Geomorphology 135 (2011) 21–34

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Quantifying dust emissions from desert landforms, eastern Mojave Desert, USA

Mark R. Sweeney [a,*], Eric V. McDonald [b], Vicken Etyemezian [c]

[a] University of South Dakota, Earth Sciences, 414 E. Clark St., Vermillion, SD 57069, United States
[b] Desert Research Institute, Division of Earth and Ecosystem Sciences, 2215 Raggio Parkway, Reno, NV 89512, United States
[c] Desert Research Institute, Division of Atmospheric Sciences, 755 East Flamingo Rd, Las Vegas, NV 89119-7363, United States

ARTICLE INFO

Article history:
Received 22 October 2010
Received in revised form 14 July 2011
Accepted 15 July 2011
Available online 6 August 2011

Keywords:
Dust
Mojave Desert
Landforms
PI-SWERL

ABSTRACT

The measurement of natural dust emissions from desert landforms is crucial in environmental hazard assessment and field checking the accuracy of global dust models. More than 500 individual dust measurements from eight common desert landforms in southern California were collected using the PI-SWERL (Portable In Situ Wind Erosion Lab). The largest emitters of dust are dry washes (13.787 to 0.007 mg m^{-2} s^{-1}), dunes, playa margins, distal alluvial fans, and lacustrine beaches. Low emitters include salt-crusted playas (0.692 to 0.002 mg m^{-2} s^{-1}), silt–clay-crusted playas, and desert pavements. High emissions are a function of saltating sand that bombards the surface, liberating dust-sized particles for entrainment. Low dust emissions are primarily a function of surface crusting, gravel armoring, and vegetation density. PI-SWERL measurements reveal that emission rates can vary by at least three orders of magnitude, reflecting local variability in soil texture and continuity of surface crusts. Shear-stress partitioning models can be applied to dust data measured by the PI-SWERL to account for large surface roughness features, such as vegetation. The results presented here give an approximation of the contributions to atmospheric dust loading by landforms in the Mojave Desert, and can potentially be used to improve atmospheric dust models.

1. Introduction

The impact of atmospheric dust on the environment is important because it affects human health and visibility at the local scale (Watson, 2002; Goudie and Middleton, 2006) and contributes to the radiative forcing of climate at the global scale (Tegen et al., 1996; Harrison et al., 2001; Mahowald et al., 2006). In addition, dust that has accumulated on the surface plays an important role in biogeochemical cycles (Harrison et al., 2001; Okin et al., 2004; Neff et al., 2008) and in the evolution of landscapes, soil properties and hydrology (McFadden et al., 1987; Wells et al., 1987; Young et al., 2004). Identifying natural sources of dust and quantifying the magnitudes of dust production from landforms are therefore important in order to assess the potential environmental impacts of dust.

Deserts are the largest dust-producing regions and contain a variety of landforms with the propensity to emit dust. Dry lake beds have been emphasized as the primary dust sources in global dust models (Tegen et al., 2002; Tegen, 2003), and have been identified as the largest point sources of dust in the world (Cahill et al., 1996; Prospero et al., 2002; Mahowald et al., 2003; Washington et al., 2006). Dry lake beds, however, account for approximately 1% of most global desert terrains (Thomas, 2000). Other desert landforms, such as ephemeral washes and distal alluvial fans, cover far more area than dry lake beds and are important sources of dust as well (Gillette et al., 1980; Reheis and Kihl, 1995; Prospero et al., 2002; Goudie and Middleton, 2006).

