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Suspended dust particle characteristics during an sandstorm on 29 February 2008 in Minqin area, China

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ABSTRACT

Aeolian dust is one of the main aerosols in the troposphere, and plays an important role in the Earth's climate system. In this study, detailed meteorological conditions and dust particle diameters were measured at three sites with different landscape characteristics in the Minqin oasis area of northwest China, on 29 February 2008. We show that as dust storms progressed through the desert into the oasis, variation in the character of the underlying land surface not only influenced the wind profile by modifying the frictional velocity of air (U_*), aerodynamic roughness length (Z_0), horizontal sediment flux, and dust concentration of the near surface sublayer (1–49 m), but it also changed the vertical structure of the aeolian sediment transport pattern. The particle size frequency distributions at three distinct sites were all unimodal, comprising a large number of aeolian dust particles with sizes less than 63 μm (more than 65%). During transport, dust particle populations shifted to smaller sizes. Clearly, the influence of landform, windbreaks, and vegetation cover on horizontal sand-dust flux decreased with height as well as increasing particle size, with smaller aeolian particles being more easily captured by windbreaks, and vegetation.

1. Introduction

Aeolian dust is one of the main aerosols in the troposphere, and plays an important role in the Earth's climate system. It has generated much concern over past decades because of its effects on air quality, global biogeochemical cycles, the radiative balance of the atmosphere, as well as Asian monsoon and climate changes (Han et al., 2004; Duce, 1995; Zhang et al., 1998; Sokolik et al., 1998). According to the Intergovernmental Panel for Climate Change, the uncertainty in aerosol radiative forcing is among the largest on the climate system (IPCC Fourth Assessment Report, 2007).

Aeolian dust is carried by wind from the source region as a suspended load, before being deposited back to the surface as wind dynamics change or diminish. During gales, the horizontal sand-dust flux, dust concentration, and particle size vary at different heights and change over the process of atmospheric transport, resulting in huge variability across regions. Chen and Fryrear (2002) collected dust samples from within the 0–15.67 m-zone of a sandstorm and found that concentrations of suspended dust decreased as a power function of height. The vertical distributions of dust particles were unimodal, with a peak diameter of 40 μm in the 550-cm flow layer, while above this layer, their peak diameter was 20 μm (Chen and Fryrear, 2002). Gillies et al. (1996) monitored an intense dust plume in the Inland Delta region of Mali; they found that the particle size distribution of aeolian dust was unimodal, with a mean of 3 μm at a height of 10 m.

The energy of aeolian dust as it moves through the air is acted on by two opposing forces: the force of gravity, and internal resistance of the air (Bagnold, 1941). The effect of these two forces are dependent on the diameter of aeolian dust and wind speed (Phillips, 1980; Huang et al., 2006; Tong and Huang, 2012). Thus, particle size characteristics have a profound influence on the aeolian dust's residence time in the atmosphere (Han et al., 2004). During transport, the larger particles (with diameter, d > 30 μm) usually travel a shorter distance and are deposited closer to their source region. In contrast, finer particles (d < 10 μm) float in the air for longer, sometimes being transported over thousands of kilometers (Shao, 2008). For this reason, particle size parameters form the basis of many schemes for classifying sedimentary environments because they reflect the fluidity and energy regimes of the

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depositing media during deposition (Alsharhan and El-Sammak, 2004; Sahu, 1964). Gillette (1974) suggested that sedimentation velocities of particles smaller than 0.02 mm are usually less than 0.1 U_*; hence, for almost all eroding wind conditions they will remain in suspension for great distances and to great heights.

Deserts and desertified lands in arid to semi-arid regions of China are currently considered to be the main sources of Asian dust. In particular, the Hexi Corridor located in northwest China is an important dust source region, where dust transport occurs as a result of the area's "funneling effect" which is form by the mountains on the north (BeiShan) and south (Qilian mountain and A-erh-chin Mountains) and vast expanses of deserts and desertified lands (Dong et al., 2010). The Minqin area in the eastern part of the Hexi Corridor is the source area for many Chinese dust storms (Youngsin et al., 2001; Liu et al., 2004). Meteorological records (from 1952 to 2000) reveal that the Minqin area has a frequency of severe sand and dust storms that is higher than in any other area of China (Qian et al., 2002). The dust raised by wind from this area usually sweeps across North China and much of East China, transporting it thousands of kilometers, before depositing it in the North Pacific Ocean.

To study changes in the vertical distribution of the horizontal sand-dust flux, dust concentration, and particle-size characteristics of aeolian dust transported from the Minqin area, we set up three monitoring sites. These sites had various land surfaces, with different vegetation characteristics, representing a transition from desert to oasis. We documented dust and meteorological parameters during the sandstorm's progress across our sites using three towers of 50-m height. We carried out a statistical analysis of particle size distributions along our downwind trajectory to determine the effect of landscape characteristics on aeolian transport during sandstorms.

