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ORIGINAL PAPER

Relationship between African dust carried in the Atlantic trade winds and surges in pediatric asthma attendances in the Caribbean

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Abstract Asthma is epidemic in developed and developing countries including those in the Caribbean where it is widely believed that African dust, transported in high concentrations in the Trade Winds every year, is a major causative factor. The link between asthma and dust in the Caribbean is based largely on anecdotal evidence that associates sharp increases in the occurrence of asthma symptoms with hazy conditions often caused by dust. Here we report on a 2-year study of the relationship between the daily concentrations of dust measured in on-shore Trade Winds at Barbados and pediatric asthma attendance rates at Queen Elizabeth Hospital (QEH). We looked for large increases in QEH daily attendances in relation to daily dust concentrations as previously suggested by anecdotal observations. We could not find any obvious relationship although there may be more subtle linkages between dust and asthma. Our measurements show, however, that the concentration of dust in the size range under 2.5 μm diameter is sufficiently high as to challenge United States Environmental Protection Agency air quality standards for respirable particles. Thus, African dust may constitute a health threat of a different nature, producing symptoms less obvious than those of asthma.

Keywords African soil dust · Pediatric asthma · Aerosols · PM 2.5 · PM 10

Introduction

Asthma prevalence has increased at an alarming rate over the past several decades (Cookson 1999; Eder et al. 2006). While these increases have been best documented in economically advanced nations, they have also been seen

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in developing nations (Ait-Khaled et al. 2001), including Africa (Ait-Khaled et al. 2007). The increase is attributed to many causes, including exposure to increased levels of gaseous and particulate pollutants and household dusts (Holt et al. 1999; Leikauf 2002), and to other environmental factors associated with changing lifestyles (Cookson 1999).

Asthma prevalence on Barbados, West Indies (13.17N, 59.43W), is among the highest in the world, currently 19.5% among 6- to 7-year-olds (Bousquet et al. 2005) about half of whom are classified as extrinsic or allergic asthma (Blades et al. 2004). Between 1973 and 1996, the number of asthmatic patients seeking medical attention at Queen Elizabeth Hospital (QEH) grew from 1,886 to 10,903 annually (Howitt et al. 1998).

On Barbados and elsewhere in the Caribbean, it is widely believed that asthma is strongly linked to African dust. African dust is the dominant aerosol constituent in Barbados Trade Winds (Li et al. 1996). There is a strong seasonal cycle in dust transport to the Caribbean that has been documented by surface-based aerosol measurements (Prospero and Lamb 2003) and by various satellite sensors (Husar et al. 1997; Chiapello et al. 1999, 2005). In winter, African dust is transported mainly in latitudes south of Barbados (Husar et al. 1997) into South America; consequently dust concentrations are extremely low on Barbados. In spring, the main transport band remains south of Barbados; concentrations remain low but there are brief periods when they increase sharply. By early summer, Barbados lies in the main dust stream; substantial quantities of dust are constantly present in the Trade Winds, subsequently decreasing through the fall. Summer dust transport is associated with the passage of easterly waves that move through the region in cycles over a period of several days to a week (Dunion and Velden 2004). These waves produce a strong modulation of dust concentrations from day-to-day, often by a factor of ten or more (Li et al. 1996). Over the past 30 years, on average the daily dust concentration on Barbados exceeds 10 $\mu g\ m^{-3}$ 153 days each year, and on several days a year it exceeds 100 $\mu g\ m^{-3}$ (Prospero and Lamb 2003).

Dust concentrations in the Caribbean are strongly linked to climate in Africa. In the early 1970s, severe drought afflicted the Soudano-Sahel region of North Africa and continues in varying degree to this day. In concert with the drought, dust concentrations increased dramatically in the Caribbean (Prospero and Lamb 2003) and the southeastern United States (Prospero 1999). The increase in dust transport over this period roughly parallels the great increase in asthma prevalence in the region (Blades et al. 2004; Howitt et al. 1998).

Caribbeans are generally aware of the African dust phenomenon, which is widely reported in the media. Weather reports include forecasts of large dust events, which are generally associated with dense haze and reduced visual range (Huang et al. 2006). This knowledge, coupled with the awareness of the increased asthma in the region, has led to a widely held belief that the two phenomena are closely linked, and that increased dust is associated with the onset of symptoms. Based on such anecdotal evidence (McCarthy 2001; Taylor 2002), and on a preliminary study (Gyan et al. 2005), it has been suggested that African dust could be a major causative factor for increased asthma on Barbados and Trinidad (Monteil et al. 2005).

