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Concentrations of mineral aerosol from desert to plains across the central Rocky Mountains, western United States

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ABSTRACT

Mineral dusts can have profound effects on climate, clouds, ecosystem processes, and human health. Because regional dust emission and deposition in western North America are not well understood, measurements of total suspended particulate (TSP) from 2011 to 2013 were made along a 500-km transect of five remote sites in Utah and Colorado, USA. The TSP concentrations in $\mu g\ m^{-3}$ adjusted to a 24-h period were relatively high at the two westernmost, dryland sites at Canyonlands National Park (mean = 135) and at Mesa Verde National Park (mean = 99), as well as at the easternmost site on the Great Plains (mean = 143). The TSP concentrations at the two intervening montane sites were less, with more loading on the western slope of the Rocky Mountains (Telluride, mean = 68) closest to the desert sites compared with the site on the eastern slope (Niwot Ridge, mean = 58). Dust concentrations were commonly highest during late winter-late spring, when Pacific frontal storms are the dominant causes of regional wind. Low concentrations (<7 wt%) of organic matter indicated that rock-derived mineral particles composed most TSP. Most TSP mass was carried by particle sizes larger than 10 μm ($PM_{>10}$), as revealed by relatively low average daily concentrations of fine (<5 $\mu g\ m^{-3}$; $PM_{2.5}$) and coarse (<10 $\mu g\ m^{-3}$; $PM_{2.5-10}$) fractions monitored at or near four sites. Standard air-quality measurements for $PM_{2.5}$ and PM_{10} apparently do not capture the large majority of mineral-particulate pollution in the remote western interior U.S.

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1. Introduction

Deserts produce massive quantities of mineral aerosols with implications for air quality, human health, biogeochemistry, and climate. At a global scale, the large deserts of Asia and Africa dominate dust production and generate aerosols that are frequently transported over thousands of kilometers. Over these long transport distances, dusts are generally in the PM_{10} (particulate matter less than 10 μm in aerodynamic diameter) size class (Pye, 1987; VanCuren and Cahill, 2002; Goudie and Middleton, 2006; Mahowald et al., 2013; Menéndez et al., 2014). Particles in this size class can remain suspended in the atmosphere for many days. At a more local scale, strong winds can create large dust clouds that can temporarily diminish visibility and air quality. When these local events occur, they are intense but are often restricted to small areas close to (<100 km) large dust sources. In this study, we focus on dust transport at an intermediate, regional spatial scale of about 100 km to about 1,000 km that lies between local and the global scales. This spatial scale is critical to understand because many population centers lie on the margins of deserts and because large amounts of dust can be transported over these intermediate distances with effects on air quality, human health, and biogeochemistry that are unique to this regional scale. Moreover, such regional dust-transport events are rarely documented, and their dusts include particle-size classes that are not commonly captured by the air quality/particulate monitoring techniques used in most economically developed nations (but see Knight et al., 1995; Chan et al., 2005; McTainsh et al., 2005; Shao et al., 2007; Leys et al., 2011, as examples of regional dust studies in Australia).

Atmospheric particulate monitoring generally focuses on small particles less than 2.5 μm in diameter ($PM_{2.5}$) and on the slightly larger PM_{10}. We previously showed that the $PM_{2.5}$ and PM_{10} particle-size classes composed only a small amount of the total suspended particulate (TSP) concentrations in desert settings on

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the Colorado Plateau (southeastern Utah and southwestern Colorado) (Neff et al., 2013). This finding is not surprising in deserts where local wind erosion mobilizes large amounts of particles in the range of medium to coarse silt, approximately 20–60 μm (Pye, 1987). This result suggests the possibility of broad regional transport of dust particles that are too large to be detected by protocols of $PM_{2.5}$ or PM_{10} sampling but small enough to be carried for hundreds of kilometers. To further suggest such a possibility, studies of dust deposition to snow cover in the San Juan Mountains, several hundred kilometers downwind from desert dust sources, including those on the Colorado Plateau, indicated that western U.S. desert dusts with a median size of ~40 μm in diameter can be mobilized and transported high into the Rocky Mountains (Lawrence et al., 2010). These observations are further complemented by an expanding body of literature showing that desert-derived particulate matter is routinely deposited to high-elevation soil and lake sediments (Neff et al., 2008; Reynolds et al., 2010; Lawrence et al., 2010, 2013; Ballantyne et al., 2011; Brahney et al., 2014; Routson et al., 2016) at sites in Colorado and Wyoming, USA. Such dust deposition is relevant because of its role in the biogeochemical cycles of high-elevation ecosystems (e.g., Lawrence et al., 2013; Brahney et al., 2014) and because dust on snow cover adversely affects water resources by accelerating melting of snow in downwind mountain ranges (Painter et al., 2010, 2012; Skiles et al., 2012, 2015).