2. Methods

2.1. Experimental method

Three observation towers (50 m in height) were constructed at three sites along the prevailing wind direction in the Minqin area of Gansu Province, China. These sites represent desert, the edge of the oasis, and oasis, respectively. The sites define a downwind trajectory for dust transport (Figs. 1 and 2), as sandstorms pass through the desert and into the oasis. The distances between the desert and the edge of the oasis, and the edge of the oasis and the oasis are 4.8 km and 3.5 km. At each tower, wind velocity and horizontal sand-dust flux were observed at 13 different heights (i.e., 1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, and 49 m above the ground). Three-cup anemometers (DES1, Changchun, China) and a horizontal sand dust flux sampler systems were used for wind velocity measurement and sand dust collection, respectively. The horizontal sand dust flux sampler (Fig. 3) was developed by the Gansu Desert Control Research Institute, which had a 30 mm diameter sampler nozzle designed to self-orient and always face into the wind, an outlet in a bag sealed with a microporous membrane, and the area of the filter bags/area of sampler nozzle ratio of 60:1. The sample efficiency is more than 93% when the diameter of sample particle is within 3–100 um (Zhao et al., 2011).

The samples collected by the vertical array of horizontal sand dust flux samplers were oven dried at 85 °C for 24 h and weighed using an electronic balance. Horizontal sand-dust flux at a given height was calculated using Eq. (1); while dust concentration was calculated using horizontal sand-dust flux and wind velocity in Eq. (2). Particle sizes were measured using a Mastersizer 2000 (Malvern Instrument Co., Ltd, UK). Wind velocity was measured using three-cup anemometers every 5 min. Mean values were used to obtain wind velocity profiles. Frictional velocity (u_*) and roughness length (z_0) were calculated using the Prandtl Eq. (3):

$$F_{(z)} = Q_{(z)}/TA, \tag{1}$$

$$C_{(z)} = (Q_{(z)} * 1000)/(U_{(z)}TA), \tag{2}$$

$$U_{(z)} = (U_*/k)\ln(Z - D/Z_0), \tag{3}$$

where $F_{(z)}$ is the horizontal sand-dust flux at height z ($gm^{-2}\,h^{-1}$); $Q_{(z)}$ is the total dust quantities measured by samplers at height z (g); T is the duration of sampling (h); A is the intake area of the samplers (m^2); $C_{(z)}$ is the concentration at height x ($mg\,m^{-3}$); $U_{(z)}$ is the mean wind velocity at height z (ms^{-1}); U_* is the frictional velocity (ms^{-1}); k is Karman's constant, equal to 0.4 in this case; Z_0 is the aerodynamic roughness length (mm); and D is the zero-

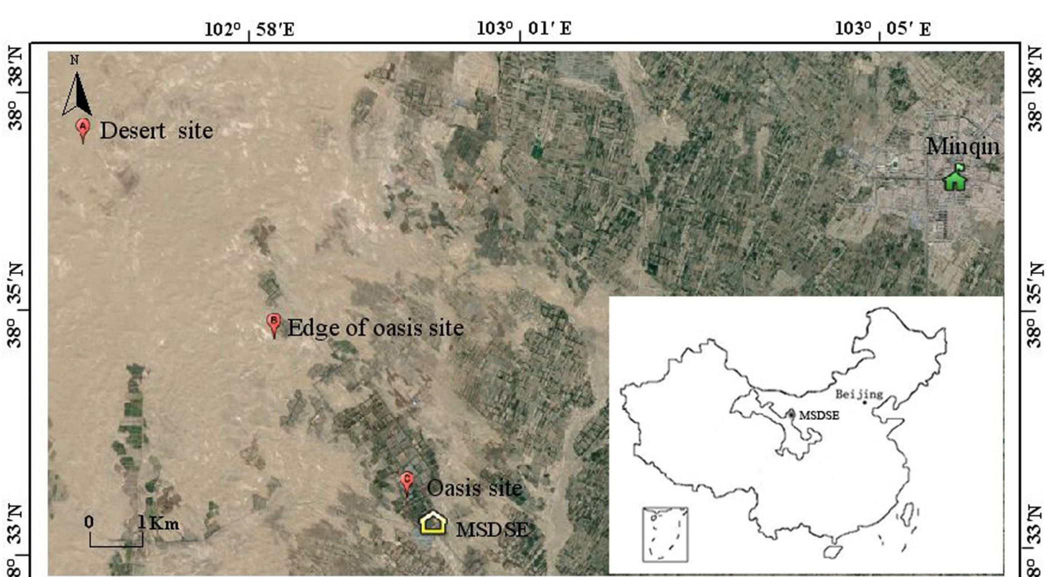

Fig. 1. Location of the Minqin study area in northwest China, showing the position of the three sandstorm observation towers.