The possible link between asthma and African dust is relevant to the increasing interest in the intercontinental transport of particles and gases, especially pollutant species, on the air quality at distant receptor sites (Akimoto 2003) and the implications for human health. Regional increases of certain species have been linked in some cases to such long-range transport: e.g., ozone and aerosols in the western United States traced to the transport of polluted air masses from Asia (Jaffe et al. 2003). However, there is no evidence that such transport events have had a discernable impact on health. If African dust is indeed affecting asthma in the Caribbean, it would be the first clear example of the health impact of intercontinental transport of a substance. This impact could conceivably extend beyond the Caribbean. High concentrations of African dust are measured in Florida (Prospero 1999; Prospero et al. 2001) and the southern and eastern United States (Perry et al. 1997) every summer.

The objective of our study is to ascertain if the temporal variability of African dust carried in Barbados Trade Winds can be linked to the short-term variability in asthma on the island. This work was motivated in part by the observations of one of the authors (R.N.) who, in his role as chief of the Accident and Emergency Department (AED) of QEH, established an asthma bay to deal with the often heavy case load (Howitt et al. 1998). Attendance at the bay appeared to be especially brisk on days when there was a noticeable dust-haze on the island. In an effort to test this hypothesized relationship, we carried out this retrospective study in which we make use of the daily concentration of African dust measured in on-shore winds at a site on the east coast of Barbados (Prospero and Lamb 2003). We compared the dust time-series with the concurrent time-series of daily pediatric asthma attendances (DPAA) at QEH. Our primary objective was to look for abrupt changes in DPAA that occur over a period of days in response to sharp changes (increases or decreases) in dust concentration so as to test the common perception that the two are closely linked. We also looked for seasonal changes that might be linked to the strong seasonality of dust transport, although we recognize that any interpretation would be confounded by other environmental factors that affect asthma prevalence.

Barbados is ideally suited for such a study. The population is relatively homogeneous and public health services are widely available. Furthermore, air quality on Barbados is generally thought to be very good, although there are no measurements to substantiate this belief. There is very little manufacturing that might be a source of gaseous and particulate pollutants that are often a complicating factor in many health studies. Although automobile emissions could conceivably be a problem in some areas, the island is well ventilated by the Trade Winds so that pollution build-up is not a major concern. For these reasons, the effects of dust on asthma rates should be more readily detectable.

Methods

Asthma study procedures

We used daily attendance data at the asthma clinic in AED of QEH Barbados over the period 1996–1997. On arrival at AED/QEH all patients are assessed by a triage nurse. Those complaining of “wheezing”, “tightness in the chest” or “shortness of breath” are sent to the asthma clinic. Barbados is associated with the Global Initiative for Asthma (GINA) and the International Study of Asthma and Allergies in Childhood (ISAAC) (Bousquet et al. 2003). The clinic follows the protocols and recommended practices of GINA and ISAAC. In the clinic patients are screened and managed for asthma following a protocol that includes the monitoring of peak flow rates; all patients are subsequently classified according to the International Classification of Diseases (ICD-9 1999).

We focused on pediatric patients, aged 18 years and under, who comprise 63% of total attendees. Asthma prevalence is very high amongst school children on Barbados (Howitt et al. 1998). Based on experience in the AED/QEH clinic, asthmatic children are ideal for this study because parents respond rapidly to the appearance of symptoms in their children and their consequent discomfort. In contrast, adults tend to suffer through the symptoms and self medicate; if they do appear at the clinic, it is usually after a considerable and variable delay. A similar prompt pediatric response was noted in asthma attendance rates in Trinidad–Tobago (Gyan et al. 2005). Thus, associations of asthma attendances at QEH with dust, if any, should be more readily apparent and more robust with children than with adults.

Aerosol study procedures

Aerosol sampling is carried out at Ragged Point at a site located immediately on the easternmost coast of Barbados where we have made aerosol measurements continuously since 1965 (Li et al. 1996; Prospero and Lamb 2003). The site was originally established for the study of African aerosols and their impact on atmospheric chemistry and on climate over the tropical Atlantic. A major effort was made to minimize the impact of local aerosol sources on our samples. To this end, sampling is carried out at the top of a 17 m high walk-up tower standing on a 30 m high bluff on the coast. The pump is controlled by a wind sensor via a computer so as to sample only over-ocean winds. Sampling is continuous during the 24-h period so long as the wind sector condition is met (on average, about 95% of the time) and it is not raining. Samples are collected by drawing air through 20×25 cm Whatman 41 (W-41) cellulose fiber filters at a flow rate of about 1.1 $m^3 min^{-1}$.

