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Variation with height of aeolian mass flux density and grain size distribution over natural surface covered with coarse grains: A mobile wind tunnel study

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ABSTRACT

The vertical distributions of aeolian mass flux density and grain size with height over the natural surface covered with coarse grains were investigated using a mobile wind tunnel in the Yardang Geological Park, Dunhuang, China. Results reveal that the mass flux density of mix-sized sediments decays exponentially with increasing height. However, the mass flux density profiles of separate grain-size groups depend on size grading: those of coarse sand groups (0.8–2.0 mm) can be described by exponential decay functions while those of fine sand groups (0.063–0.8 mm) can be expressed by Gaussian distribution functions. Therefore, the mass flux density profile of mix-sized saltating particles is a superposition of many different profiles. In addition, results of grain-size analysis show that the size distribution of eroded sediments close to the ground reflects that of the loose material in the parent soil. The mean grain size first deceases remarkably with increasing height in the near-surface region, this trend is reversed at heights of 60–80 or 120–140 mm above the bed and then there is a coarsening trend of mean size with height. Sorting only improves with height in the region above 80 or 100 mm, but it declines in the near-bed region. These experimental data are significant for studies of heterogeneous saltation and numerical modeling of grain trajectories.

1. Introduction

Aeolian transport is an important geomorphologic process operating in arid regions (Nickling and Neuman, 2009). Aeolian transport contains various transport modes, and saltation is the most important one (Bagnold, 1941). Saltation in nature is heterogeneous: saltating particles differ in size, follow different trajectories and respond differently to turbulence (Shao and Mikami, 2005). The mass flux density profile of saltating sands is a macroscopical representation of the microcosmic saltating sand movement, and thus it is significant for understanding the microscopic process of heterogeneous saltation (Li et al., 2008). For saltation of mix-sized particles, Shao (2005) proposed a similarity theory and revealed that the saltation mass flux density profile was a weighted superposition of many profiles differing for different particle sizes. A great deal of research has been performed to measure the mass flux of sediments transported by wind at different elevations above the bed and thus to define the mass flux density profile of mix-sized sediments (e.g., Butterfield, 1999; Namikas, 2003). However, relatively little attention has been given to grain-size characteristics of wind-transported sediments and the saltation mass flux density profile of particles in terms of a given size grading. Therefore, there is a lack of adequate experimental data to support this similarity theory. The coarsest fraction of a grain-size population in aeolian saltation flux research is mainly with the largest grains of 1 mm, and thus the study on characteristics of the saltation flux and grain-size distributions over flat natural surfaces with very coarse sand particles (e.g., 1–2 mm) is rarely reported.

In this study, we conducted field wind tunnel tests on variations with height of aeolian mass flux density and grain-size distribution over the natural flat surface covered with coarse grains (1–4 mm). The objectives of this research are (1) to determine the mass flux density profiles of different size grading; (2) to investigate characteristics of the variation of grain-size distribution with height; (3) to provide experimental data for aeolian transport models at levels of grains and grain trajectories.

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2. Material and method

The study site is located in the central part of the Yardang Geological Park (40.51°N, 93.07°E) (Fig. 1). The Yardang Geological Park, covering an area of 100 km^2, is located in the northeast of the Kumtagh Desert, China, where the most typical yardangs have developed (Dong et al., 2012). The study natural surface, mainly covered with very coarse sand (1–2 mm), consists of particles ranging from very fine sand to granular gravel (mean grain size, 0.87 mm) (Table 1).

The experiment was carried out in a mobile wind tunnel (Fig. 2). This wind tunnel, made of hard aluminum alloy panels, has a total length of 11.4 m and a 6.0-m-long working section with a cross-sectional area 0.6 m × 0.6 m. The power is offered by a gasoline engine with output power 13 kilowatt, and the centerline wind speed can be changed continuously from 0 to 16 m s^{-1}. The axial pressure of the working section is almost constant and the wind tunnel walls have minimal influence on the wind field, so the airflow in the working section is assumed to the characteristics of airflow near the earth's surface. The depth of the boundary layer in the wind tunnel is about 0.2 m.

