Assessing the Impact of Advected African Dust on Air Quality and Health in the Eastern United States

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ABSTRACT

Large quantities of African dust are carried into the southeastern United States each summer with concentrations typically in the range of 10 to 100 μg m⁻³. Because approximately one-third to one-half of the dust mass is in the size range under 2.5 μm diameter, the advection of African dust has implications for the EPA's newly implemented standard for PM₂.₅, particulate matter and for the assessment of human health effects. It will be difficult to assess the impact of African dust events on air quality because they occur during the summer (maximum in July) when photochemical pollution events are frequent and intense in the eastern United States. Indeed, the presence of dust could affect the evolution of photochemical dust events. In order to assess the role of African dust in air quality in the United States, it will be necessary to develop a set of diagnostic indicators; it appears that dust mineralogy and elemental composition might be useful for this purpose. Various satellite products can be used to characterize the spatial coverage of dust events and, when coupled with meteorological tools, to predict impact regions.

Key Words: PM₂.₅, PM₁₀

INTRODUCTION

The EPA's new standard for ambient airborne particulate matter is based on the mass concentration of particles in two size classes, those under 2.5 μm...
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diameter (PM$_{10}$) and those under 10 µm diameter (PM$_{2.5}$). The PM$_{10}$ standard specifies an annual mean of 15 µg m$^{-3}$ and a 24-hour mean of 65 µg m$^{-3}$ based on the 98th percentile of the frequency distribution averaged over 3 years. The PM$_{2.5}$ annual mean standard is retained at 50 µg m$^{-3}$; the 24-hour standard remains at 150 µg m$^{-3}$, but it is based on the 98th percentile of the frequency distribution averaged over 3 years. The PM$_{2.5}$ standard is of special interest because studies show that particles less than 2.5 µm diameter can efficiently penetrate into the lungs (Wilson and Spengler, 1996). The present PM$_{2.5}$ standard is based solely on mass concentration because it has not been possible to establish a link between health effects and specific aerosol species. Although there is clear evidence for a causal relationship between health and specific types of particles found in well-characterized environments and at high concentration (e.g., asbestos, various silicates, coal dust, tobacco smoke), the health effects of particles at ambient concentration levels are largely unknown. Consequently, it has not been possible to unambiguously identify cause-effect relationships for specific components in aerosols or to validate mechanisms by which low concentrations of particles could cause cardiopulmonary toxicity (Uetrecht and Samet, 1996). There is clearly a need for detailed information about aerosol properties in ambient air.

The purpose of this note is to alert the community to the possible impact of the long-range transport of mineral dust particles on PM$_{2.5}$ measurements and related health issues. There is considerable evidence that mineral dust transported from sources in North Africa plays an important role in air quality in the eastern United States. It has been known for some time that large quantities of African mineral dust are carried across the North Atlantic every year by the trade winds (Prospero and Nees, 1986; Li et al., 1996; Li-Jones and Prospero, 1998). Recently, Prospero (1999) reported on the results of a continuous daily aerosol sampling study carried out at a coastal site in Miami, Florida, over the period 1974 to 1996. These data show that African dust is transported into Florida every summer, yielding daily concentrations that are typically in the range of about 10 to 100 µg m$^{-3}$. Dust events usually last at least several days and can extend over several weeks. Maximum dust concentrations usually occur in July (monthly mean, 16.5 µg m$^{-3}$), but relatively high concentrations are also observed in June (8.4 µg m$^{-3}$) and August (9.8 µg m$^{-3}$). African dust was always the dominant aerosol constituent during the summer months over the 23 years of record. In contrast, during the remainder of the year soil dust concentrations average about 1 µg m$^{-3}$.

Satellite studies have shown that African dust events often extend over huge areas of the western Atlantic (Husar, Prospero, and Stowe, 1997; Herman et al., 1997). Consequently, we might reasonably expect that the dust measurements made in Miami are representative of a large area of the eastern United States. This was confirmed by Perry et al. (1997), who assessed the temporal and spatial variability of PM$_{2.5}$ mineral dust concentrations in a network of approximately 70 sites located in national parks and wilderness areas during the period 1992 to 1995. The highest concentrations were associated with sites in the central and eastern United States during the summer, not in the arid

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southwest as one might assume. Furthermore, there was a large-scale coherence in the temporal variability of the high PM_{10} dust values, suggesting that they were associated with synoptic-scale processes that are typical of African dust events (Karyampudi and Carlson, 1988; Westphal, Toon, and Carlson, 1987, 1988).

Given that African dust is a frequent and prominent component in aerosols over a large area of the United States, we must consider what impacts dust might have on PM standards, on air quality in general, and on human health. To address these questions, we need detailed information on the physical properties of dust (especially particle size) and its elemental and mineralogical composition.