Filters are returned to Miami where they are first extracted with deionized water and subsequently ashed in a muffle furnace. The ash residue weight (less the filter blank, which is minimal compared to typical dust loads) is ascribed to mineral dust based on extensive chemical and mineralogical studies (Glaccum and Prospero 1980). For a detailed description of the site and of the techniques employed, see Savoie et al. (2002). Previous studies of African dust size distributions over the western Atlantic show that about one-third to one-half of the dust mass is under 2.5 μm diameter (and about 90% is under 10 μm) based on measurements using United States Environmental Protection Agency (US EPA)-qualified dichotomous samplers (Prospero et al. 2001) and cascade impactors (Li et al. 1996). Thus a large fraction of the dust mass is “respirable” according to the definition of the US EPA.

We also routinely analyzed the filter extracts for all major ionic species in trade wind aerosols: nitrate, sea-salt (based on sodium concentrations), sulfate, and methanesulfonic acid (an oxidation product of dimethylsulfide emitted from sea water). This data is widely reported elsewhere (e.g., Savoie et al. 2002) and we only make cursory reference to these data in this report.

Statistical methods

In an effort to establish a link between periods of high concentrations of dust with DPAA, we compared DPAA rates during strong dust surge events in 1996 and 1997 with rates obtained when little dust was present both immediately before the dust surge had begun and immediately after it had ended. We tested for significance using the Mann-Whitney rank-sum test, two-tailed.

Results

We present results for a 2 year period, 1996–1997. Descriptive statistics of DPAA and aerosol measurements are presented in Table 1 and summarized in Fig. 1. In 1996, the total number of asthma attendances of all ages was 10,903, of which 7,158 (66%) were pediatric (ages 18 years and younger). In 1997, the total was 12,717, of which 8,584 (68%) were pediatric. These rates are within the normal range for the past decade. We assess these data in two sections. In the first section, we discuss the general features of the data time series. In the second, we focus on two periods in the spring of 1996 and 1997 when dust concentrations increased sharply; we compare DPAA rates before, during, and after this dust surge.

Seasonal trends in aerosols and asthma DPAA

The DPAA rates on Barbados based on pediatric patients drawn from all 11 parishes on the island (Fig. 2a) show a clear annual progression in three waves: from early January to late April; from early May to mid-July; from late August to late December. DPAA data for the years 1998–2003 (not presented here) shows a similar annual temporal cycle.

During 1996–1997 the annual mean aerosol concentrations (Table 1; Fig. 1) were comparable to those measured over the past two decades: dust, 14.2 µg m^{-3} (Prospero and Lamb 2003); sea-salt, 21.8 µg m^{-3}; nss-sulfate, 0.66 µg m^{-3}; nitrate, 0.57 µg m^{-3} (Savoie et al. 2002). The very low concentrations of nss-sulfate and nitrate are indicative of the minimal impact of pollutant-related aerosols in the Trade Winds. Approximately half of the nss-sulfate and nitrate aerosol mass is attributed to pollutant transport (Savoie et al. 2002) believed to be derived largely from Europe. In contrast, dust concentrations are often very high and they vary over a huge range, i.e., by more than three orders of magnitude. The dust concentration frequency distribution is logarithmic (Savoie et al. 1987); accordingly in Table 1 and Fig. 1 the mean is 2.5 times the median value. In Fig. 2, one clearly sees the previously noted strong seasonal dust cycle, with low concentrations in winter and high concentrations in summer (Prospero and Lamb 2003), and the large day-to-day dust concentration changes (Li et al. 1996; Savoie et al. 2002).

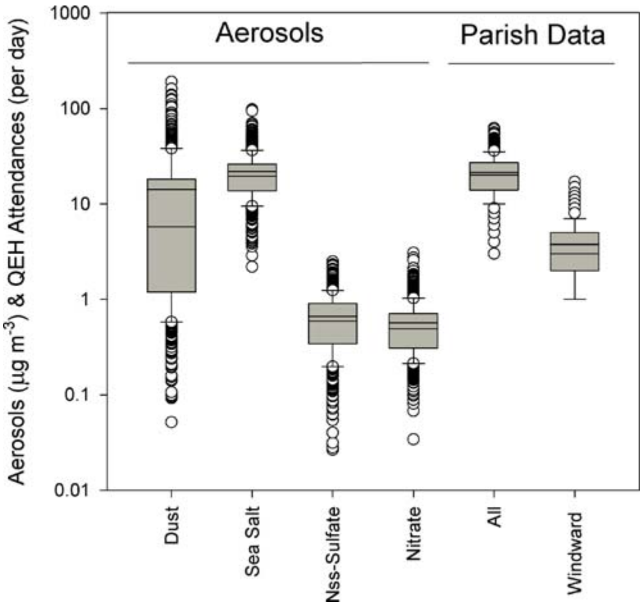

Fig. 1 Descriptive statistics for daily Barbados Trade Wind aerosol concentrations, 1996–1997, and for daily pediatric asthma attendances (DPAA) at Queen Elizabeth Hospital (QEH) based on parish (*All* and *Windward*) residence. Box plot upper and lower boundaries mark the 75th and 25th percentile respectively; whiskers indicate the 10th and 90th percentiles. In each box the median is indicated by the *thin horizontal line* and the mean by the *thick line*

It is immediately apparent from Fig. 2a that there is no obvious relationship between the seasonal pattern of dust and that of DPAA. It is notable that the highest DPAA values occur in fall and winter when dust concentrations are lowest.