The evidence for transport and deposition of desert dust into mountain regions of the western interior U.S. raises a number of questions about regional dust. These questions include the key issue of how far might large (defined here as greater than 10 μm in diameter) dust particles dominate regional mineral aerosol transport? For example, are large particles routinely transported from the deserts of the western U.S. into and across the Rocky Mountains, and can such particles reach the heavily urbanized areas on the eastern edge of these mountains such as the Colorado Front Range? If such particles are an important part of regional mineral aerosol concentrations, then what implications do they have for air quality, human health, cloud formation and precipitation, as well as ecological/biogeochemical processes and effects?

Our primary purpose herein is to report on concentrations of TSP at five sites from the Colorado Plateau desert to the Great Plains in northeastern Colorado across the central Rocky Mountains, (Fig. 1) and to assess some causes, primarily seasonality of winds, for observed variability in these concentrations. This study, focusing on TSP deposition mainly during 2011 to early 2013, expands temporally and spatially a study by Neff et al. (2013) who measured TSP deposition during 2008–2011 at two dryland sites on the Colorado Plateau. At four of the sites in the current investigation, the TSP concentrations were compared to concentrations of PM_{10} and $PM_{2.5}$ along with the derived difference between these measures, $PM_{2.5-10}$ (coarse PM) and particles larger than PM_{10} (denoted as $PM_{>10}$). By comparing concentrations of TSP, $PM_{2.5-10}$, and $PM_{2.5}$, we evaluate the efficacy of PM_{10} and $PM_{2.5}$ monitoring for particulate air pollution in part of the western interior United States. We complemented concentration measurements with particle-size distributions in samples from dust-on-snow collections in 2013 across much of the Rocky Mountain portion of the study area. These collections represent regional dust that is transported mainly between the Colorado Plateau and Great Plains during the late winter-spring period of high dust activity. These results help document how particle sizes change with roughly estimated distances from source regions.

2. Materials and methods

2.1. Study sites

The TSP sites span 505 km from the Colorado Plateau in Utah on the west to the Great Plains in Colorado on the east (Fig. 1; Table 1).

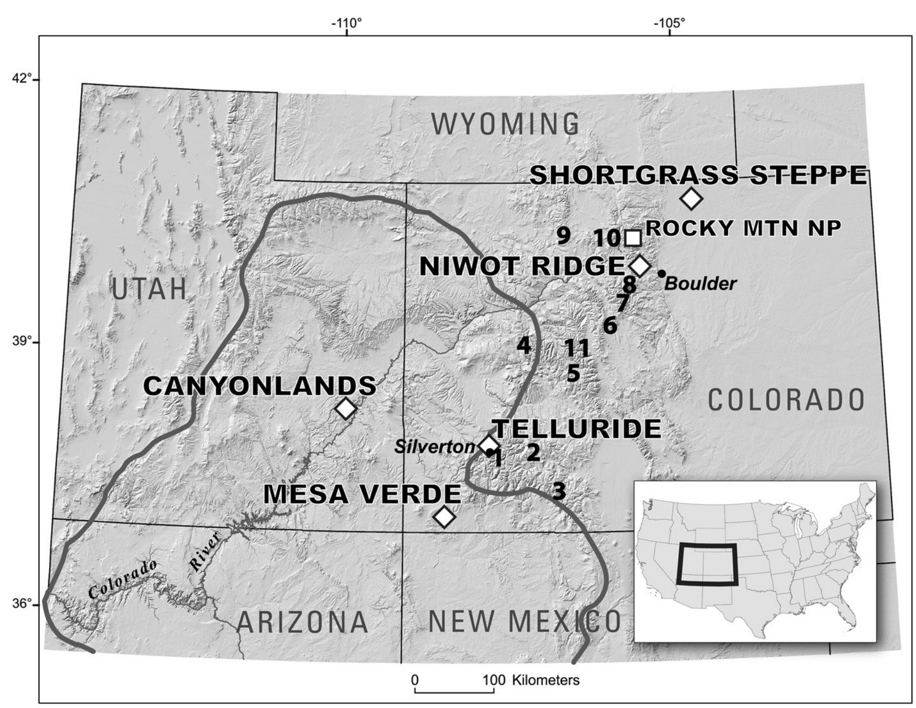

Fig. 1. Map showing locations of TSP sampling sites (open diamonds) and dust-on-snow (DOS) sampling sites (numbers) across Utah and Colorado, USA, and outline of the Colorado Plateau (solid gray line). Open square denotes location of PM_{10} and $PM_{2.5}$ monitoring in Rocky Mountain National Park. Locations of PM_{10} and $PM_{2.5}$ monitoring for all other sites, except Shortgrass Steppe, were ⩽4 km from the associated TSP site. Locations of DOS sites are centered on the following: 1, Swamp Angel (SASP) near Silverton; 2, Spring Creek Pass; 3, Wolf Creek Pass; 4, McClure Pass; 5, Park Cone; 6, Hoosier Pass; 7, Grizzly Peak; 8, Berthoud summit; 9, Rabbit Ears Pass; 10, Willow Creek Pass; 11, Independence Pass; http://snowstudies.org/CODOS; accessed 18 April 2016).