African Dust and PM Standards

There are not many data on the size distribution of African dust at sites in the United States. Nonetheless, there is evidence that roughly a third to a half of the PM_{10} soil dust mass falls into the PM_{10} fraction. Cascade impactor measurements made in African dust-laden trade winds in the Caribbean show that 43% of the dust mass was less than 2.5 µm aerodynamic diameter and 18% less than 1.25 µm diameter (Li-Jones and Prospero, 1998). Hardy et al. (1976) made size distribution measurements with a single stage cascade impactor at three sites in the Miami area in July 1974 at a time when African dust concentrations were high (Prospero, 1999). The size distribution of Fe (computed from Table 1, Hardy et al.) shows that 52% of the mineral dust mass was less than 2 µm diameter and 75% was below 4 µm diameter. The importance of recognizing the presence of African dust is illustrated by the Hardy paper. They were unaware that an African dust event had occurred during their measurements; they simply assumed that the very high soil dust concentrations were due to local sources such as road dust.

Although dust concentrations can reach very high values, based on EPA's PM averaging criteria it seems unlikely that African dust alone will cause a violation of the PM_{10} or PM_{2.5} standards either on the basis of the annual standard or the 24-hour standard. During the 1990s (Prospero, 1999), the maximum dust concentration occurred on June 29 to 35, 1993, 121 µg m^{-3}; if we assume that a third to a half of the dust is under 2.5 µm diameter, then the PM_{2.5} concentration would be about 40-60 µg m^{-3}. The highest dust concentration obtained over the 25 years of measurements in Miami was 149 µg m^{-3} on July 16 to 18, 1983; this would have yielded a PM_{2.5} concentration in the range of 49 to 74 µg m^{-3}. Although dust concentrations is themselves are unlikely to trigger a violation of the 24-hour PM_{2.5} standard (65 µg m^{-3}), dust in conjunction with emissions from local and regional sources could conceivably present a problem. The probability of such an occurrence is heightened by the fact that dust concentrations are highest in the summer when pollution levels are often at a maximum in the eastern United States.
AFRICAN DUST AND HEALTH

Although the mass concentration of PM$_{2.5}$ African dust might not present a problem from the standpoint of compliance, concentrations are great enough to warrant consideration of possible health effects. African dust is composed of a wide range of minerals that are commonly found in soils (Glaccum and Prospero, 1980; Prospero, 1981; Herrmann, Jahn, and Sahir, 1996; Molinaroli, 1996; Avila, Queralt-Mills, and Alcaron, 1997; Caspian et al., 1998). Although the composition varies somewhat with source region, in general it is rather uniform. Quartz is the dominant constituent. Kaolinite and illite are prominent and in some regions kaolinite might be important. In addition, a wide range of other minerals could be present although generally in minor or trace amounts (e.g., gypsum, dolomite, wollastonite, chlorite, palagorskite, micas). The soil particles in this size fraction usually show signs of severe chemical and physical weathering and a large fraction of the aerosol mineral mass is relatively amorphous and yields a broad X-rays diffraction pattern (Glaccum and Prospero, 1980). The particle surfaces are often coated with oxides and salts; other particles (e.g., very fine clay) could be attached to the surface or the particle itself might be made up of an aggregation of smaller particles. Consequently the dust particles will have very complex physical and chemical properties.

Dust particle coatings could play a role in health impacts. Amund (1996) and Uell and Samet (1996) review various hypotheses regarding particle health mechanisms. They present evidence that suggests that aerosols coated with first row transition metals are especially efficient in producing an inflammatory response in the lungs. In particular, they suggest that surface-complexed iron can generate hydroxyl radicals in lung tissue and that these radicals produce acute lung toxicity. African dust particles have an Fe content of about 5 to 10% (Zhu, Prospero, and Miller, 1997; Gaie and Thomas, 1996). A substantial fraction of the iron is present on the particle surface; indeed, one of the more notable characteristics of African dust is that it has a very pronounced red-brown coloration (Prospero, Ners, and Uematsu, 1987) because of iron oxide coatings (Glaccum and Prospero, 1980). Studies of the dissolution properties of dust-bound Fe show that it is relatively insoluble; nonetheless, of the total Fe in dust, roughly 5 to 10% is readily leachable (Zhu et al., 1997; Chester, Nimo, and Keyse, 1996); thus, we might expect that a substantial fraction of the Fe on dust could be readily mobilized once the particles are deposited on lung tissue.

Other metals could conceivably play a role in health. Studies have shown that the elemental composition of African dust is relatively uniform and for most elements quite similar to that of average crustal material (Schatz, 1989; Molinaroli, Guerinoni, and Rampazzo, 1995; Gullu, Olmer, and Tucel, 1996; Gata and Prospero, 1996; Perry et al., 1997; Guie and Thomas, 1996; Chester et al., 1996). Of the first row transition metals, the concentrations of V, Cr, Mn, Fe, Co, and Ni generally appear to be close to average crustal values (Guie and Thomas, 1996; Chester et al., 1996; Gullu et al., 1996). In PM$_{2.5}$ African dust

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particles Zn can be as high as 10 times greater than in average crustal material. (Gulhi et al., 1996; Molinaroli et al., 1993), but in some regions it is close to average crustal abundances (Schutz, 1989; Rahn et al., 1979; Chester et al., 1996). Thus, based on the work of Andur (1996) and Uziel and Samet (1996), the chemistry of transitory elements in dust warrants investigation. In particular, it is not clear where these elements reside in the dust particle — that is, are they incorporated in surface coatings, along with Fe, or are they buried within the dust mineral matrix where they would be less readily released to tissue surfaces?