Throughout the record in Fig. 2a, we note sharp multi-day peaks in dust concentration, some approaching or exceeding 100 µg m^{-3}. These are associated with the passage of particularly intense dust outbreaks (Prospero and Lamb 2003), which sharply reduce visual range (Huang et al. 2006). Satellite aerosol sensors show that these events impact a large area of the Caribbean and the southeastern United States (Chiapello et al. 1999, 2005).

In seeking a link between dust and asthma as reflected in near-term changes in DPAA, it had been our intention to

Table 1 Descriptive statistics: Barbados aerosols and daily pediatric asthmas attendances (DPAA) at Queen Elizabeth Hospital (QEH), 1996–1997

Parameter	Mean	Median	SD	Range	Maximum	Minimum	25%	75%	Samples	Missing
Aerosols										
Dust	14.17	5.67	21.50	189.72	189.67	-0.05	1.20	18.17	711	0
Sea salt	21.84	19.47	12.57	95.42	97.61	2.19	13.69	26.02	711	0
NO_3	0.57	0.49	0.36	3.03	3.06	0.03	0.31	0.71	711	0
$NssSO_4$	0.66	0.59	0.43	2.77	2.48	-0.29	0.34	0.90	711	30
Attendances										
All parishes	21.37	20	9.80	59	62	3	14	27	711	1
Windward parishes	3.77	3	2.65	17	17	0	2	5	711	1

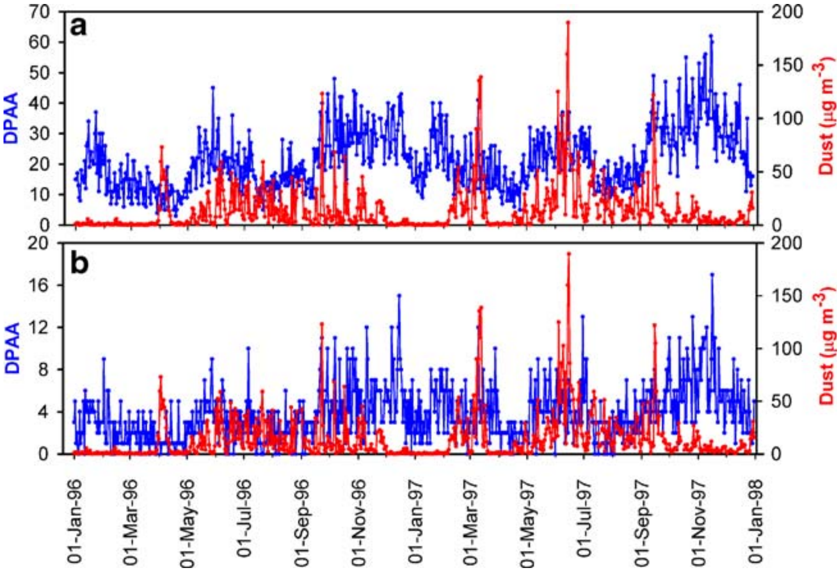

Fig. 2 Daily mineral dust concentrations measured in the Trade Winds on the east coast of Barbados and DPAA at QEH. **a** DPAA for patients from *All* Barbados parishes (*blue*) and dust (*red*). **b** DPAA for patients from the *Windward* rural parishes (St. John, St. Peter, St. Philip, St. Joseph, St. Andrew, St. Lucy) (*blue*) and dust (*red*)

search for large increases in DPAA immediately following a sharp spike in dust concentrations, consistent with anecdotal reports of the effects of African dust on pediatric asthmatics. This could not be readily done because of the very strong weekly cycle in attendance rates at QEH. Although the asthma clinic is open 7 days a week, there is nonetheless a strong attendance peak on Mondays and Tuesdays. The 7-day cycle is readily apparent from a casual inspection of the DPAA time series (Fig. 2a). In some cases, dust peaks fall on DPAA peaks. To a casual observer, the occasional concurrence of a dust peak with a peak in DPAA could conceivably lead them to conclude that the two were somehow linked and might explain the anecdotal association of asthma with African dust (McCarthy 2001; Taylor 2002).