Experimental wind velocities were 12, 14 and 16 m s^{-1} measured by a Pitot-static probe placed in the centre of the wind tunnel at the height of 300 mm above the ground, and a wind profiler was placed at 0.6 m from the downwind edge of the study bed to measure the centerline wind velocity at heights of 5, 9, 15, 22, 43, 83, 163 and 202 mm. The experimental periods, decreasing with the increase of the experimental wind velocity, were 600, 180 and 60 s, respectively. When one run of wind tunnel tests was finished, the wind tunnel was moved for next run based on the access for the tunnel and minimal disturbance to the study surface. Measurements of the mass flux density profile were performed using a vertical passive sand trap 0.6 m in height (Fig. 3). This sand trap consists of a stainless casing with a total length of 850 mm and can be pushed into the sand 250 mm deep to support it. The total thickness of the trap is designed to be 32 mm so that it has no significant disturbance on the airflow while maintaining enough sampling volume of the sand chambers. The trap has 30 nozzle orifices connecting to 30 sand chambers. Each orifice is 20 mm high and 20 mm wide. The size of the sand chamber is 150 × 28 × 12 mm and all the chambers are fixed by a side removable cover. Each chamber is vented and there are also venting holes (6 mm in diameter) covered with the same fine stainless steel wire mesh (62.5 μm openings and 60% porosity) in the removable cover at the back of the trap. The main role of the vent is to reduce the positive stagnation at the inlet at low velocities, allow relatively unimpeded air flow through it and weaken the flow separation to each side of the trap. This design helps to ensure the isokinetic sampling which is considered as a desirable property for any sampler (Shao et al., 1993; Nickling and McKenna Neuman, 1997). This sand trap is a similar design of the WITSEG sampler with sampling efficiency ranging from 0.87 to 0.96 differing for wind speeds and an average value of 0.91 (Dong et al., 2004a). The sand trap was laid about 0.6 m from the downwind edge of the working surface. Sand samples collected at the trap chambers were weighed with an accuracy of 0.001 g and then each sample at wind speeds of 14 and 16 m s^{-1} was sieved at 1/3ϕ interval using a standard vibrating sieve shaker. When the experimental wind speed was low, it was difficult to trap sufficient sands for sieving to obtain accurate results, and thus sand samples at the two highest wind speeds were selected for grain-size analysis. Grain size parameters were determined using the logarithmic method of moments in GRADISTAT software (Blott and Pye, 2001).

3. Results and discussion

3.1. The mass flux profile

Fig. 4 shows the total mass flux density profiles at all the tested wind speeds. Regression analysis shows that under all the tested wind speeds, the total mass flux density of mix-sized sediments decreases exponentially with height:

$$q_z = A\exp(Bz) \quad (1)$$

where q_z is the total mass flux density at height z, in kg m^{-2} s^{-1}, z is height, in mm, A and B are regression coefficients. Table 2 indicates that the correlation between the total mass flux density and height is reasonably good. The correlation coefficient R is over 0.96.

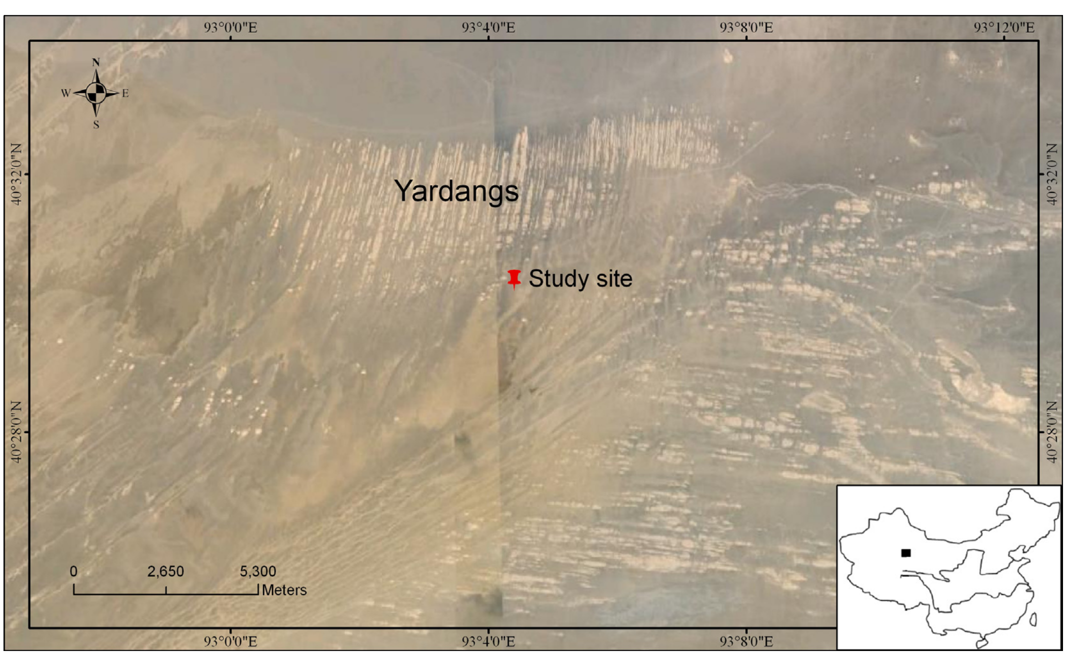

Fig. 1. Location map (data from Google Earth) for the study site in the Yardang Geological Park.

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