Characterization of African Dust (PM$_{2.5}$) across the Atlantic Ocean during AEROSE 2004

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1. Introduction

African dust storms, also known as Saharan dust events, are responsible for injecting large quantities of mineral dust into the atmosphere over the Atlantic Ocean. As much as three billion tons of Saharan dust is estimated to be transported across the Atlantic Ocean annually (Prospero et al., 1996). Generally, maximum transport to the Caribbean, Central and North America (latitudes 15–25 North) occurs during the months of June to October (Graham and Duce, 1979). We have also reported increases in PM$_{10}$ and PM$_{2.5}$ throughout the island of Puerto Rico during this period, particularly during the summer (Gioda et al., 2007). In the last decades an increase in dust flux across the Atlantic has been occurring, probably due to an increase in drought periods throughout Africa (Prospero, 1999). These increases in mass transport across the ocean have been thought to be associated to environmental and health issues in the American Continent. Some of these aspects are briefly discussed herein.

Satellite-derived aerosol optical depth products have facilitated the observation of seasonal trans-Atlantic transport of Saharan dust into the Caribbean and the eastern seaboard of the United States (Reid et al., 2003; Prospero, 1999). Since a large fraction of the dust reaching the tropical Western Atlantic is in the PM$_{2.5}$ size range, it has a potential health impact. Several studies have reported associations with PM and health effects in the Caribbean region. A positive association between PM$_{10}$ values and hospital admissions of adults due to asthma exacerbations was reported in Puerto Rico in the year 1992 (Montealegre et al., 1993). Other investigators have reported an association between Saharan dust events and the prevalence of asthma in the Caribbean. One of these studies performed in Barbados, found associations between the biogenic content in the Saharan dust event and acute asthma symptoms (Blades et al., 1998). The second study reported a significant association between increased pediatric asthma with emergency room visits and Saharan dust events reaching the island of Trinidad (Gyan et al., 2005).

The effects of Saharan dust in the Caribbean have been monitored for several years, particularly in terms of total mass deposition (Prospero, 1999). Saharan dust transport is also responsible for heavy metal and mineral deposition in the tropical Atlantic, which may have impacts on regional ecology, atmospheric chemistry (Goudie and Middleton, 2001) and phytoplankton fertilization (Lenes et al., 2001). Saharan dust aerosols have been implicated as a significant forcing factor in regional climate changes, specifically in influencing precipitation patterns (Prospero and Lamb, 2003).

The components of the Saharan dust have been changing with time incorporating compounds originating from urban...
development and agricultural activities. It was previously thought that ultraviolet radiation would destroy microorganisms engulfed in the storm cloud particles during transport before reaching the western hemisphere. However, recent evidence indicates that this is not the case since viable fungi and bacteria were identified from dust particles (Prosero, 2004; Griffin, 2003).

A better understanding of the impacts of Saharan dust on the Caribbean and eastern Atlantic seaboard requires that direct measurements of density, size distribution, chemical and biological composition, and basic microphysical properties be obtained as the dust is transported across the Atlantic Ocean. This paper characterizes PM$_{2.5}$ across a Saharan dust storm in the Atlantic Ocean during a March 2004 storm event, and compares these analyses to similar measurements performed as the dust storm reaches the Puerto Rican coast.

2. Materials and methods

The main mission of the 2004 Aerosol and Oceanographic Science Expedition (AEROSE) was to provide a set of critical measurements to characterize the impacts and microphysical evolution of Saharan dust aerosol transported across the Atlantic Ocean (Morris et al., 2006). The 27 days mission on the NOAA Ship Ronald H. Brown began on February 29, 2004 in Bridgetown, Barbados and ended in San Juan, Puerto Rico on March 27. The route and sampling stations are depicted in Fig. 1A. PM$_{2.5}$ air samples were obtained at stations within portions of the ship trajectory using a Fine Particulate Chemical Speciation Air Sampler RAAS 2.5-400 (Andersen Instruments Inc., Franklin, MA, USA). This instrument was placed on deck near the bow of the ship. The instrument flow meters (FM) were set to intake air at flows of 17 L min$^{-1}$ (FM 1 and 4), 4.1 L min$^{-1}$ (FM 2 and 5) and 3.5 L min$^{-1}$ (FM 3 and 6). Teflon filters were preconditioned according to EPA protocols (USEPA, 1998) and then weighed for mass determination. Upon collection, filters were stored on a clean Petri dish and stored in a refrigerator on board until transferred to the laboratory for weighing and chemical or biological analyses. Three consecutive weights were obtained with a standard deviation of 0.00002 g or less and the amount of PM$_{2.5}$ mass determined.