In an effort to minimize the possible effects of asthma stimulants that are often associated with urban environments (Leikauf 2002), we focused on a subset of the Barbados population that lived in the non-urban sections of Barbados. Barbados has a population of 260,491 (1990 census) living on an area of 430 km^2 divided into 11 parishes. The most populous are St. Michael on the southwest coast (the location of Bridgetown, the principal city, population 104,000) and Christ Church on the south coast. We might expect that people living in these parishes, with 55% of the total population, would be exposed to a wider range of substances, including pollutants, that could conceivably precipitate an asthmatic response. To minimize possible urban effects we developed DPAA statistics for the populations in the "*Windward*" parishes that lie along the east coast: St. John, St. Peter, St. Philip, St. Joseph, St. Andrew, St. Lucy. Together these have a population of 66,000 (25% of the total island population) and account for 20% of total pediatric asthma cases. Moreover, because of the persistent Trade Winds and the proximity to the coast, these parishes would be less impacted by natural substances (e.g., pollen from trees, flowers, agricultural crops) that could precipitate asthma symptoms. Under these conditions, the effect of dust, if any, might be more readily detected.

Nonetheless, the *Windward* data (Fig. 2b) show the same seasonal patterns as the data drawn from *All* 11 parishes (All; Fig. 1a). Although the *Windward* data are more variable than the *All* data because of the relatively small DPAA sample size, there is no evidence of any substantial increase in DPAA that could be readily associated with peaks in dust.

DPAA associated with spring dust surge events

In an alternative approach, we focused on two winter-spring periods in 1996 and 1997 when dust concentrations rose abruptly for extended periods and then dropped sharply (Fig. 3). As previously stated, brief dust surges in spring are a common feature in our 42-year dust record on Barbados (Prospero and Lamb 2003). We compared DPAA during the dust surges with those obtained before and after the surge and we assessed whether there is a significant difference that can be associated with the dust event. In this way we also address the issue raised by Gyan et al. (2005), who suggested that the absence of a clear and immediate DPAA response to peak dust events might be due to a lag or latency interval between the occurrence of a dust event and the onset of symptoms.

As seen in Fig. 3a, DPAA rates were high in early 1996, peaking in mid-January and thereafter ranging mostly between 10 and 20 per day until late April. In contrast, dust levels were extremely low between 1 January and 29

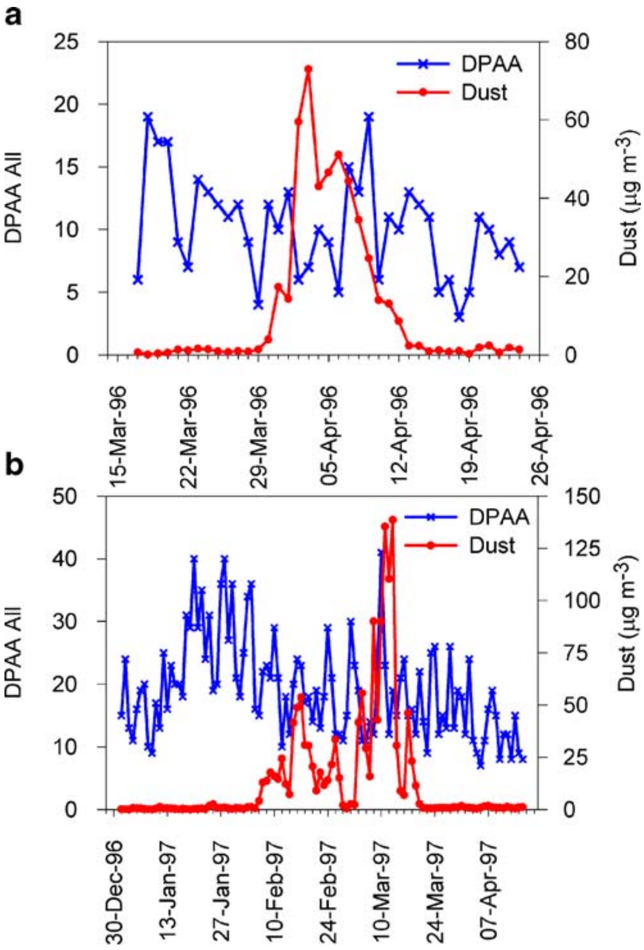

Fig. 3 Daily mineral dust concentrations measured in the Trade Winds on the east coast of Barbados and DPAA at QEH from *All* Barbados parishes (*blue*) and dust (*red*). **a** Period from 17 March to 24 April 1996. **b** Period from 1 January to 16 April 1997

