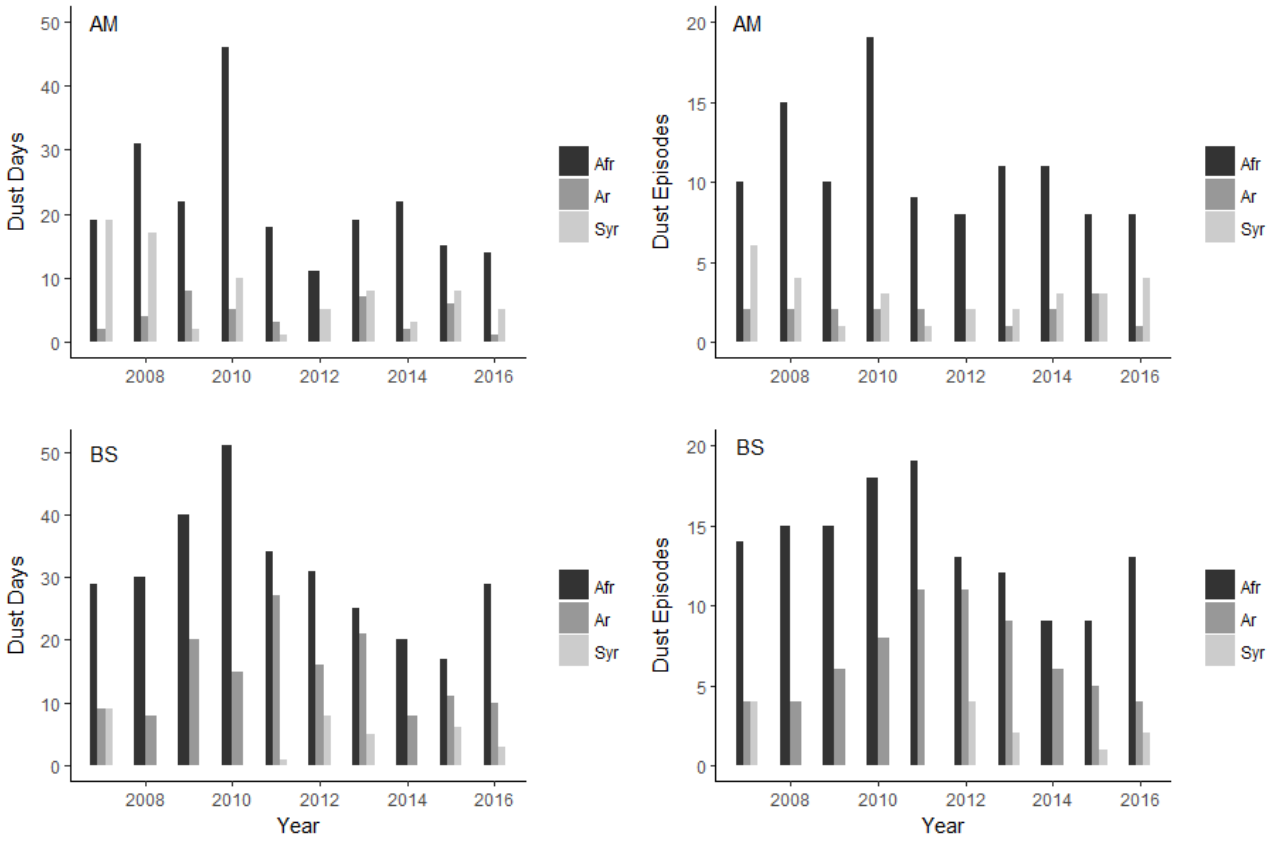

Figure S2. Number of dust days and episodes by desert source (Afr=Sahara, Ar = Arabian, Syr=Syrian) in AM and BS.