Cape San Juan (CSJ). Fajardo, located at the most northeastern part of Puerto Rico, serves as a reference site (Fig. 1B). This site receives the trade wind (NE) air masses from the Atlantic Ocean. Very little if any anthropogenic influence is present, although during weekends, emissions from recreational boat traffic are present. This site was used to collect airborne material in order to compare its chemical composition to that of Saharan dust collected at sea and to monitor the amount reaching the island. Particulate matter (PM$_{2.5}$) samples were collected in Teflon and quartz filters during March 2004 using an Andersen Instruments RAAS 2.5-400.

Filters were extracted individually by adding concentrated nitric acid (7 mL) and ultra pure water (2 mL) in a reaction vessel heated at 90 °C ± 5°C for 2 h. Trace elements were determined by Atomic Absorption Spectroscopy (Perkin Elmer Atomic Absorption Spectrophotometer Model AAAnalyst 800, Norwalk, CT, USA) using Flame mode (Na and K) or Graphite Furnace mode (Al, As, Cd, Cu, Fe, Pb, Ni and V), following USEPA (1978–1996) methodologies. Blank filters were processed simultaneously with samples filters and were handled in an identical manner. The average trace elements values in blanks were subtracted from those obtained for each sample filter. The accuracy of the methods employed was evaluated using blanks spiked with known metal concentration and the use of a standard reference material (Urban Particulate Matter Standard Reference Material (SRM) 1648), National Institute of Standards and Technology (NIST), Gaithersburg, MD). The recovery efficiency was calculated on the basis of the concentration obtained from the SRM. The detection limit was calculated as the standard deviation of 3 blank injections.

Statistical analyses were performed using GraphPad Prism version 4.0. Two-tailed t-test paired analyses were performed to establish statistical differences between the means of PM$_{2.5}$, metal and arsenic concentrations between sites at the 95% confidence interval (P ≤ 0.05).

3. Results and discussion

3.1. PM$_{2.5}$ concentrations

The amount of particulate matter PM$_{2.5}$ collected at the beginning of AEROSE (March 3–5) was relatively low (2 µg m$^{-3}$), therefore it was used as our reference value (Table 1). On March 6, 2004, AEROSE encountered a massive plume of Saharan dust mid-way across the Atlantic Ocean (Fig. 2). The leading edge of this dust storm event had an instantaneous mass density, which peaked at 200 µg m$^{-3}$ in the size range of PM$_{2.5}$ (Morris et al., 2006). This represents an increase of two orders of magnitude over the reference value obtained from filters collected on the previous days (2 µg m$^{-3}$) (Table 1, March 3–5, Fig. 3). The maximum surface mass densities occurred from March 5–9 (stations 2 and 3) across the AEROSE eastbound transect, whose levels of collected PM$_{2.5}$ at sea ranged from 103 to 120 µg m$^{-3}$ (Fig. 3 and Table 1). These PM$_{2.5}$ concentrations at sea were around 7 times over the annual suggested EPA mean value of 15 µg m$^{-3}$, twice that of the 65 µg m$^{-3}$ daily permissible standard. The PM$_{2.5}$ levels start to decrease at station 4, but still considerably higher (55 µg m$^{-3}$) than at the reference site (station 1). This is due to the fact that we were still sampling the tail of the Saharan cloud over the ship during the

Fig. 1. Cruise track during AEROSE with stations indicated (A). Map of Puerto Rico showing the reference site in Fajardo (Cape San Juan) (B).
sampling period. Stations 5 and 6 presented low concentrations of PM$_{2.5}$ (20–16 μg m$^{-3}$, respectively) and in this case no Saharan outbreak was noticeable, though it was still apparently detected. These concentrations were higher than the transect reference site (station 1) where Saharan events were absent. These higher concentrations in PM$_{2.5}$ can also be due its proximity to the African continent, where a high number of anthropogenic sources (forest fires and fossil fuel burning) contribute to ambient particulate matter. In summary, a significant ($P < 0.05$) increase in PM$_{2.5}$ concentrations during storm period (mean 112 μg m$^{-3}$) as compared to non-storm-events (mean 18 μg m$^{-3}$) in the Atlantic Ocean (measurement throughout the transect) was observed.