One of the largest data gaps identified by the dust modeling community is the lack of dust emission measurements and the contribution and natural variability of dust emissions from landforms (Zender et al., 2004; Kohfeld et al., 2005). The IPCC cites a low level of understanding with regards to how aerosol loading will affect future climates (IPCC, 2007). In order to accurately forecast climate perturbations associated with atmospheric dust loading, a better understanding of natural dust emission potential from landforms at the local scale is needed (Kohfeld et al., 2005). Estimates of atmospheric dust loading vary by a factor of two or more because detailed field information regarding soil properties, surface roughness, and wind events are lacking, resulting in large uncertainty when trying to understand and model the climatic effect of dust (Tegen, 2003; Zender et al., 2004). Remote sensing techniques using the Total Ozone Mapping Spectrometer (TOMS) and the Moderate Resolution Imaging Spectroradiometer (MODIS) have been used to help identify regional dust sources and to estimate the amount of dust loading in the atmosphere, but results can be negatively affected by cloud cover, presence of other aerosols such as black carbon, reflective surfaces, image processing issues, and low spatial resolution (Prospero, et al., 2002; Mahowald et al., 2003; Tegen, 2003; Goudie and Middleton, 2006; Baddock et al., 2009). Other researchers have estimated potential dust loading by considering an erodibility index, soil texture, precipitation, and evaporation (Dong et al., 2000; Xuan et al., 2000,

---

* Corresponding author. Tel.: +1 605 677 6142; fax: +1 605 677 6121.
E-mail addresses: mark.sweeney@usd.edu (M.R. Sweeney), Eric.McDonald@dri.edu (E.V. McDonald), vic@dri.edu (V. Etyemezian).

0169-555X/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.geomorph.2011.07.022

2004). Direct measurement of dust fluxes from landforms can fill gaps and help to more accurately determine dust loading.

Previous field-based studies of dust emissions from desert environments have utilized different types of dust traps (e.g., Nickling and Gillies, 1993; Reheis and Kihl, 1995; Wang et al., 2004) and wind tunnels (Gillette et al., 1980, 1982; Nickling and Gillies, 1989). While these field-based studies have been informative, they lack the spatial resolution necessary to capture the heterogeneity of dust emissions from desert landforms. Dust traps are fixed and are an indirect indicator of source area. Large field wind tunnels can collect direct information about dust emissions from discrete landforms, but because of their size they are limited by the terrain, the number of measurements, and cost.

This study implements innovative wind-tunnel technology, the PI-SWERL (Portable In Situ Wind Erosion Lab; Etyemezian et al., 2007), to measure PM-10 (particulate matter less than 10 μm) as a means to judge emission potential of dust from desert landforms. This study provides one of the most comprehensive and unique data sets of dust flux data from a large suite of desert landforms that will help to address: 1) the potential of desert landforms to emit dust, 2) the spatial heterogeneity of dust emissions from individual landforms, and 3) an estimate of dust emissions from landforms that will be useful in understanding the contribution of desert sources to atmospheric dust loading. A total of 531 individual PI-SWERL measurements were collected from eight distinct landforms in southern California, with the bulk of the measurements taken in the Mojave Desert of southwestern USA (Figs. 1 and 2). The Mojave Desert, while not a major global dust producer today (Bach et al., 1996; Tanaka and Chiba, 2006), has been extensively studied and is a starting point for understanding how dust emissions vary within and between landforms.

1.1. Controls on dust emissions

Dust particles are entrained and emitted from surfaces when a critical threshold friction velocity is met by the wind and is often assisted by the impacts of saltating particles (Bagnold, 1941; Shao et al., 1993; Rice et al., 1997). Factors that affect the threshold friction velocity of wind required to entrain particles primarily include soil moisture, surface roughness, vegetation cover, and degree of surface crusting.

Soil moisture increases the threshold friction velocity of soil (Chepil, 1956; McKenna Neuman and Nickling, 1989; Saleh and Fryrear, 1995). The capillary effect of soil moisture causes particles to bind together (McKenna Neuman and Nickling, 1989), shutting down eolian transport when soil moisture typically exceeds 4% by weight (Bisal and Hsieh, 1966). Recent studies have shown that atmospheric relative humidity also increases the threshold friction velocity of soil (Ravi and D'Odorico, 2005).

