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Airborne desert dust and aeromicrobiology over the Turkish Mediterranean coastline

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Abstract

Between 18 March and 27 October 2002, 220 air samples were collected on 209 of 224 calendar days, on top of a coastal atmospheric research tower in Erdemli, Turkey. The volume of air filtered for each sample was 340 liters. Two hundred fifty-seven bacterial and 2598 fungal colony forming units (CFU) were enumerated from the samples using a low-nutrient agar. Ground-based dust measurements demonstrated that the region is routinely impacted by dust generated regionally and from North Africa and that the highest combined percent recovery of total CFU and African dust deposition occurred in the month of April (93.4% of CFU recovery and 91.1% of dust deposition occurred during African dust days versus no African dust present, for that month). A statistically significant correlation was observed (peak regional African dust months of March, April and May; $r_s = 0.576$, $P = 0.000$) between an increase in the prevalence of microorganisms recovered from atmospheric samples on dust days (regional and African as determined by ground-based dust measurements), versus that observed on non-dust days. Given the prevalence of atmospherically suspended desert dust and microorganisms observed in this study, and that culture-based studies typically only recover a small fraction (<1.0%) of the actual microbial population in any given environment, dust-borne microorganisms and other associated constituents (organic detritus, toxins, etc.) may play a significant role in the regional human and ecosystem health.
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Keywords: Turkey; Middle East; Desert dust; African dust; Microbiology; Aerobiology; Bacteria; Fungi; Public health; Mediterranean; Ecosystem health

1. Introduction

Of an estimated 2 billion metric tons of dust that move some distance in Earth's atmosphere each year, approximately 75% originates from the Sahara and Sahel regions of Africa (Goudie and Middleton, 2001; Moulin et al., 1997; Perkins, 2001). African dust studies conducted in Barbados and Miami, Florida, recorded an increase in the quantity of dust moving across the Atlantic Ocean that started with the onset (~1970) of the current North African drought (Prospero, 1999; Prospero and Lamb, 2003). Analysis of long-term satellite data implicated drought and its influence on the

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position of vegetative boundaries in the southern Sahara, as the primary cause of annual variability in dust transport across the Atlantic (Moulin and Chiapello, 2004). Precipitation and dust generation patterns in North Africa are influenced by pressure cell-system flux (the North Atlantic Oscillation) over the North Atlantic Ocean (Turkes and Erlat, 2003). Drought conditions in North Africa are marked by a 'weakening of the land–sea pressure gradient over the eastern South Atlantic and a strengthening of the high-pressure cell over the North Atlantic' (Mulitza and Ruhlemann, 2000, p. 270). This type of pressure cell flux results in colder North Atlantic and warmer equatorial waters and this sea-surface temperature gradient was noted during two regional early Holocene droughts which occurred ~10,000 and 8000 years ago, respectively (Mulitza and Ruhlemann, 2000). The African Sahel climate is sensitive to sea-surface temperature flux which occurs in any tropical oceanic waters whether they are remote (Pacific) or regional (Atlantic and Indian) and drought strength may also be influenced by land–atmosphere and human–land interactions (Giannini et al., 2003).

The primary sources of Saharan dust to the eastern Mediterranean are the arid regions of eastern Algeria, Libya, and western Egypt (Israelevich et al., 2003; Larrasoana et al., 2003). In addition, the vertical distribution of dust moving from the Sahara over the Mediterranean ($\leqslant 8$ km) is typically greater than that seen crossing the Atlantic Ocean ($\leqslant 5$ km) (Alpert et al., 2004). Dust sources to the eastern Mediterranean vary throughout the year with the northcentral Sahara dominating in the spring, the northeast Sahara in the summer, and the Middle East in the autumn (Alpert et al., 1990; Dayan, 1986; Israelevich et al., 2002, 2003; Kubilay et al., 2000). In the summer and autumn, dust transport to the region occurs at higher atmospheric altitudes (>700 hPa $= \sim 3000$ m), while the lower altitudes are impacted by urban and industrial aerosols transported from the north (Kubilay et al., 2003). Regional studies have shown that the majority of the dust-carrying winds have a westerly (87%) or southwesterly (61%) component (i.e., from North Africa) and that the Arabian dust fraction of the total (African and Arabian dust) is relatively small (Dayan et al., 1991; Yaalon and Ganor, 1979).

Dust deposition in 1992 at Erdemli, Turkey (the research site in this study), was estimated at 13 tons km^{-2}. Approximately 30% of the annual deposition of dust occurred during two Saharan episodes. Based on these data, the authors advocated frequent (daily) sampling to enhance understanding of this atmospheric process and its implications (Kubilay et al., 2000). Recently, Kubilay et al. (2005) have shown that (using multiyear aerosol Al measurements together with airmass back trajectory analysis and NASA's Total Ozone Mapping Spectrometer (TOMS) data) dust transport from North Africa constitutes a large fraction of atmospheric dust concentration in the eastern Mediterranean. Figs. 1a and b illustrate the impact of Saharan dust storms on air quality in this region (Erdemli, Turkey, photo dates, 30 May, 2003) versus clear or normal atmospheric conditions (4 June, 2003).

