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Review

Wind erosion mass variability with sand bed in a wind tunnel

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ABSTRACT

Sand bed length is an important parameter that affects soil wind erosion. Although there has been a series of studies about the effect of sand bed length on wind erosion rate, many discrepancies have been found on how to express the change of wind erosion rate along bed length. To explore these discrepancies, a Trimble CX 3D laser scanner was used to continuously scan for changes in a sand bed at three friction velocities with four durations and the wind erosion mass was measured by weighing bed sediments before and after each experiment at four friction velocities with different durations in a wind tunnel. The results showed: (1) The bed form consisted of three zones, a pre-bowl zone, a bowl zone and a post-bowl zone, respectively at friction velocities of 0.35 and 0.41 m/s or two zones with the pre-bowl zone missing at high friction velocity of 0.47 m/s. The length of the pre-bowl change zone decreased with wind velocity and was independent of time; the length of the bowl zone decreased with wind velocity and increased with time; the length of the post-bowl zone occupied over 70% of the bed characterized by regular ripples with wavelengths and heights increasing with wind velocity and run duration. (2) The wave length and height of sand ripples increased with friction velocity and time. The frequency distribution of wave lengths followed$f(x) = ae^{-(\ln(x/b))^2/2c^2}$, (a, b and c are the fitting coefficients); while we did not find a uniform function to characterize frequency distribution of wave height. 3) Wind erosion rate along the sand bed could be described by $f(x)=f_{max}(1-exp^{-(x-x0)/b})+f_0$, where f_{max} is the wind erosion rate at the dynamic equilibrium stage, b is the corresponding sand bed where wind erosion rate is equal to 0.63 f_{max} and f_0 is the wind erosion rate for the sand bed between the initial bed position and above the first inflection point of wind erosion rate along the bed. These results can help to describe the effect of sand bed on soil wind erosion.

Contents

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1. Introduction

Sediment transport is an interactive process between airflow and the soil and is one of the world's major eco-environmental issues, particularly in arid and semiarid zones. Aeolian sand transport develops when sand particles are first driven by the airflow shear stress, move in the airflow and collide with other particles in bed, which results in other particles to depart from the bed or creep along the bed. Aeolian sand transport rate under steady wind increases with increasing bed length until to its dynamic equilibrium (Bagnold, 1941; Chepil and Milne, 1941; Chepil, 1946; Chepil et al., 1963; Woodruff and Sideways, 1965; Stout, 1990; Zou et al., 1994; Fryrear and Salen, 1996; Shao and Raupach, 1992; Gillette et al., 1996; Hersen et al., 2002; Dong et al., 2004; Elbelrhiti et al., 2005; Andreotti, 2004; Andreotti et al., 2010; Pähtz et al., 2013) and the corresponding upwind distance is called bed length. In nature, unsaturated aeolian sand clouds on vegetated patch surface, narrow beaches, or in the blowout are often observed because there is enough bed length. Therefore, sand bed length is an important parameter to model sediment transport. Bagnold (1941) first presented the concept of saturated length and discovered that the saturated length had a significant influence on the sediment transport, which was verified by later studies with wind tunnel experiments (Shao and Raupach, 1992; Dong et al., 2004) and field observations (Chepil and Milne, 1941; Chepil, 1946, 1950). Dong et al. (2004) reported that the wind erosion mass increased via a power function as the sand bed length increased. Based on the mass conservation equation applied to the sand bed under the action of the wind, Stout (1990) proposed the exponential function $f(x) = f_{max}(1 - e^{-x/b})$ to relate the wind erosion mass to the bed length, where $f(x)$ is the wind erosion mass for a sand bed length x; f_{max} is the saturation wind erosion mass; and b is the corresponding sand bed length where $f(x)$ is equal to $0.63f_{max}$. Due to the fluid shear stress in the initial section of the bed, few sand grains began to move at this location, and wind erosion mass was small. Particularly at low wind velocities, wind erosion mass followed a sigmoid curve rather than a simple exponential or power function (Fryrear and Saleh, 1996). To overcome the limitations of Stout's model, Andreotti et al. (2010) proposed the revised equation $f(x) = f_{max}(1 - exp^{-(x-x0)/b})$ by adding an initial sand bed length (X_0) near $0.25f_{max}$. However, Andreotti et al. (2010) did not explain why X_0 was nearly equal to the sand bed length where wind erosion mass accounted for $0.25f_{max}$. Thus, studies are necessary about the change of wind erosion mass as sand bed length increases to further explore these discrepancies.

