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Regional transport of a chemically distinctive dust: Gypsum from White Sands, New Mexico (USA)

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A B S T R A C T

The White Sands complex, a National Monument and adjoining Missile Range in southern New Mexico, occupies the dry bed of an ice-age lake where an active gypsum dunefield abuts erodible playa sediments. Aerosols entrained from White Sands are sometimes visible on satellite images as distinct, light-colored plumes crossing the Sacramento Mountains to the east and northeast. The IMPROVE network (Interagency Monitoring of PROtected Visual Environments) operates long-term aerosol samplers at two sites east of the Sacramento range. In recent years a spring pulse of sulfate aerosol has appeared at these sites, eclipsing the regional summer peak resulting from atmospheric reactions of sulfur dioxide emissions. A significant fraction of this spring sulfate is contributed by gypsum and other salts from White Sands, with much of the sulfur in coarse particles and concentrations of calcium and strontium above regional levels. The increase in these gypsiferous species coincides with a drought following a period of above-average precipitation. White Sands and the IMPROVE samplers together provide a natural laboratory: a climatically sensitive dust source that is both well characterized and chemically distinct from its surroundings, with a signature that remains identifiable at long-term observatories 100–200 km downwind.

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1. Introduction

Mineral dusts are poorly accounted for by existing models of atmospheric aerosols (e.g. Park et al., 2010; Huneeus et al., 2011). The particles entrained as aerosol are a non-random selection of the material present in the soil, and are not easily predicted from bulk soil composition (e.g. Bullard et al., 2007; Kok, 2011). The episodic and unconfined character of emissions complicates their characterization at the source, and the ubiquity of sources generally makes it hard to isolate specific source–receptor relationships for observation and study (e.g. Schutz and Sebert, 1987; Kavouras et al., 2009). This paper documents a “natural laboratory” where dust from a specific dry lake can be chemically identified in aerosols sampled more than 100 km downwind.

White Sands sits in the Tularosa Basin, whose geology is described by Fryberger (2001), Langford (2003), and KellerLynn (2012). A closed drainage within the northern Chihuahuan Desert, the Basin is a down-faulted block of earth’s crust along the Rio Grande continental rift. The depression held a pluvial lake during the wetter climate of the most recent (Pleistocene) glaciation, and the lake collected mineral salts dissolved from exposed neighboring strata. As the waters evaporated in the more arid regional climate that followed, they left behind the gypsiferous deposits that characterize the area now known as White Sands. These Pleistocene deposits are easily identified in satellite imagery by their high albedo; as illustrated in Fig. 1, they appear as a distinctive white field in a landscape of desert browns. The darker north–south mountain ranges visible west (San Andreas) and east (Sacramento) of this field follow the faults delineating the Basin.

Much of White Sands is now protected by the National Park Service (NPS) as a National Monument, “the world’s largest gypsum dunefield” (www.nps.gov/whsa/). Extensive research has been conducted on the hydrologic and aeolian processes shaping White Sands (e.g. Allmendinger, 1971; Schenk and Fryberger, 1988; Ghrefat et al., 2007; Kocurek et al., 2007; Langford et al., 2009; Szynkiewicz et al., 2010; Jerolmack et al., 2011). These investigations typically focus on the generation, saltation, and alteration of sand particles within the lake bed and dunefield, treating the

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escape of much smaller dust particles as minor leakage from the system of interest. White Sands' dust exports are harder to ignore in satellite imagery, where their distinctive whiteness can be easy to spot: Fig. 1 shows an example plume. The complex sedimentary environment of the White Sands places loose sand-sized sediments and finer-textured interdune and playa deposits adjacent to each other, facilitating dust generation through saltation and sandblasting-abrasion (Cahill et al., 1996). The alignment of prevailing springtime air flow with the orientation of the San Andres range creates a topographically-driven hydraulic enhancement of wind velocity in the Tularosa Basin, further enhancing dust emission (Novlan, 2011). White Sands has long been identified as a prototypical source and recurring "hotspot" of distinctive dust emissions (Savage, 1981; Breed and McCauley, 1986; Baddock et al., 2011).

The dominant springtime wind regime typically carries White Sands dusts over the Sacramento Mountains, to the White Mountain and/or Salt Creek Wilderness Areas to the north and east. A third Wilderness Area, Bosque del Apache to the north and west, is usually windward of the San Andreas Mountains and outside the White Sands plume. Atmospheric visibility is explicitly protected at all three of these "Mandatory Class I Federal Areas" (www.epa.gov/visibility/class1.html), so visibility-reducing fine particles are monitored at each as part of the Interagency Monitoring of PROtected Visual Environments (IMPROVE) program (http://vista.cira.colostate.edu/improve). The stars in Fig. 1 indicate the three sampler locations, and the star colors will distinguish the data from different samplers in subsequent plots. References to "background" (Bosque del Apache) and "downwind" (White Mountain and Salt Creek) measurements will be understood to assume a prevailing airflow similar to that in Fig. 1.

2. IMPROVE measurements

The IMPROVE monitoring program is described by Hand et al. (2011, Chapter 1). Standard operating procedures and details of quality assurance are collected at http://vista.cira.colostate.edu/improve/, and the precision of collocated measurements has been characterized by Hyslop and White (2008, 2009, 2011). Detailed site descriptions are available at http://views.cira.colostate.edu/web/SiteBrowser, and all ambient concentration data in this paper were downloaded from the public-access server at http://views.cira.colostate.edu/fed/DataWizard.