In addition to serving as a source of nutrients for aquatic and terrestrial microorganisms and plant life, dust storms can also deposit soil-associated pollutants (chemicals, metals, etc.) and microbes to

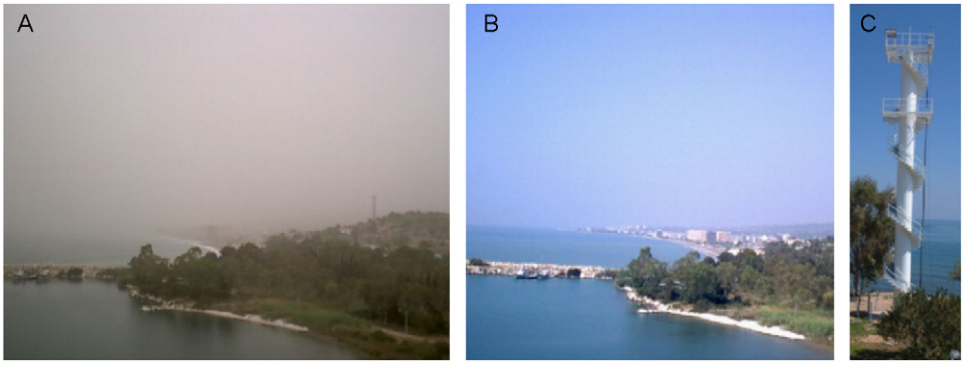


Fig. 1. Two images depicting the impact of African desert dust storms on air quality in Erdemli, Turkey. (a) 'Dust event' on 30 May, 2003. (b) Clear atmospheric conditions on 4 June, 2003. Both pictures were taken from atop the 21-m-high atmospheric-sample collection tower used in this study to collect air samples (c).

downwind ecosystems (Herut et al., 2002; Lenes et al., 2001). Falkovich et al. (2004, p. 18) demonstrated that concentrations of organics increased along the coast of Israel during dust events, indicating that 'dust can be an efficient medium for pollutant transport in the troposphere'. A correlation has been made between an increase in total protein concentrations (a surrogate of total biological concentration) in the atmosphere and elevated PM10 (particles less than 10 μm in size) in desert and urban-fringe aerosols (Boreson et al., 2004).

Historic studies which focused on understanding aeromicrobiology whether ground or airplane-based, noted that elevated concentration of airborne soil equated to an increase in airborne microbial concentrations (Brown et al., 1935; Fulton, 1966; Proctor, 1935). In studies addressing microbial transport in clouds of desert dust moving within and from the Saharan and Sahel regions of North Africa aeromicrobiology concentrations were noted to be higher when dust was present (in Africa and emanating out over the Atlantic to the Americas) than when it was not (Griffin et al., 2001, 2003, 2006; Kellogg et al., 2004; Prospero et al., 2005). Studies of microbial transport in clouds of desert dust in the Middle East and emanating out of the Asian deserts have also documented this common observation (Abdel-Hafez and Shoreit, 1985; Abdel-Hafez et al., 1986; Choi et al., 1997; Ho et al., 2005; Kwaasi et al., 1998; Wu et al., 2004; Yeo and Kim, 2002). At estimates of $\sim 10^9$ bacteria and 10^6 fungi per gram of top soil it should not be surprising that when soil is mobilized into the atmosphere by storm activity, concentrations of airborne microorganisms increase in the environment and later in the downwind regions (Tate, 2000; Whitman et al., 1998). While atmospheric sources of stress are lethal (UV-damage, desiccation, temperature, humidity, etc.) to a portion of the microbial populations moving with these airborne soils, some organisms are resistant to stress (i.e., pigmentation, high G + C nucleic content, and enhanced DNA repair ability, impart UV resistance) and movement within dust clouds (dust particle shielding from UV) and over certain environments (over water) limits UV or humidity stress (Dowd and Maier, 2000; Gregory, 1961; Mohr, 1997).

In this paper, we report aeromicrobiology data from a Mediterranean coastal site in Erdemli, Turkey, and its relation to desert dust and human health.

2. Material and methods

2.1. Sample site and dates

Atmospheric samples were collected on top of a 21 m tower located on the Mediterranean coastline in Erdemli, Turkey (Fig. 1c). Detailed information about the sampling site, sample collection and analytical methodology for the analysis of the samples, together with chemical and physical