March—around 1 µg m^{-3}, the lowest levels of the year. Starting on 30 March there was an abrupt increase in dust that extended to 12 April. For a period of 8 days, dust concentration exceeded 25 µg m^{-3}, reaching a maximum of 73 µg m^{-3} on 3 April. During this period, the DPAA rates were essentially unchanged from those preceding the dust event.The rates following the event were among the lowest of the year. In 1997 there was a similar situation (Fig. 3b). There was essentially no dust from 1 January until 6 February (36 days), then moderate-to-high dust (139 µg m^{-3} on 13 March) until mid-March (42 days) followed by essentially no dust until late April (28 days). Again, there is no substantial change in DPAA either during or after the dusty period; in fact, DPAA-All rates were lower during, and lowest after, the dust pulse. In Fig. 3b, one can readily see the effect of the weekly cycle of attendance at QEH. The amplitude of this weekly cycle is fairly constant throughout the record; there is no evidence of any increase that one might expect in response to the surge in dust concentrations in late February and early March. Indeed the largest spike in DPAA occurred on 10 March, a day *before* the sharp peak in dust concentration.

The data for the two dust surge cases in 1996 and 1997 are summarized in Fig. 4 and in Table 2, which shows the descriptive statistics for *Dust*, DPAA rates for all parishes (*All*), and DPAA rates for windward parishes (*Windward*) for the periods *Before*, *During*, and *After* the two selected dust surges; Table 3 presents the results of tests of statistical significance. In both 1996 and 1997, dust levels *Before* and *After* the dust surge were at background levels; during the dust surge concentrations were much greater, about a factor of 30 in the means. In every comparison pair except *Before–After* in 1996, these dust changes were highly significant, as might be expected from simple inspection of the data in Fig. 4.

In contrast, in 1996 there was no statistically significant change in DPAA rates (Table 3) in either the *All* data set or the *Windward* set, although in both data sets the mean

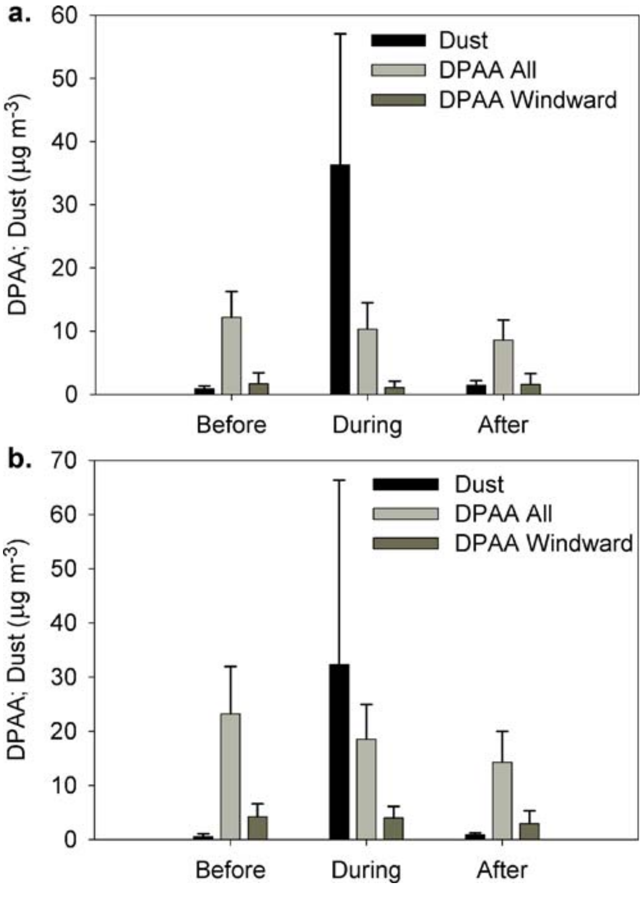

Fig. 4 Mean and standard deviations of *Dust*, *DPAA-All*, and *DPAA-Windward* for the periods *Before*, *During* and *After* the dust surges in Spring 1996 and 1997. **a** Period 17 March–24 April, 1996. *Before* 17–29 March; *During* 30 March–12 April; *After*:13–24 April. **b** Period 1 January–16 April 1997. *Before* 1 January–5 February; *During* 6 February–19 March; *After* 21 March–16 April

Table 2 Descriptive statistics: daily dust concentrations and DPAA at QEH relative to spring dust surges, 1996 and 1997