During the course of wind erosion process, sand ripples are initiated and migrate in the sand bed surface. Although ripple initiation and migration will affect aeolian sand transport, it seems that there is no effect of bed length on wind erosion rate for the same wind duration because ripples simultaneously occur. Thus, wind erosion rate variability along bed length can be studied by detailed measurement of the development of the sand surface morphology under the action of wind (Andreotti et al., 2010). In this study, a Trimble CX 3D laser scanner was used to scan for the sand bed morphology in a wind tunnel for three friction velocities with four action times and the wind erosion masses were measured by weighing bed sediments before and after each experiment at four friction velocities with different durations in a wind tunnel. We studied the development of the sand surface morphology and described the evolution of the wind erosion rate with distance. The results of this study provide new information for understanding the influence of the length of a sand bed on the wind erosion mass.

2. Material and methods

The wind tunnel experiments were performed at the State Key Laboratory of Earth Surface Processes and Resource Ecology, Beijing Normal University, Beijing, China. The experimental section was 3 m wide, 2 m high and 24 m long. The wind velocity of the central axis could be continuously adjusted from 1 to 45 m/s. To satisfy the similarity principle of the wind tunnel test, bricks that were 24 cm long × 11.5 cm wide × 5 cm high were used as a roughness element (Fig. 1). The details of the roughness elements is described in Cheng et al. (2015).

Sand with a mean diameter of 152 μm was obtained from the center of the Taklimakan Desert in China. To create a steady aeolian sand flow, a sand bed that was 10 m long, 1 m wide and 3–5 cm thick was placed in the wind tunnel. The windward edge of the sand layer was positioned 7.01 m downwind from the entrance of the experimental section (Fig. 1).

The profile of the wind velocities were drawn based on the measured mean wind velocities at 8 heights (2, 5, 10, 20, 30, 40, 50 and 70 cm) using pitot tubes 8.5 m from the test section entrance (Fig. 1). The entire profile satisfied the logarithmical law u = a ln (z) + b (u is wind velocity (m/s); z is height (cm); a and b are the

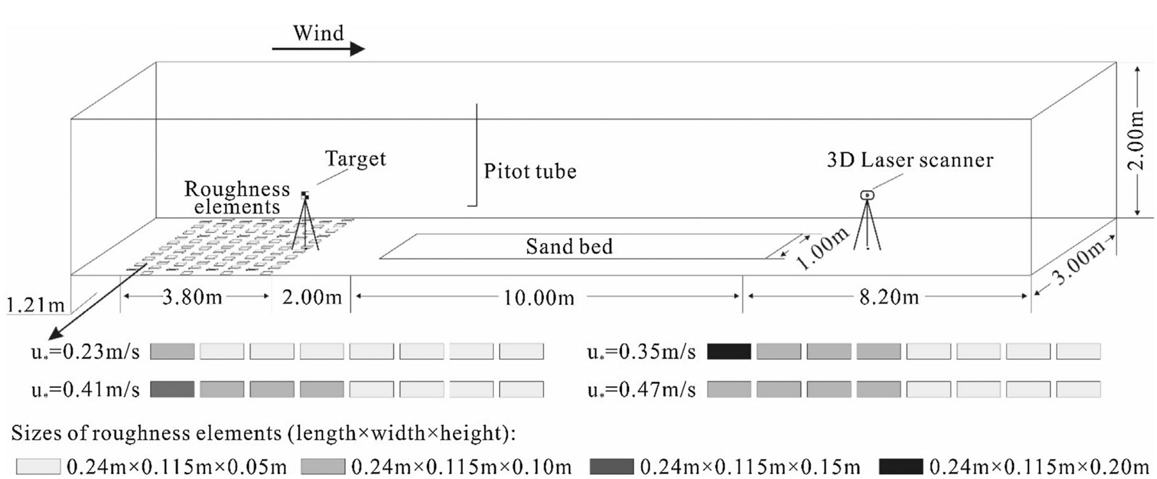

Fig. 1. Schematic diagram of bed surface and roughness elements.