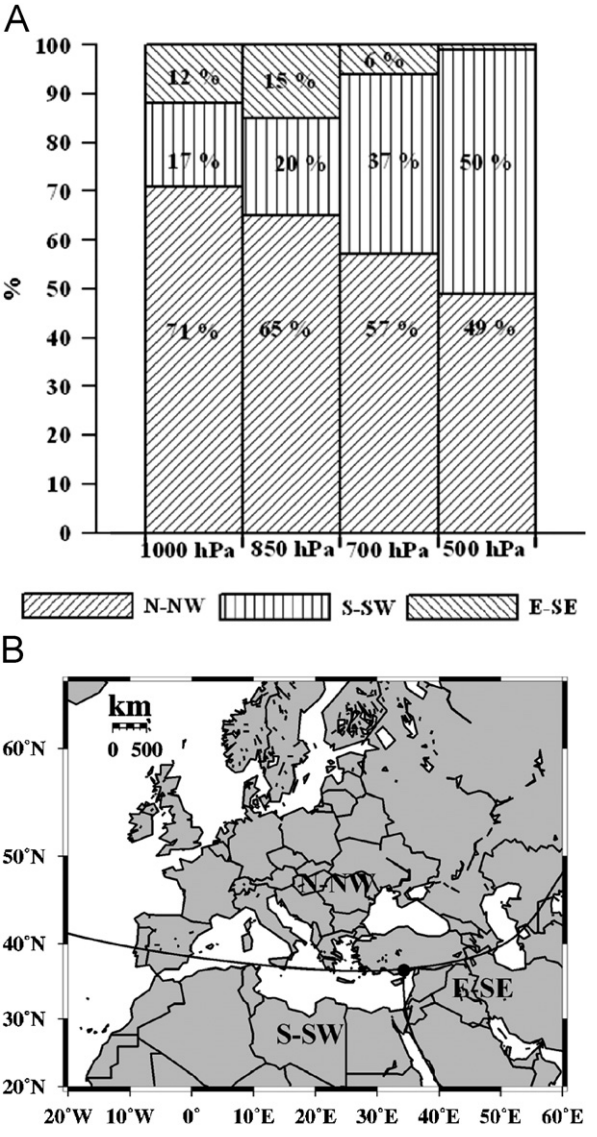


Fig. 2. (a) Summary of airmass back-trajectory source data for March through October 2002. Data are reported as percent source contributed at altitudes of 1000, 850, 700, and 500 hPa. (b) Airmass sources relative to Erdemli, Turkey, as depicted in legend for (a).

characteristics of aerosols and precipitation, can be found elsewhere (Koçak et al., 2004a, b; Kubilay et al., 2000, 2003; Özsoy and Saydam, 2000, 2001). Two hundred and fifty-eight samples (including 38 controls) were collected between 18 March and 27 October, 2002. Samples were collected on 209 of 224 calendar days during this period. Sterile technique was used during sample collection and processing.

2.2. Air samples for isolation of bacteria and fungi

Air samples were collected by membrane filtration, refrigerated at 4 °C until shipment to the U.S. Geological Survey (USGS) microbiological laboratory in St. Petersburg, Florida, and the filters processed for microbial colony forming unit (CFU) counts using R2A medium (Fisher Scientific, Atlanta, GA, catalog # DF1826-17-1) (Reasoner and Geldreich, 1985) as previously described (Griffin et al., 2003). For selected dates, bacterial CFU isolates were identified by amplifying (polymerase chain reaction, PCR) and sequencing a 1538-base pair segment of the 16S rDNA gene as previously published (Griffin et al., 2003). For these same dates fungi were identified to the genus level using standard light microscopy and an identification key (St-Germain and Summerbell, 1996), or to the genus/species level using PCR as previously published (Griffin et al., 2003). GenBank accession numbers for the bacteria and fungi DNA sequences included in this report are AY741223 through AY741279.

2.3. Ground-based dust-concentration data/ statistical analysis

To determine dust concentration, bulk aerosol samples were collected using a high-volume sampler and Whatman 41 filters. Dust concentration was estimated from aerosol Al measurements obtained from daily ground based collection aerosol samples (Kubilay et al., 2000). The microbiology ($N = 166$, $\alpha = 0.05$, 2-tailed, $P = 0.003$) and dust ($N = 166$, $\alpha = 0.05$, 2-tailed, $P = 0.190$) concentration data were tested for normality using a one-sample Kolmogorov–Smirnov Test (Dytham, 1999), which demonstrated that the microbiology data were not normally distributed. The microbiology data and the dust-concentration data were then evaluated using Spearman's rank-order correlation (Dytham, 1999). Significance was evaluated at $\alpha = 0.01$ ($N = 166$, 2-tailed). SPSS 13.0 for Windows (SPSS Inc., Chicago, IL) was used for statistical analysis of this data set.

2.4. Airmass back trajectories

Airmass back trajectories were calculated using a kinematic model based on global meteorological analyses from the European Center for Medium Range Weather Forecasts (ECMWF, Reading,

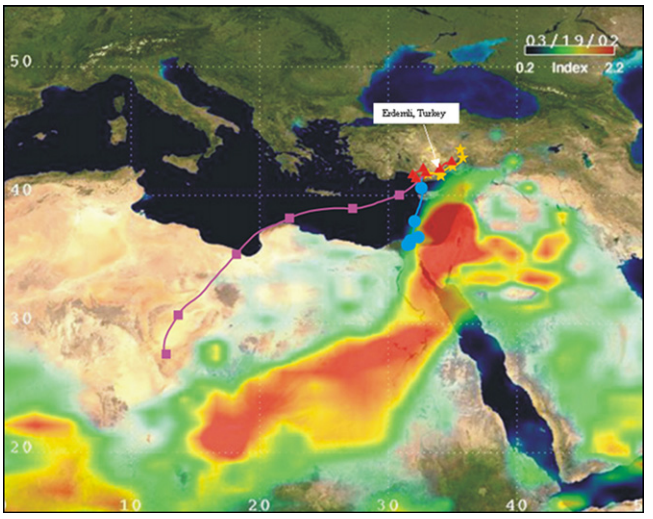


Fig. 3. African dust storm impacts air quality in the eastern Mediterranean with a superimposed airmass back trajectory. NASA — TOMS aerosol image, 19 March 2002. Red triangles = 1000 hPa = ~100 m altitude; yellow stars = 850 hPa = ~1500 m altitude; blue circles = 700 hPa = ~3000 m altitude; purple squares = 500 hPa = ~5500 m altitude.

England). Three-day back trajectories were calculated daily at 1200 UT for Erdemli for 1000, 850, 700 and 500 hPa and classified into airflow sectors of origin (Fig. 2).