The discussion of mineral dust effects is complicated by the fact that African dust’s not necessarily a “pure” soil product. Measurements over the eastern and western Atlantic (Savoie, Prospero, and Salzman, 1989; Savoie et al., 1992; Prospero et al., 1995), including Maine (Prospero, 1996), show that dust is associated with chemical species that suggest pollution sources. For example, the concentrations of NO3-, non-sea-salt SO42-, and NH4+ in dust-laden African air masses is substantially greater than that expected for “background” ocean air. Pollutants derived from sources in Europe and North Africa become mixed with dust over Africa where the high concentrations of sulfur, calcium, and alkaline earths are not as pronounced (Prospero et al., 1995). The concentration of many elements that are typically associated with pollution sources are often greatly increased in dust. In particular, Cu, Cd, As, Sb, and Se are enriched by factors ranging from about 20 to 500 (Gulhi et al., 1996) and Pb, 42 (Molinaroli et al., 1993). It is not clear to what extent these enriched elements are due to pollution inputs and how much is naturally a part of the dust matrix. The origin of the elements is important because it is well established that the anthropogenic component is much more soluble than the soil dust component (Chester et al., 1996).

INTERACTION OF AFRICAN DUST WITH LOCALLY GENERATED POLLUTANTS

It is also necessary to consider the possible interactions between locally generated pollutants and advected African dust. As previously noted, African dust events usually occur during the summer months. A season when pollution episodes are common in the eastern United States. Indeed, the presence of an African dust event could be masked by local pollution haze. Conversely, because African dust events are characterized by extremely hazy conditions, a dust event could be misidentified as a pollution event. Because of the large surface area afforded by African dust, photochemical processes could be substantially affected (Dentener et al., 1996). Recently, Dickerson et al. (1997) presented evidence that aerosols, by modifying the radiative balance in the atmosphere, can have a pronounced effect on photochemical smog formation; they predict that UV-absorbing aerosols such as mineral dust should

DISCUSSION AND RECOMMENDATIONS

Because of the very complex atmospheric chemical environment that exists during pollution events in the United States, it may be difficult to establish causal relationships between specific aerosol components and health effects. This is particularly true for mineral dust because of the complex properties of individual dust-aerosol particles. To assess dust health effects it may be neces-
sary to reduce the number of variables by studying health impacts in regions where dust concentrations are high and the concentration of other pollutants is relatively low. West Africa is the logical place for such studies because of the frequent dust events and the very high dust concentrations (Moussiou, Bertrand, and Nicholson, 1997). For example, in Mali, West Africa, during dust events, dust concentrations are in the range of about 3000 to 15000 μg m⁻³ and the mean diameter is 3 μm (Gillies, Nickling, and McTainsh, 1996; McTainsh, Nickling, and Lynch, 1997). The extremely high concentrations of mineral aerosol, which is largely derived from proximate sources, should overwhelm the effects of other types of aerosols including pollutants. Under such condi-
tions both chronic and short-term health effects of mineral dust should be readily apparent.

In order to assess the impact of African dust on air quality in the United States, it will be necessary to develop a set of diagnostic indicators. The mineral and elemental composition of the dust might serve this purpose. Dust col-
lected in the western Atlantic is identical to that collected off the coast of Africa and the composition is relatively invariant from event to event (Glaccum and Prospero, 1980). Perry et al. (1997) and Gatz and Prospero (1996) showed that during African dust events the ratios of a wide variety of elements were quite constant and distinctly different from elemental ratios observed during periods when African dust was not present. The relative constancy of North African dust characteristics has been noted in various studies carried out in that region (see, for example, Schütz, 1989; Chester et al., 1996; Gulew and Thomas, 1996; Gullu et al., 1996). Herwitz et al. (1996) showed that on Bermuda the incursion of African dust could be clearly distinguished from that advected from North America on the basis of trace metal composition.

The large-scale temporal-spatial homogeneity of dust concentration and dust composition during African dust incursions can also serve as a clue (Prospero, 1999; Perry et al., 1997; Gatz and Prospero, 1996). The advection of African air can be identified on the basis of meteorological characteristics (Carlson and Prospero, 1972; Gatz and Prospero, 1996). Various satellite products can provide information on the spatial extent of African dust events and also a rough indication of relative dust concentrations (Husar et al., 1997; Herman et al., 1997). By coupling atmospheric transport models with information

provided by satellites, it should be possible to predict the areas that will be impacted by specific dust events.

REFERENCES


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