### 3.2. Trace elements

The trace elements exhibiting the highest concentration in the Saharan PM$_{2.5}$ were Al (10.5 μg m$^{-3}$) and Fe (3.6 μg m$^{-3}$) and the lowest measured was Cd (0.0003 μg m$^{-3}$). This is consistent with previous reports (Prospero et al., 2001) for Saharan dust. Most of these elements co-varied with PM$_{2.5}$ concentrations across the Atlantic Ocean. During the strongest Saharan dust events (March 5–9) the PM$_{2.5}$ concentrations were as high as 120 μg m$^{-3}$ (see Table 1). Interestingly, some elements also presented highest concentrations in these stations (Al, Fe, K and V). The Al and Fe concentrations were two orders of magnitude higher in the Saharan particulate matter while As, Cd, Pb, and V showed a one order of magnitude increase. Similar results were found during the Puerto Rico Dust Experiments (PRIDE), where Fe, Al and K in coarse mode ($d_{ae} < 11$ μm) showed peak coincidence during Saharan dust events (Reid et al., 2003).

To evaluate the relationship among trace elements and particulate matter, a series of regressions were performed. High correlations were obtained between PM$_{2.5}$ and Fe ($r^2 = 0.96$); PM$_{2.5}$ and Al ($r^2 = 0.83$); PM$_{2.5}$ and K ($r^2 = 0.98$) and PM$_{2.5}$ and V ($r^2 = 0.91$). These correlations between PM$_{2.5}$ and trace elements (Al, Fe, K and V) prove that the particulate matter has a similar source of origin. These results are expected since these elements form the important constituents in surface soil. However, no correlations were obtained between PM$_{2.5}$ and Pb and Ni. This is also expected since these trace elements are mainly anthropogenic;

### Table 1

PM$_{2.5}$ and trace element concentrations from Saharan dust collected across the Atlantic Ocean during AEROSE 2004.

<table>
<thead>
<tr>
<th>Station</th>
<th>Sampling Date</th>
<th>Start Position</th>
<th>Concentrations (μg m$^{-3}$)</th>
<th>Concentrations (ng m$^{-3}$)</th>
<th>V/Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>PM$_{2.5}$</td>
<td>Al</td>
<td>Fe</td>
</tr>
<tr>
<td>1</td>
<td>Mar 3–5</td>
<td>6° 9.06’ N, 40° 6.12’ W</td>
<td>2.01</td>
<td>0.19</td>
<td>0.05</td>
</tr>
<tr>
<td>2</td>
<td>Mar 5–7</td>
<td>6° 10.80’ N, 40° 25.00’ W</td>
<td>120.42</td>
<td>6.57</td>
<td>3.61</td>
</tr>
<tr>
<td>3</td>
<td>Mar 7–9</td>
<td>9° 51.3’ N, 33° 7.4’ W</td>
<td>103.47</td>
<td>10.51</td>
<td>2.66</td>
</tr>
<tr>
<td>4</td>
<td>Mar 9–11</td>
<td>12° 48.2’ N, 24° 41.1’ W</td>
<td>54.89</td>
<td>4.03</td>
<td>2.00</td>
</tr>
<tr>
<td>5</td>
<td>Mar 11–13</td>
<td>18° 00.00’N, 19° 00.00’ W</td>
<td>19.89</td>
<td>0.75</td>
<td>0.52</td>
</tr>
<tr>
<td>6</td>
<td>Mar 13–15</td>
<td>23° 33’ N, 10° 10’ W</td>
<td>15.96</td>
<td>0.98</td>
<td>0.15</td>
</tr>
</tbody>
</table>
or between PM$_{2.5}$ and Na, which originates mostly from sea spray. In addition, strong correlations were obtained between Al and other crustal elements such as Fe ($r^2 = 0.73$), K ($r^2 = 0.89$), and V ($r^2 = 0.97$). Correlations were also observed between crustal elements Fe and K ($r^2 = 0.92$), Fe and V ($r^2 = 0.86$) and V and K ($r^2 = 0.94$). These uniform metal distributions provide evidence that they originate from a common source. This hypothesis is further supported by reports of a correlation between Fe and Al in PM$_{2.5}$, which also suggests the African dust events as sources of these elements (Prospero et al., 2001). Dust is predominantly composed by aluminum silicates and trace amounts of gypsum, calcium carbonates and species rich in Fe (hematite) (Reid et al., 2003). Aluminum and iron however, are the major components in soil and have been reported to constitute 6–8% and 2.5–5%, respectively of the total mass of PM (Prospero et al., 2001; Reid et al., 2003). We found an average of 7.6% for Al and 2.8% for Fe during Saharan events, which is in agreement with previous findings of average concentration found in crustal material. Potassium is also considered a tracer for biomass burning in submicron fraction. In this study we did not determine this fraction separately and hence do not report any findings on the same.