3. Results

Of the 258 samples (online supplemental table), 38 were negative controls and 21 of the samples were collected over 10 days (two samples a day for nine of the days and one day in which three samples were collected). Two hundred and fifty-seven bacterial CFU were enumerated from the atmospheric samples, and two were detected in negative controls (1 CFU on controls 14 and 34). Two thousand five hundred and ninety-eight fungal CFU were enumerated from the air samples, and seven were found in negative controls (2 CFU on controls 13 and 34 and 1 CFU on controls, 22, 25, and 38). Seventy-one of the 220 atmospheric samples had a combined bacterial and fungal CFU count of greater than 10 (~32%). The percent fungal CFU relative to total CFU (bacteria and fungi) in these 71 samples ranged from 50 to 100% with an average of ~91%. No CFU were detected in 52 of the atmospheric samples. The highest fungal CFU count (239) occurred on 14 August, 2002.

Dust-concentration data were available for 167 of the 209 sample dates. Data are listed in the online supplemental table and ranged from 0.6 to 183.9 $\mu g\,m^{-3}$. The dust concentration data and the corresponding total microbial CFU m^{-3} data for each respective day were statistically compared using Spearman's rank–order correlation, which demonstrated a weak but significant correlation ($r_s = 0.223$, $P = 0.004$). Statistical analysis of the March, April, and May data (peak regional African dust season), demonstrated a significant correlation of moderate strength ($r_s = 0.576$, $P = 0.000$).

Bacterial and fungal CFU were isolated and later identified in samples collected on dates 18 March through 29 March, 2002 (15 bacteria and 31 fungi; Table 1) and on 20 October, 2002 (20 bacteria and 64 fungi; Table 2).

4. Discussion

The ground-based dust-concentration data demonstrate that atmospherically suspended desert dust is common in the eastern Mediterranean atmosphere (Kubilay et al., 2005). Fig. 2 shows the percent contribution of source regions for the period of this study along with major air flow-sectors to Erdemli, Turkey. Although the different source areas are predominant throughout the year at various altitudes (~100, 1500, 3000, and 5500 m), at lower altitudes dust from the Middle East is predominant with a stepped increase in the contribution from North Africa with increasing altitude. At the highest altitude, air masses originating from North Africa account for 50% of the source load. It should be noted that there is no stratification within these altitudes, and thus particles are subject to vertical mixing and continual fallout. Meteorological research has previously shown that airmass trajectories, which show North Africa as the source at upper altitudes, also coincided with an increase in ground-based measurements in Erdemli, Turkey (Kubilay et al., 2000). The highest percent 'African dust-day months' (airmass trajectories showing African dust at some altitude of entire air column up to ~5500 m = April and September) coincided with the highest percent CFU and dust-concentration data relative to non-African source days (Table 3). An interesting note is that in April at an altitude of 1000 hPa, North Africa was only identified as the source for 14.8% of the month's days, but during this timeframe (when African dust was present) 61% of the month's total microbial CFU were enumerated. In addition, the month's overall dust concentration for the same 14.8% time period was 46.3%. The highest CFU count for April (127 CFU) occurred on the 15th, and airmass back trajectories for this date identified North Africa as the source at all altitudes. With the exception of July, the peak CFU count for each month coincided with the airmass back trajectories identifying North Africa as a dust source for at least one of the four altitudes. It should be pointed out that CFU counts for the majority of sample dates were based on a single sample acquired over a 20-min period (between the hours of 07:12 and 16:59) while the measured dust concentrations occurred over a 24-h period. Considering the fact that dust concentrations during a dust storm event may have strong daily cycles (Alpert and Ganor, 2001), CFU counts based on a single 20 min sample may not coincide with a given days peak dust concentration. Due to this sampling scheme, peak CFU concentrations may have been missed on many of the sample dates. While the size of the presented data set provides a reasonable glimpse of the relationship between airborne dust and microorganisms at this particular research site, the reported correlation strengths may

Table 1
Identified microorganisms for sample dates 18 March through 29 March, 2002