Group	Date span	*N*	Mean	Median	SD	25%	75%	Maximum	Minimum
1996									
Dust[a]									
Before dust	17–29 March	13	0.93	0.91	0.43	0.63	1.36	1.56	0.11
During dust	30 March–12 April	14	32.00	29.55	21.28	14.02	46.59	72.95	3.97
After dust	13–24 April	12	1.42	1.25	0.74	0.84	2.12	2.43	0.29
Pediatric asthma attendances at QEH: all parishes[b]									
Before dust	17–29 March	13	11.5	12.0	4.5	8.5	14.8	19	4
During dust	30 March–12 April	14	10.4	10.0	3.9	7.0	13.0	19	5
After dust	13–24 April	12	8.3	8.5	3.2	5.5	11.0	13	3
Pediatric asthma attendances at QEH: windward parishes[b]									
Before dust	17–29 March	13	1.5	1.0	1.3	0.8	3.0	4	0
During dust	30 March–12 April	14	1.1	1.0	0.9	1.0	1.0	4	0
After dust	13–24 April	12	1.6	1.0	1.7	1.0	1.5	5	0
1997									
Dust[a]									
Before dust	1 January–5 February	36	0.59	0.50	0.48	0.29	0.70	2.43	0.00
During dust	6 February–19 March	42	32.29	19.12	34.08	11.64	41.66	138.59	0.55
After dust	21 March–16 April	28	0.98	0.87	0.46	0.67	1.07	2.67	0.48
Pediatric asthma attendances at QEH: all parishes[b]									
Before dust	1 January–5 February	36	23.2	20.5	8.7	16.5	30.0	40	9
During dust	6 February–19 March	42	18.5	18.0	6.4	13.0	23.0	41	10
After dust	21 March–16 April	28	14.6	13.0	5.8	10.0	18.5	26	7
Pediatric asthma attendances at QEH: windward parishes[b]									
Before dust	1 January–5 February	36	4.3	4.0	2.3	2.0	6.0	8	1
During dust	6 February–19 March	42	4.0	3.5	2.1	3.0	5.0	12	0
After dust	21 March–16 April	28	3.1	2.0	2.4	2.0	4.0	10	0

[a] Dust concentration units, µg m^{-3}

[b] Pediatric asthma attendances at QEH, per day

DPAA decreased progressively from *Before* through during to *After*. In 1997 (Table 3), DPAA-*All* declined from *Before* through *During* to *After*, and the differences (including *Before–After*) were all statistically significant. The tests of the DPAA-*Windward* data sets show no significant change for *Before-During* but significant decreases for *During-After* and *Before-After*, although the latter was marginal.

To further test for differences associated with the spring 1996 and 1997 dust events, we compared the data obtained *during* the dust event with that from the *before* and *after* periods composited into one single control period. This corresponds to controlling for the mean changes in pediatric asthma attendance rates over time when testing the difference between the attendance *during* the dust event and that during the no-dust periods *before* and *after* the event. In addition by grouping these two periods we will tend to minimize any differences that might be introduced by the day-to-day variations observed in weekly attendance patterns. Using the Mann-Whitney rank sum test we find that the differences in the dust concentrations (*during* vs

Table 3 Statistical significance of changes in DPAA *During* dust surges as compared to low dust periods *Before* and *After*

	1996						1997					
	Dust		DPAA–*All*		DPAA–*Windward*		Dust		DPAA–*All*		DPAA–*Windward*	
Comparison phase	*P*	Change[a]	*P*	Change[a]	*P*	Change[a]	*P*	Change[a]	*P*	Change[a]	*P*	Change[a]
Before–During	<0.001*	Inc*	0.528	Dec	0.576	Dec	<0.001*	Inc*	0.016*	Dec*	0.551	Dec
During–After	<0.001*	Dec*	0.208	Dec	0.717	Inc	<0.001*	Dec*	0.012*	Dec*	0.024*	Dec*
Before–After	0.121	Inc	0.073	Dec	0.935	Inc	<0.001*	Inc*	<0.001*	Dec*	0.050*	Dec*

*Statistically significant change ($P<0.05$)

[a] Direction of change—increased (*Inc*) or decreased (*Dec*)—relative to the initial condition

before plus after) remained highly significant (P=<0.001) for both the 1996 and 1997 events; in contrast there was no significant difference in pediatric asthma attendances for either the *All* data set or the *Windward* data set.

Discussion and conclusions

We found no substantial changes in pediatric asthma attendances that could be linked to short-term surges in dust concentration. Thus, our data do not provide any support for the broadly accepted anecdotal association of African dust and asthma—that there is a sharp increase in the incidence of asthma symptoms (and attendances at the QEH asthma clinic) when dust concentrations are high. In addition, over an annual cycle, the temporal pattern of dust transport to Barbados has a distinctly different pattern from that of DPAA at QEH.

Nonetheless, our findings do not preclude the possibility that dust may have an impact on asthmatics that is not apparent in the simple approach used in this study. A more detailed study of the relationship using more sophisticated statistical techniques could possibly reveal such a relationship, if present, but we suspect that any affect would be weak.