Correlations were observed for Ni and Pb ($r^2 = 0.81$), which suggests an anthropogenic origin of these elements. However, Ni and V presented low correlation ($r = 0.4$). V and Ni are considered emission tracers of combustion by fuels from stationary sources. The V/Ni ratio for gasoline and diesel engine is 0.3–0.5 (Gioda et al., 2006). The V/Ni ratios calculated (Table 1) showed a combination of V and Ni from crustal and non-crustal sources. Our results indicate that when near the continent and without or little Saharan dust influence the V/Ni ratios were around 0.5; but during the events, the ratio was higher (1.4–7.0). Therefore, in the proximity of the continent the source of these species is mainly anthropogenic, while in the ocean, it is natural. Previous results in Puerto Rico also presented this tendency, i.e., the Saharan storm events also contribute to the concentrations of V to airborne particulate matter in Puerto Rico (Gioda et al., 2006).

The possibility also exist that Na could be contributing to the mass of particulate matter, however, no correlations were obvious between sodium and other elements, which suggests that it is incorporated from the ocean spray in a random manner. Sodium is considered a tracer for sea salt and, as expected, no correlations were obtained with crustal (K, Al, Fe and V) or anthropogenic (Pb, Ni) elements.

To further support our hypothesis and differentiate between potential sources of anthropogenic and crustal elements we calculated the enrichment factor (EF) using Fe as a reference source according to

$$EF = \frac{(C_x/C_{Fe})_{aerosol}}{(C_x/C_{Fe})_{crust}}$$

where $(C_x/C_{Fe})_{aerosol}$ is the ratio of the concentration of the element (x) to that of Fe (element selected as crustal reference) in aerosol and $(C_x/C_{Fe})_{crust}$ in the correspondent ratio in soil (Duce and Zoller, 1975).

Elements with an EF value close to unity indicate a strong influence of a natural component, while higher values indicate anthropogenic sources. The EF is particularly useful as a fingerprint for identifying Saharan airborne particulate matter collected in Puerto Rico. Two distinct groups arise from the EF obtained for Saharan and non-Sahran events during AEROSE 2004 and in Puerto Rico (Table 2). The first group contains Al, K, and V, which originates from African crustal soil and the other group includes (As, Cd, Pb, Ni) which are related to anthropogenic emissions. A significant reduction in the EF during Saharan events supports their source of origin while an exception was noticed for Pb, As, Na and V. These results indicate that during Saharan events the elements come from soil and that the most abundant elements are Fe and Al. Conversely, in the absence of Saharan dust events the EFs are higher for most elements (except for Fe, Al, V, and K) indicating that the source of these elements is anthropogenic. These results were verified and supported using the Total Ozone Mapping Spectrometer (TOMS) satellite data (Fig. 2).

### 3.3. Fajardo vs. AEROSE: PM$_{2.5}$ and metal concentrations

The concentrations of PM$_{2.5}$ and some metals collected in Fajardo during the AEROSE dust storm are shown in Table 3. The PM$_{2.5}$ concentrations were low before and after the cloud of African dust crossed Puerto Rico (average of 3.9 μg m$^{-3}$) as compared to Saharan influence (8 μg m$^{-3}$) (Table 3, Fig. 3), with a twofold increase during the storm. Considerably lower values were encountered on land when compared that obtained at the sea, as expected. The average PM$_{2.5}$ concentration at Fajardo (8 μg m$^{-3}$) was 14 times lower than that encountered in the Atlantic Ocean during AEROSE (average of 112 μg m$^{-3}$). For metals, a significant difference in Al concentration from the storm cloud (average 8.5 μg m$^{-3}$) and inland in Puerto Rico (2.9 μg m$^{-3}$) was also observed. However, variation in Fe was not so marked. No differences in Na or K occurred, as expected.