Isolate designation	Isolate type	# isolates	% DNA homology and (base pairs)	Closest GenBank match (bacteria and fungi) or morphological identification of fungi where stated
T31802FW0	Fungi	1	97 (562/579)	*Letendraea helminthicola*
T31802FG0, T31902FG0, FB0, FB2, FB3, FB4, T32902FG0	Fungi	7	96 (357/370), 99 (658/663), 99 (573/576), 98 (574/581), 99, (531/532), 99 (593/595), 99 (583/585)	Equal match to *Cladosporium* and *Raciborskiomyces sp.*
T31902FW2	Fungi	1	n/a	Morph. ID—*Microsporum* sp.
T31902FW3, FW6, FW8	Fungi	3	n/a	Morph. ID—*Alternaria* sp.
T31902FW7	Fungi	1	100 (207/207)	Id'd equally to many fungi
T31902FW9, T32102FW0, FW1	Fungi	3	99 (643/647), 97 (566/583), 99 (629/634)	*Pleospora herbarum*
T31902FW1	Fungi	1	99 (565/568)	*Alternaria infectoria*
T31902FG1, FG3	Fungi	2	98 (560/569), 99 (701/705)	Equal match to 5 and 4 species of *Penicillium*, respectively
T31902FG2	Fungi	1	98 (659/667)	*Penicillium brevicompactum*
T31902FG4, FG5	Fungi	2	100 (583/583), 99 (583/586)	Equal match to *Penicillium*, *Eupenicillium* and *Talaromyces* sp.
T31902FB1, FB2a	Fungi	2	n/a	Morph. ID—*Cladosporium* sp.
T31902FP0	Fungi	1	98 (471/480)	Equal match to *Ulocladium*, *Setosphaeria*, *Clathrospora*, *Pleospora* and *Alternaria* sp.
T32102FP0	Fungi	1	98% 649/656	Equal match to *Ullocladium, Clathropora* and *Alternaria* sp.
T32502FP0	Fungi	1	99 (669/674)	Equal match to *Alternaria* species *brassicae* and *alternata*
T32602FW1	Fungi	1	99% 716/723	Equal match to *Escovopsis* and *Penicillium* sp.
T31902FW1, T32002FG0, T32602FW0, T32602FG1	Bacteria/ Gram +	4	99 (637/638), 99 (602/604), 99 (595/596), 100 (538/538)	*Streptomyces pseudogriseolus*
T31902FW4	Bacteria/ Gram +	1	99 (590/592)	*Streptomyces* species
T31902FW5	Bacteria/ Gram +	1	100 (591/591)	*Streptomyces ambifaciens*
T31902BY0	Bacteria/ Gram +	1	95 (572/602)	*Corynebacterium* cf. *Aquaticum*
T31902BO0	Bacteria/ Gram +	1	98 (559/570)	*Saccharothrix texasensis*
T31902BO1	Bacteria/ Gram +	1	99 (649/653)	*Microbacterium aerolatum*
T32102BO0	Bacteria/ Gram +	1	98 (722/730)	*Arthrobacter* sp.
T32102BY0, BY1	Bacteria	2	98, (677/684), 98 (441/447)	Uncultured soil isolate
T32102BY2	Bacteria/ Gram +	1	97, (615/632)	*Nocardioides nitrophenolicus*
T32602BY0	Bacteria/ Gram +	2	99, (615/620), 94, (522/584)	*Planococcus koreense*

Designation code = T = Turkey, following five numbers equal date isolated (month, day, year), F = fungi or B = Bacteria, following letter equals pigmentation color (B = black/brown, G = green/grey, O = orange, P = pink, W = white, Y = yellow), last number is the isolate number for that pigmented color.

underestimate the true relationship due solely to the sampling protocol.

A high-resolution NASA Earth Probe—TOMS satellite image taken on 19 March, 2002 shows an African dust storm impacting the eastern Mediterranean and our sampling site (Fig. 3). Six bacteria and 21 fungi were isolated from the atmospheric sample collected on that date. A NASA

Table 2
Identified microorganisms for sample date 20 October, 2002

Isolate designation	Type	# isolates	% DNA homology and (base pairs)	Closest GenBank match for bacteria. Morphological ID for fungi
T213FW0	Fungi	1	n/a	*Acremonium* sp.
T213FB5, 7–14, 16, 19–22, 28, 36–47, 49–50, 52–55, 57–58	Fungi	35	n/a	*Alternaria* sp.
T213FB0-4, 15, 29–35, 48, 56, 59	Fungi	16	n/a	*Cladosporium* sp.
T213FB23-27	Fungi	5	n/a	*Fusarium* sp.
T213FB6, FB18	Fungi	2	n/a	*Microsporum* sp.
T213FG0-2, FB51	Fungi	4	n/a	*Penicillium* sp.
T213FB17	Fungi	1	n/a	*Trichophyton* sp.
T213BYO	Bacteria/Gram +	1	100, (609/609)	*Bacillus* sp.
T213BY1, T213BO2, BO3	Bacteria/Gram +	3	99, (676/679), 99 634/635), 99 (632/633)	*Kocuria* sp.
T213BY2	Bacteria	1	98, (549/560)	unidentified
T213BY3	Bacteria/Gram −	1	95, (647/679)	uncultured bacteroidetes bacterium
T213BY4	Bacteria/Gram +	1	99, (751/754)	*Agrococcus jenensis*
T213BY5	Bacteria	1	99, (712/713)	unidentified glacial ice isolate
T213BY6, BY8	Bacteria/Gram −	2	97, (688/704), 97 (667/681)	*Massilia timonae*
T213BY7	Bacteria/Gram −	1	98 (689/703)	*Duganella zoogloeoides*
T213BY9	Bacteria/Gram +	1	98, (683/695)	*Microbacterium barkeri*
T213BY11	Bacteria/Gram +	1	99, (698/700)	*Kocuria rosea*
T213BWO, BW3	Bacteria/Gram +	2	98, (694/707), 98, (673/683)	*Arthrobacter* sp.
T213BW1	Bacteria/Gram +	1	99, (744/747)	*Bacillus subtilis*
T213BW2	Bacteria/Gram +	1	99, (711/717)	*Arthrobacter crystallopoietes*
T213BOO	Bacteria/Gram +	1	99, (740/746)	*Curtobacterium luteum*
T213BO1	Bacteria/Gram +	1	99, (702/709)	*Microbacterium* sp.

Designation code = T = Turkey, following five numbers equal date isolated (month, day, year), F = fungi or B = Bacteria, following letter equals pigmentation color (B = black/brown, G = green/grey, O = orange, P = pink, W = white, Y = yellow), last number is the isolate number for that pigmented color.