Our results would seem to conflict with many studies that show that "dust" is often found to be associated with the onset of asthma symptoms (Eder et al. 2006). In such studies, however, the term "dust" is usually applied to measurements made in urban environments where particles are composed of complex mixtures of pollutant and natural materials; in most cases, natural soil mineral particles are a minor component. In households, "dust" is comprised largely of cloth fibers, human and animal hair, mites, and insect parts (Holgate 1999). The particulate matter in such environments often includes soluble proteinaceous allergenic materials that are known to trigger an asthmatic response (Cookson 1999).

Although Trade-Wind African dust has not been extensively analyzed for the presence of other commonly suspected pollutant stimuli, the concentrations of major pollutant aerosol species (Savoie et al. 2002) and ozone (Oltmans and Levy 1994) are low. The concentration of organic matter is also low, at most a few percent of the mass, and is believed to be composed largely of heavily weathered materials or biomass burning products (Eglinton et al. 2002) and leaf waxes (Conte and Weber 2002), materials that are not regarded as effective triggers. Low concentrations of viable (cultivable) bacteria and fungi are often measured in association with African dust at Barbados along with occasional pollen (Prospero et al. 2005) but, as with the dust, these show no obvious relationship to DPAA.

Our results differ from those of an earlier study in Trinidad (Gyan et al. 2005), which compared asthma attendances with visual range used as a proxy for dust. Based on our experience on Barbados, and on an analysis of our aerosol data and its relationship to 30 years of daily visibility measurements made at the Barbados airport (Huang et al. 2006), we find that visibility is an unreliable proxy for the day-to-day concentration of dust because of the presence of other aerosols, especially sea-salt, and because of changing relative humidity, which strongly effects aerosol optical properties. Smoke from pollution and local agricultural fires further complicates the problem, one which would be more severe on Trinidad because of the location of the observations in the western urbanized region (Gyan et al. 2005).

About one-third of the Earth's land surface is arid and frequently impacted by high concentrations of dust. Thus, if arid-region soil dust were to be a significant factor in asthma, it could play a major role on a global scale. Yet, few studies have attempted to relate soil dust to asthma in such regions. In Riyadh (Kwaasi et al. 1998) and Brisbane (Rutherford et al. 1999), dust storms have been associated with an increase in asthma prevalence but it is not clear that the dust itself is the causative agent. In Riyadh, asthma symptoms increased during dust storms but the response is attributed to the increased concentrations of proteinaceous materials associated with the dust, not necessarily with the mineral particles themselves (Kwaasi et al. 1998). High asthma prevalence is observed in North Africa (Ait-Khaled et al. 2007), but these data are obtained in coastal urban areas rather in than in the interior, where asthma symptoms could be most clearly linked to dust storms.

Our study focuses on African dust carried in the Atlantic Trade Winds. This dust is derived mainly from a wide range of sources in West Africa and the Soudano-Sahel region of North Africa (Prospero and Lamb 2003; Prospero et al. 2002). The physical effects of mineral dust can vary widely depending on the source and past history of the particles (Duzgoren-Aydin 2008). While we cannot generalize our results to other dust sources and their possible impact on asthma, it should be noted that, on a global scale, the major sources have a number of features in common (Prospero et al. 2002): they are located in arid regions (rainfall less than about 250 mm per year); they are situated in topographical lows or in regions adjacent to highlands (and consequently function as a deposition basin for weathering products from the surrounding terrain); they were all flooded in the Pleistocene or Holocene when deep alluvial deposits were formed. This similar history suggests that fine-grained dusts lifted from such sources might possess somewhat similar physical and chemical properties (Prospero 1996), which might also be relevant to the asthma issue.

Although our research suggests that desert-dust-related asthma does not appear to be a dominating factor in the

Caribbean, other health issues must be considered (Kuehn 2006). As previously stated, measurements in the Trade Winds at Barbados (Li-Jones and Prospero 1998) and in the southeastern United States (Prospero et al. 2001) show that about one-third to one-half of the African dust mass is in the size range below 2.5 μm diameter, defined by the US EPA as "respirable". Dust concentrations over the Caribbean, exemplified by the data in Figs. 1 and 2, are often at levels that would challenge US EPA standards, and thus might raise health concerns for a broader spectrum of illnesses (Dominici et al. 2006). We might expect health impacts similar to those observed in populations exposed to agricultural dusts (Schenker 2000) and other environments where soil dust concentrations are high (Derbyshire 2007).

Finally, as previously noted, the transport of dust across the tropical North Atlantic has increased greatly beginning in the early 1970s with the onset of the drought that continues in varying degrees to this day (Prospero and Lamb 2003). The drought has been linked in part to global warming (Held et al. 2005). Thus, to the extent that African dust has an impact on health, the impact could be attributed in part to anthropogenic causes.

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