Surface roughness, characterized by the aerodynamic roughness length (z_0), also influences soil erosion by wind. Surfaces that are rough, containing vegetation, rocks, or microtopography, increase the threshold friction velocity by baffling wind energy close to the soil surface (Raupach et al., 1993). Values of z_0 greater than 0.001 m can dramatically subdue dust emissions (Gillette, 1999). Vegetation cover

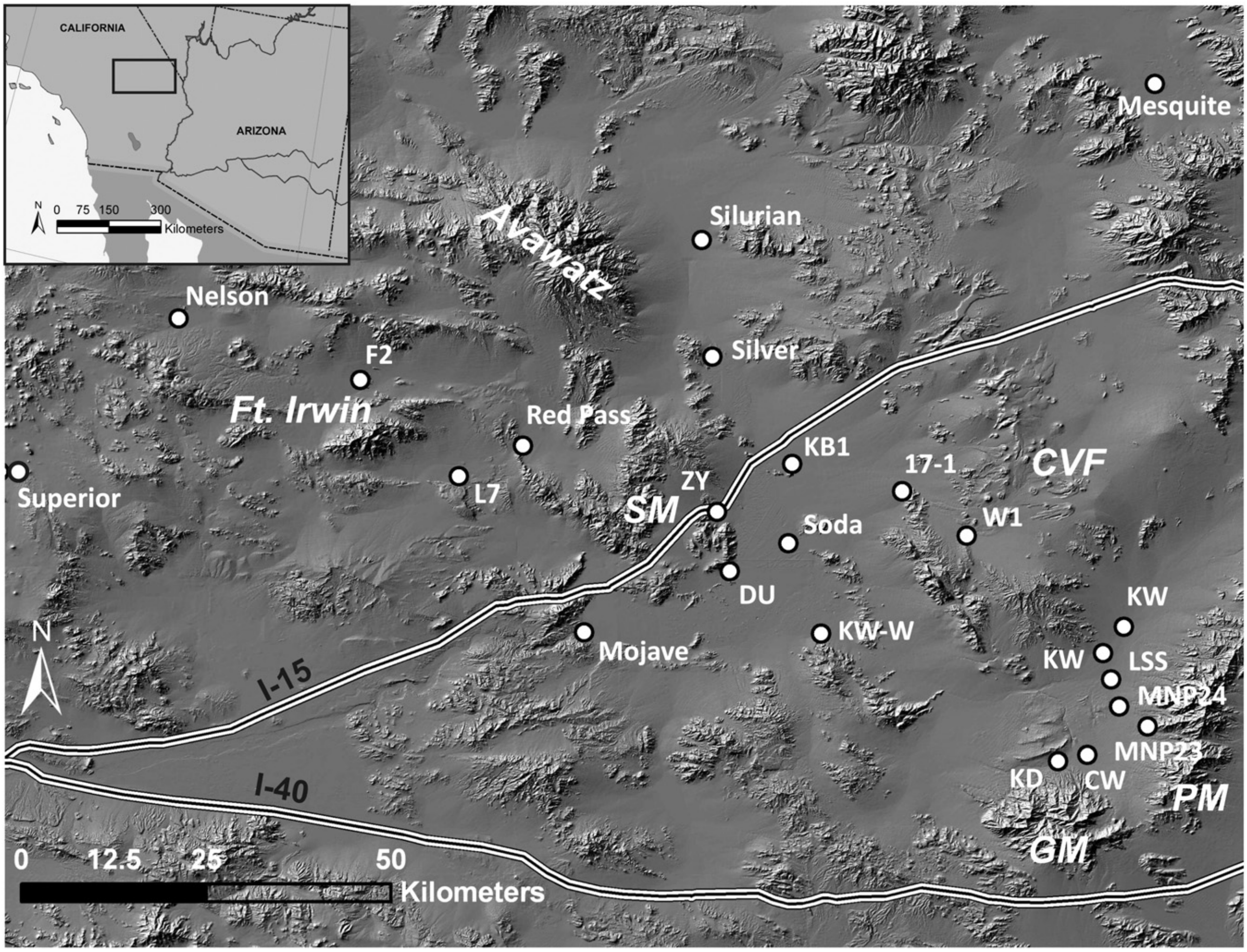

Fig. 1. Location map of selected PI-SWERL testing sites in the Mojave Desert. *CVF* = Cima volcanic field, *GM* = Granite Mountains, *PM* = Providence Mountains, *SM* = Soda Mountains. See Appendix A for all locations.