Aqua—Moderate Resolution Imaging Spectroradiometer (MODIS) satellite image taken on 19 October, 2002 shows dust of Middle Eastern origin impacting air quality in the eastern Mediterranean (Fig. 4). Two bacteria and 59 fungi were isolated from the atmospheric sample collected on that date (the ninth highest CFU count of all samples). The elevated CFU count (2 bacteria and 41 fungi) occurring in 6 May corresponds with a SeaWiFS image showing a large plume of African dust moving northward over Libya and out over the Mediterranean (http://visibleearth.nasa.gov/cgi-bin/viewrecord?13057). SeaWiFS (GSFC/SeaWiFS_2002081312) and Earth Probe—TOMS imagery along with airmass back trajectory data identify African dust/air masses impacting Erdemli, Turkey, on the 13th and 14th of August, 2002. The overall high CFU count (239 fungal CFU) for this study occurred on 14 August.

The benefit of combining air mass back trajectories and satellite data to aid in interpreting atmospherically derived microbial data is depicted in Figs. 5 and 6. Fig. 5 includes an Earth Probe—TOMS image (15 April, 2002) showing an African dust cloud beginning to impact the research site, an ECMWF airmass back trajectory demonstrating the air mass impacting the research site on 15 April, 2002 as originating from Africa, and the aeromicrobiology data for the dates 14 April through 16 April, 2002. The aeromicrobiology data clearly show an increase in the number of airborne microorganisms throughout the day on 15 April, 2002 (and high concentrations continuing on the 16th) as the dust cloud impacts the site, relative to that observed on the 14th. Fig. 6 includes an Earth Probe—TOMS image (23 May, 2002) showing African dust activity in Turkey west of the research site, an ECMWF airmass back trajectory (23 May,

Table 3
Monthly summary of airmass-trajectory data

Month	% African dust days and % total CFU on those days relative to non-African dust days				% African dust days and % dust deposition on those days relative to non-African dust days			
	Ground to ~100 m		Ground to ~5500 m		Ground to ~100 m		Ground to ~5500 m	
	% African dust days	% CFU	% African dust days	% CFU	% African dust days	% dust	% African dust days	% dust
March	30.0	17.3	40.0	76.1	30.0	9.9	40.0	30.1
April	14.8	61.0	70.3	93.4	14.8	46.3	70.3	91.1
May	13.8	15.4	58.6	86.5	13.8	16.9	58.6	71.3
June	6.7	7.5	38.4	67.7	16.6	3.6	33.3	74.5
July	13.3	0.5	46.7	51.7	15.4	32.8	50.0	66.5
August	13.3	2.2	43.3	69.0	13.3	13.0	43.3	51.2
September	36.7	39.2	76.7	70.3	46.1	38.4	61.5	82.3
October	33.3	26.8	74.1	76.4	41.1	16.5	76.5	42.1
Averages	20.2	21.2	57.2	72.3	23.8	22.2	54.2	63.6

Data presented as % African dust days (when trajectory data indicated airmasses from Africa impacting Erdemli, Turkey, at 1000 hPa and then at any altitude up to ~5500 m), % total microbial-colony-forming units (CFU), and % dust-deposition ($\mu g\,m^{-3}$) data for available airmass–data days relative to non-African dust days each month.
Example—In March, 30% of the days were predicted to have African dust present at ground level to an altitude of ~100 m. During this time, 17.3% of the total microbial CFU cultured in March was detected. From ground level to an altitude of ~5500 m African dust was present at some altitude for 40% of the month's days, and during this time 76.1% of March total CFU was detected. Same interpretation for the % dust-deposition columns.

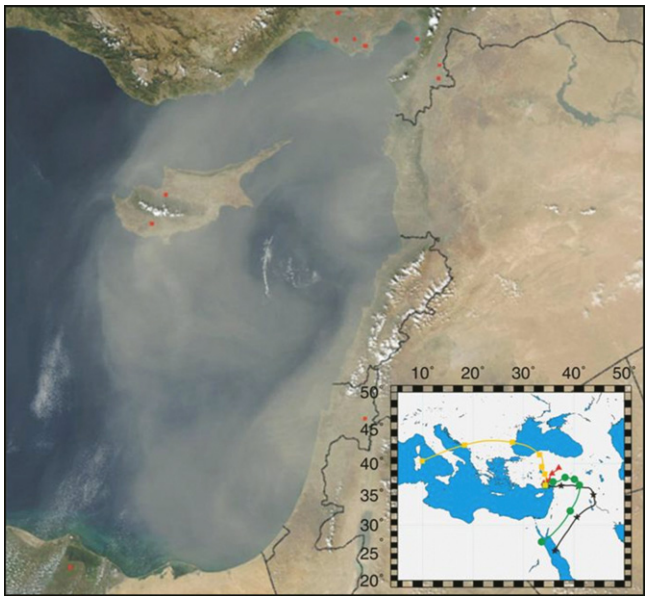
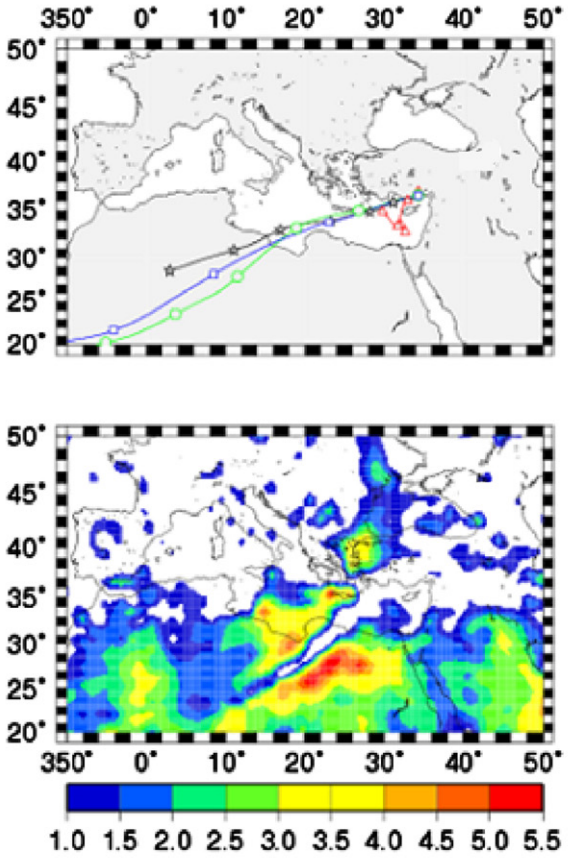