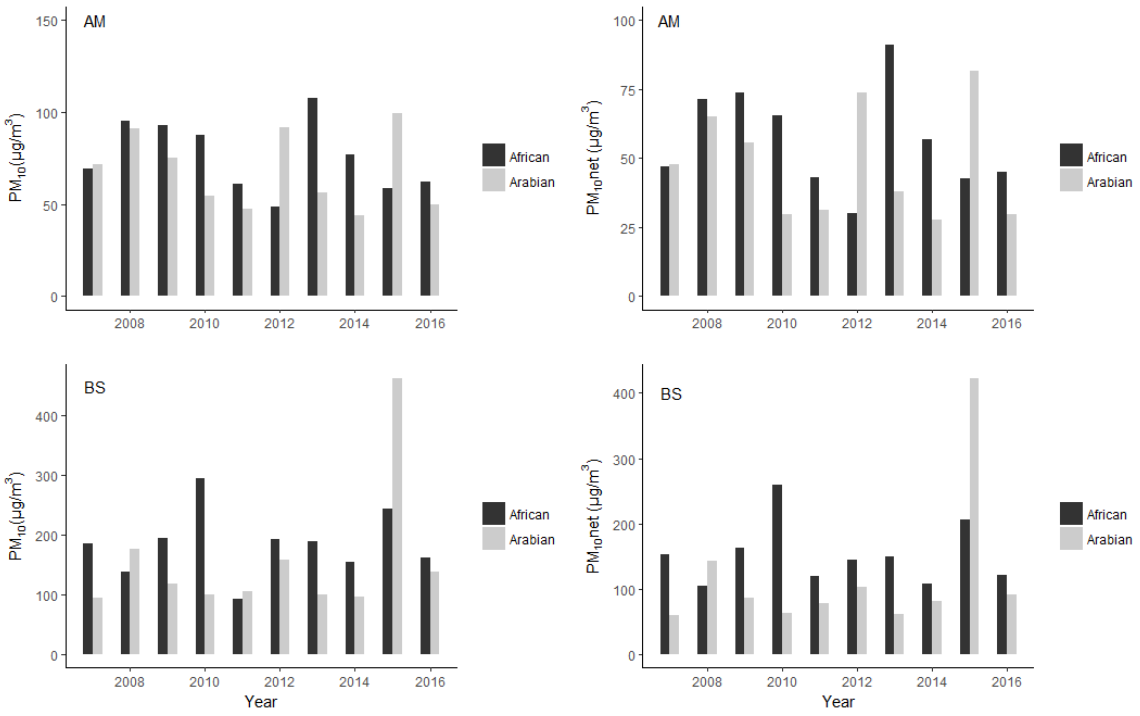

Figure S3. Mean annual contribution of dust days to PM_{10} (µg/m^3) for the study period by desert source (African=Sahara, Arabian= Arabian and Syrian) in AM and BS.