### Table 2

<table>
<thead>
<tr>
<th>Events</th>
<th>Al</th>
<th>As</th>
<th>Cd</th>
<th>Pb</th>
<th>Ni</th>
<th>V</th>
<th>K</th>
<th>Na</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEROSE Non-Saharan</td>
<td>1.7</td>
<td>18.7</td>
<td>16.7</td>
<td>328.5</td>
<td>19.6</td>
<td>2.9</td>
<td>1.7</td>
<td>7.8</td>
</tr>
<tr>
<td>AEROSE Saharan</td>
<td>1.1</td>
<td>1.8</td>
<td>1.1</td>
<td>11.4</td>
<td>1.4</td>
<td>2.0</td>
<td>1.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Fajardo Non-Saharan</td>
<td>0.08</td>
<td>2.5</td>
<td>1.9</td>
<td>52.6</td>
<td>33.5</td>
<td>17.3</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Fajardo Saharan</td>
<td>0.2</td>
<td>1.9</td>
<td>0.5</td>
<td>14.6</td>
<td>7.9</td>
<td>4.4</td>
<td>0.2</td>
<td>0.08</td>
</tr>
</tbody>
</table>

### Table 3

<table>
<thead>
<tr>
<th>Sample</th>
<th>Date</th>
<th>μg m$^{-3}$</th>
<th>PM$_{2.5}$</th>
<th>Al</th>
<th>K</th>
<th>Na</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>11-Mar-04</td>
<td>3.31</td>
<td>0.67</td>
<td>0.08</td>
<td>0.07</td>
<td>0.38</td>
</tr>
<tr>
<td>During</td>
<td>12-Mar-04</td>
<td>7.95</td>
<td>2.90</td>
<td>0.09</td>
<td>0.09</td>
<td>0.38</td>
</tr>
<tr>
<td>After</td>
<td>13-Mar-04</td>
<td>4.39</td>
<td>0.42</td>
<td>0.05</td>
<td>0.10</td>
<td>0.51</td>
</tr>
</tbody>
</table>
A comparison was also made between PM$_{2.5}$ and metal concentrations measured during Saharan and non-Saharan (clear day) events periods in the Atlantic and an annual average obtained in Gioda et al. (2007). The annual average PM$_{2.5}$ concentrations in Puerto Rico were also different between both periods (7.4 vs. 11.4 μg m$^{-3}$) (Gioda et al., 2007). Regarding to some metal, annual average concentrations of Fe and As were higher during Saharan than in non-Saharan periods, as observed for AEROSE. Conversely, concentrations of metals not derived from soil such as Pb and Cd did not change significantly during Saharan events and are higher during non-Saharan periods, indicating anthropogenic sources. These results once more corroborate the influence of metal levels and particulate matter over Saharan dust outbreaks. During the dust trajectory a decrease in concentrations due to dissipation occurs as evidenced by the dust concentrations during Saharan events for Fajardo and AEROSE. When the dust reaches Fajardo the concentrations of PM$_{2.5}$ was 10 times lower than in AEROSE and some metals 2 times (As) to 20 times (Fe) lower.

3.4. Comparison with other sites with Saharan dust influence

Presence of Saharan dust has been studied for a long time in Florida, where it has been reported, as in this study, that Al and Fe in PM$_{10}$ and PM$_{2.5}$ measured daily in rural and urban sites presented low concentrations during the year. However, a significant increase was observed during summer when African dust reached the site (Prospero et al., 2001). The Al/Fe ratio during Saharan events was 0.8, which is similar to our findings.