Fig. 4. Middle Eastern dust storm impacting the eastern Mediterranean with a superimposed 72-h airmass back trajectory from the European Center for Medium Range Weather Forecasts. Aqua—MODIS image taken on 19 October, 2002, VE Record ID: 20373. Image compliments of the SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE. http://visibleearth.nasa.gov/. Red dots on the image identify fires. Red triangles = 1000 hPa = ~100 m altitude; black stars = 850 hPa = ~1500 m altitude; green circles = 700 hPa = ~3000 m altitude; yellow squares = 500 hPa = ~5500 m altitude.

2002) demonstrating the air mass impacting the research site on the 23rd as originating from the west, and aeromicrobiology data for the dates 20 May through 25 May. The data show that the peak concentration for this period occurred on the 24th (57 bacteria and fungal CFU). Thus, while the



Sample	Date	Time	Bacterial CFU	Fungal CFU
24	4/14/02	09:00	0	4
25	4/14/02	14:54	0	2
Blank5	4/14/02	15:16	0	0
26	4/15/02	08:27	5	38
27	4/15/02	13:42	3	35
28	4/15/02	17:33	6	121
29a	4/16/02	15:03	1	33
29b	4/16/02	15:03	0	34
Blank6	4/16/02	15:47	0	0

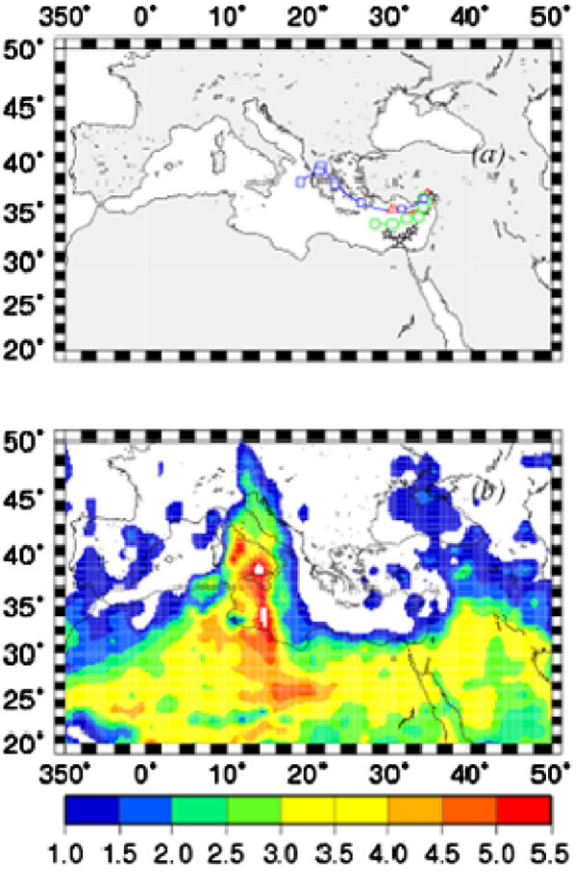
Fig. 5. Airmass back trajectory, aeromicrobiology, and Earth Probe TOMS satellite data. A 72-h airmass back trajectory identifying Africa as the source, a TOMS image showing African dust impacting the research site in Erdemli, Turkey, and the aeromicrobiology data for the dates 14 April through 16 April 2002. Airmass back trajectory data obtained from the European Center for Medium Range Weather Forecast. Red lines = 1000 hPa, black lines = 850 hPa, green lines = 700 hPa, and red lines equal 500 hPa. TOMS images compliments of NASA. Microbiology table column information — CFU = colony-forming units. Sample ID listed as Blank # = negative controls.

airmass back trajectory data for the 23rd indicate that its source was from the west and would not be suspected of being from Africa, the 23 May, 2002 TOMS image shows that African dust was impacting the projected airmass source region 24 h prior to the peak CFU recovered for the 20th to 25th of May dates.