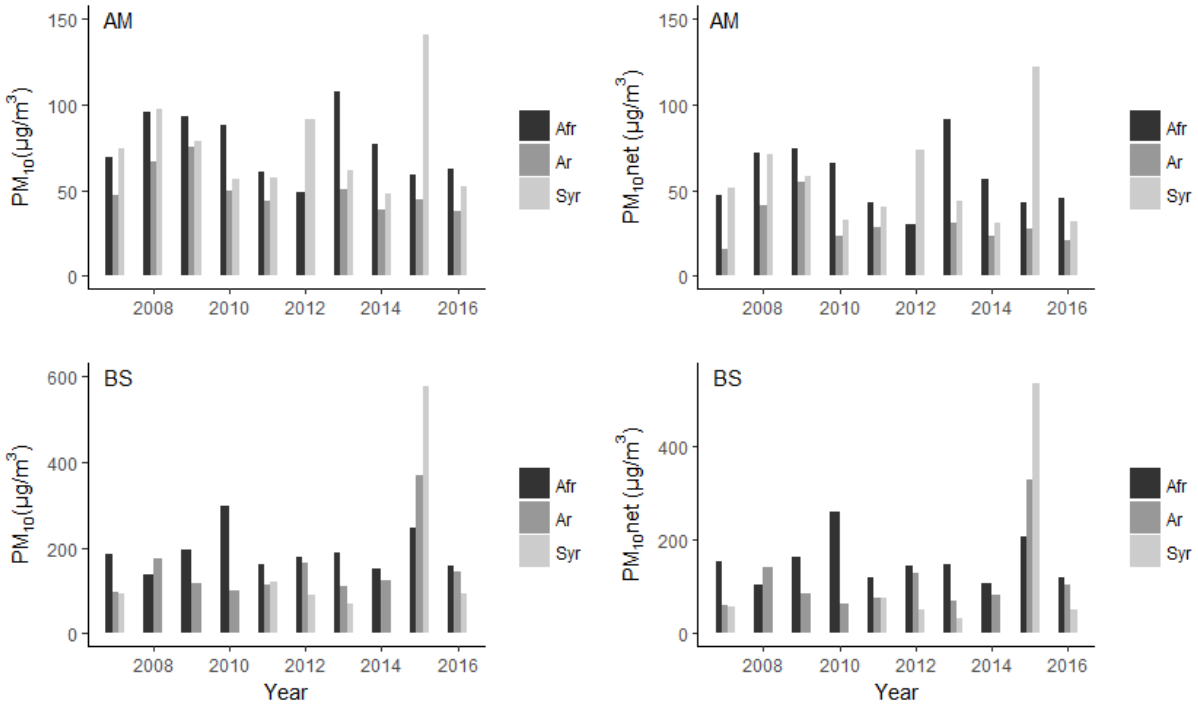

Figure S4. Mean annual contribution of dust days to PM_{10} (µg/m^3) for the study period by desert area of origin (Afr=Sahara, Ar = Arabian, Syr=Syrian)

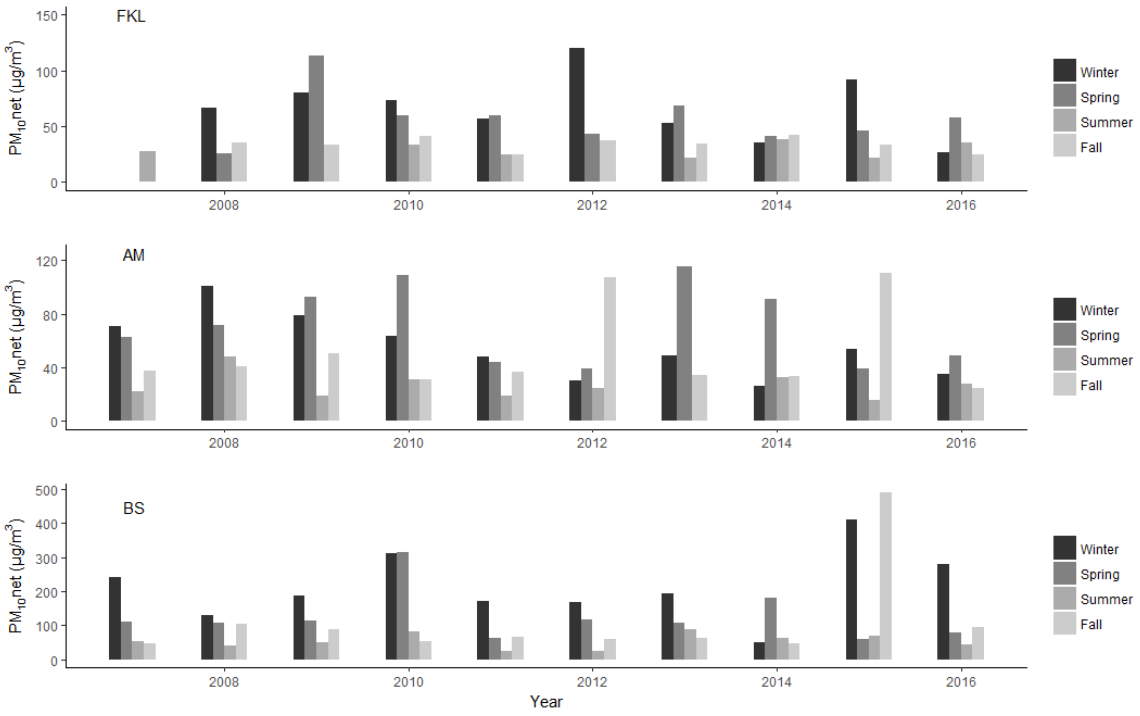

Figure S5. Mean annual and seasonal contribution of dust days to PM_{10} ($\mu g/m^3$) for the study period.