Other studies have reported different fractions of aerosols (total suspended particles, PM$_{10}$, PM$_{2.5}$) considering periods with and without Saharan outbreaks. In Puerto Rico levels of PM$_{10}$ during Saharan events were measured at 116 μg m$^{-3}$ (Morales, 1998). This concentration was very high compared to non-Saharan periods (25 μg m$^{-3}$) (Gioda et al., 2006). In those samples a high concentration of Al (4.5 μg m$^{-3}$) and Fe (3.9 μg m$^{-3}$) were also found (Morales, 1998). In the Canary Islands PM$_{10}$ concentrations were 206 μg m$^{-3}$ during Saharan incursions but low in non-Saharan period, 30 μg m$^{-3}$. Differences were also observed in the levels of Al (23.5 and 0.7 μg m$^{-3}$) and Fe (6.5 and 0.45 μg m$^{-3}$) during both periods (Viana et al., 2002). Other metals also presented high concentrations during Saharan events (K: 3.5 and 0.2 μg m$^{-3}$; Na: 5 and 1.8 mg m$^{-3}$; V: 34 and 12 mg m$^{-3}$; Pb: 45 and 26 mg m$^{-3}$) (Viana et al., 2002). The crustal elements presented high values during African dust events. Another study performed in Canary Islands during a strong Saharan dust episode evaluated the PM$_{2.5}$ levels and metals in two different sites (Alastuey et al., 2005). Levels of PM$_{2.5}$ ranging from 33 to 65 μg m$^{-3}$ were detected. Al (1–9 μg m$^{-3}$) and Fe (0.3–3.5 μg m$^{-3}$) were higher than K (0.2–0.9 μg m$^{-3}$) and Na (0.5–1.6 μg m$^{-3}$). Significant concentrations were also reported for As (1.7–2.7 ng m$^{-3}$), Cd (0.2–0.5 ng m$^{-3}$), Ni (2–16 ng m$^{-3}$) and Pb (2.4–4 ng m$^{-3}$) (Alastuey et al., 2005). The presence of these trace elements can be attributed to anthropogenic sources.

Aerosol chemical composition was also measured in Sardinia, Italy, and reflected the influence of Saharan dust (Guerzoni et al., 1999). Concentrations up to 40-fold higher were reported during Saharan dust events. During the episodes high concentrations were measured for crustal elements such as Al (3 μg m$^{-3}$), Fe (1 μg m$^{-3}$), Ca (3.3 μg m$^{-3}$) and Si (5.8 μg m$^{-3}$) compared to background sources (Al: 0.2 μg m$^{-3}$; Fe: 0.08 μg m$^{-3}$; Ca: 0.6 μg m$^{-3}$; Si: 0.6 μg m$^{-3}$). These results are in agreement with ours where an increase in the influx of Al and Fe from Saharan dust was observed in Puerto Rico. Other elements (K, Pb, Cr, Na) also changed but not as significantly as crustal species (Guerzoni et al., 1999). All of these studies showed an increased PM concentrations which are proportional to the distance from the source. However, the predominant species were from soil, such as Al and Fe.

4. Conclusions

The Saharan Dust Aerosol and Ocean Science Expedition (AEROSE) had as its main objective the study of Saharan dust aerosols and their transport across the Atlantic Ocean. PM$_{2.5}$ levels were as low as 2 μg m$^{-3}$ at the beginning of the cruise, where no anthropogenic or Saharan dust was present. The dust storm resulted in at least a 50-fold increase in PM$_{2.5}$. This PM increase also results in the amount of Al and Fe per m$^{-2}$. A major dust storm was encountered with PM$_{2.5}$ concentrations of 120 μg m$^{-3}$, which are higher than EPA standards. The chemical composition of African dust revealed that Al and Fe were the main components. The enrichment factor analysis corroborated these results. Other ions such as Pb, Ni, Cd originated from anthropogenic sources and had no correlations with Fe and Al. Similar trends were observed in the island of Puerto Rico when the Saharan dust reached its shores. However, the levels of PM$_{2.5}$ and trace elements were greatly reduced across the Atlantic. A 14-fold reduction in PM$_{2.5}$ and 4 fold in Al/m$^{-3}$ were reported. In summary, Saharan dust is a significant source of PM$_{2.5}$, Fe and Al as it crosses the Atlantic Ocean and reaches the Caribbean Basin and its contribution will depend on the frequency and magnitude of each particular storm. Measurements like the one presented here are critical for understanding global impact and possible health effects of transported dust and its constituents across the Atlantic.

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