The Turkey microbial population is quite distinct from that observed in Bamako, Mali and the USVI African desert dust studies, in that fungal CFU were greater than the bacterial CFU counts in almost all cases (Griffin et al., 2003; Kellogg et al., 2004). The air sample collected on 14 August, 2002 that contained 239 fungal CFU and no bacterial CFU is a good example of the dominance of fungi at this research site (Fig. 7). Other researchers have also shown elevated concentrations of fungal spores during dust events (mean of 29,038 m^{-3}) relative to normal atmospheric conditions (mean of 28,683 m^{-3}) along with a change in the dominant genera present (Wu et al., 2004). A prevalent fungal genus detected on both of the sample dates in this study where fungi were identified was *Alternaria* (19.3% of the March isolates and 54.7% of the 20 October isolates). *Alternaria* spores are known allergens, and human health studies have shown that childhood exposure to *Alternaria* in semi-arid environments is associated with the development of asthma (Halonen et al., 1997). *Alternaria* have frequently been isolated in Turkish atmospheric mycology studies (Asan et al., 2002, 2003). Aside from the health issues associated with exposure to spores of *Alternaria*, other studies have shown that fungal–spore exposure in general (mycotoxins) can in some cases result in asthma fatalities (Black et al., 2000). In addition, bacteria can produce endotoxins such as lipopolysaccharides, which can elicit respiratory stress (Olenchock, 1997; Yang and Johanning, 1997). Research has shown that exposure to microbial and microbial-component-laden airborne soils can cause respiratory stress (Larsson et al., 1999).

The majority of bacteria identified in this study (~77%) was high G(guanine) + C(cytosine) content Gram positive bacteria or low G + C content Gram positive spore-formers. This prevalence of high G + C or spore-forming Gram positive bacteria has also been observed in samples collected during African dust events in the USVI (Griffin et al., 2003). High G + C content or spore production are both traits that impart resistance to UV inactivation (Riesenman and Nicholson, 2000; Setlow, 2001;

Singer and Ames, 1970). The remaining bacteria recovered in this study were two non-spore-forming low G+C content Gram positives (*Planococcus* sp.) and four Gram negative bacteria (*Duganella* sp., *Massilia* sp., and a *Pseudomonas* sp.). All of the identified bacteria were pigmented, another trait that may impart some degree of UV resistance (Sundin and Jacobs, 1999). Common isolates among our Mali, USVI, and Turkey research sites to date are *Agrococcus jenensis*, *Bacillus thuringiensis*, *Bacillus* sp., *Kocuria* sp., *Kocuria rosea*, *Arthrobacter* sp., *Microbacterium* sp., and *Cladosporium* sp. Isolates identified at the species level noted at both the USVI and Turkey research sites to date are *Agrococcus jenensis*, *Bacillus thuringiensis*, *Kocuria rosea*, *Curtobacterium luteum*, and *Saccharothrix texasensis.*



Sample	Date	Time	Bacterial CFU	Fungal CFU
Blank 15	5/20/02	09:16	0	0
66	5/21/02	08:48	1	24
67	5/22/02	08:55	0	23
68	5/23/02	08:50	3	22
69	5/24/02	08:48	4	53
70	5/25/02	09:07	0	0

Fig. 6. Airmass back trajectory, aeromicrobiology, and Earth Probe TOMS satellite data. A 72-h airmass back trajectory identifying source air for the research site as coming from the west (23 May 2002), a TOMS image showing dust activity of African origin west of the research site on the 23rd of May, and aeromicrobiology data for 20 May through 25 May 2002. Airmass back trajectory data obtained from the European Center for Medium Range Weather Forecast. Red lines = 1000 hPa, black lines = 850 hPa, green lines = 700 hPa, and red lines equal 500 hPa. TOMS images compliments of NASA. Microbiology table column information — CFU = colony-forming units. Sample ID listed as Blank # = negative controls.

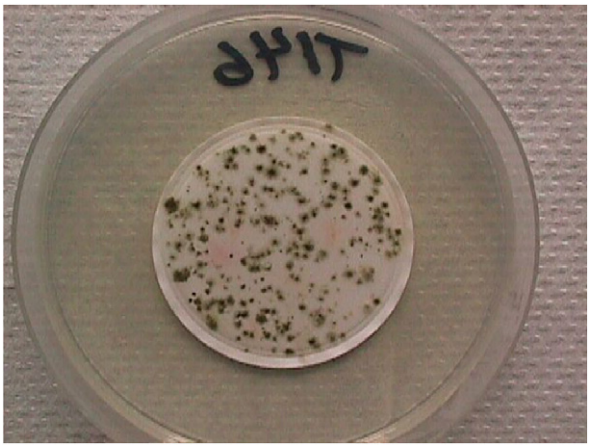


Fig. 7. Heavy fungal growth on an African desert dust air-sample filter collected on 14 August, 2002 at Erdemli, Turkey. The fungal CFU count on this filter was 239. No bacterial CFU were observed.

5. Conclusions

The statistical correlation between the presence of dust and an observed increase in culturable CFU mirrors a correlation similar to that previously reported in USVI and tropical mid-Atlantic African dust studies (Griffin et al., 2003, 2006). At all four of our research sites to date (Mali, Africa, tropical mid-Atlantic, Northern Caribbean, and Erdemli, Turkey), using the same methodologies, the trend has been the same, i.e., the presence of atmospherically suspended desert dust equates to an

increase in atmospheric CFU counts. Both the microbiology data and the measured dust data reported in this study indicate that the presence of atmospherically suspended desert dust is common in the region. It should be emphasized that microbial ecology studies have shown that only 0.001 to 15% of what is present in a given sample can be cultured, and thus the observed CFU counts in samples are but a fraction of what is actually present (Amann et al., 1995). The obvious prevalence of atmospheric desert dust in the region along with its associated constituents (microorganisms, organic detritus, toxins, etc.) may play a significant role in ecosystem and human health and warrants the need for abundant research in this emerging field.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.atmosenv.2007.01.023.

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