IMPROVE grew over time from a network of 36 sampling locations in early 1991 (Malm et al., 1994) to its current configuration of about 170. The three stations in Fig. 1 were installed during the years 2000–2001, and all were operating routinely by the start of 2002 (Fig. 2). Measurements are based on 24-h filter samples collected every third day (http://www.epa.gov/ttn/amtic/calendar.html). (The visible plume in Fig. 1 was imaged on one of the two-in-every-three idle days.) All sites report the same suite of measurements with the same sampling and analysis methods.

Each IMPROVE site employs four parallel sampling trains to collect particles for different measurements. Samples of fine particulate matter ($PM_{2.5}$, D_{aero} < 2.5 μm) are collected on three different filter media, and PM_{10} (D_{aero} < 10 μm) is collected on a fourth filter. $PM_{2.5}$ samples on appropriate media are analyzed for mass by weighing, elements by energy-dispersive X-ray fluorescence (XRF), anions by ion chromatography of deionized water extracts, and carbon by thermal–optical analysis; the PM_{10} sample is weighed, normally without any chemical analysis. The mass and elemental data are from samples collected on 25 mm PTFE membrane filters at 22.8 lpm, all analyzed by Crocker Nuclear Laboratory at the University of California, Davis. Elemental analysis through the 2010 sample year was performed on lab-built custom XRF systems whose multi-year consistency was characterized by Hyslop et al. (2012). Samples from 2011 and subsequent years were analyzed on commercial Epsilon-5 XRF systems from

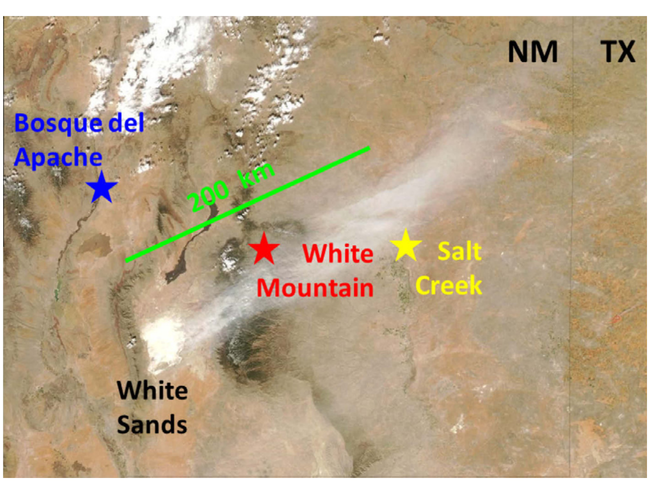

Fig. 1. A dust plume from White Sands blows north-eastward toward the New Mexico–Texas border. NASA's MODIS Aqua captured this natural-color image on February 28, 2012 (http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=77294). The green distance scale is aligned with the mean sand-transport vector calculated from 1964–2008 wind data by Jerolmack et al. (2011). The white patches to the north are clouds. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

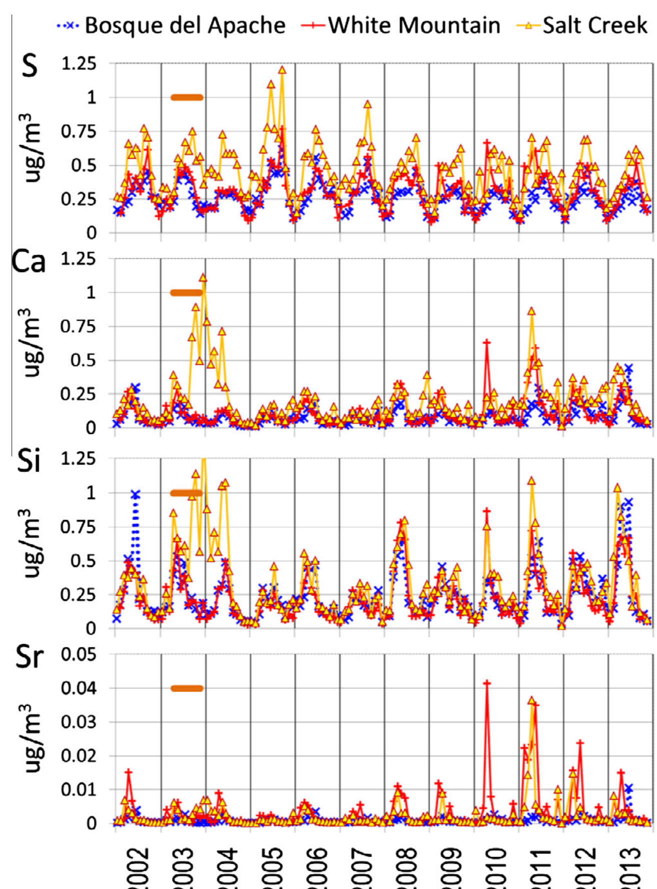

Fig. 2. Monthly mean concentrations of fine particulate matter (D_{aero} < 2.5 μm) at the three sampling sites in Fig. 1. Months with fewer than six valid samples at a site are not plotted. A period of levee construction near the Salt Creek sampler is indicated by a horizontal bar; contemporary field notes associated the 2003 onset of unusual dust levels at Salt Creek with the start of this local activity.

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