Low-Altitude Structural Characteristics of Sandstorms Inside and Outside the Shelterbelt on the Northeastern Margin of the Ulan Buh Desert (Postprint)

Authors: Luo Fengmin, Gao Junliang, Xin Zhiming, Hao Yuguang, Gegenbatu, Xinle Li, Ruibing Duan, Liu Fang, Liu Fang

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Abstract

Based on data of horizontal dust flux, vertical dust flux, and wind speed/direction for 8 dust storms collected by a near-surface (0–50 m) aeolian sand monitoring tower at the Dengkou Desert Ecosystem National Fixed-Position Observation and Research Station in Inner Mongolia, this study investigates variations in wind regime, characteristics of dust distribution, and the influence of shelterbelts on dust storms under small-to-medium scale conditions at the northeastern margin of the Ulan Buh Desert. The results demonstrate that: During dust storm events, wind speeds both inside and outside the shelterbelt exhibit an increasing trend with height, with wind speed profile characteristics following a power function. The dominant wind directions are primarily W, WNW, and NE both inside and outside the shelterbelt, though the proportion of each direction differs. Outside the shelterbelt, horizontal dust flux and dust concentration decrease significantly with increasing height, with vertical distribution characteristics conforming to an exponential function relationship; inside the shelterbelt, horizontal dust flux and dust concentration increase slowly with height, with vertical distribution characteristics conforming to a power function relationship. Vertical dust flux decreases significantly with increasing height both inside and outside the shelterbelt, with vertical distribution characteristics conforming to a power function relationship. As dust storms pass through the shelterbelt system, wind speed is significantly attenuated, with an average reduction of 31.03%; horizontal dust flux is reduced by 298.16 g · m ², vertical flux by 0.37 g · m ², and dust concentration by 22.48 g · m ².

Full Text

Preamble

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Authors: LUO Feng-min, GAO Jun-liang, XIN Zhi-ming, HAO Yu-guang, GENG Gen-batu, LI Xin-le, DUAN Rui-bing, LIU Fang
Affiliation: Inner Mongolia Dengkou Desert Ecosystem National Observation and Research Station/Experimental Center of Desert Forestry, Chinese Academy of Forestry, Dengkou 015200, Inner Mongolia, China
Corresponding Author: E-mail: lfm359541965@126.com
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1 Introduction

1.1 Study Area

The study area is located in the northeastern marginal zone of the Ulan Buh Desert, with geographical coordinates of . The region covers an area of 1.0×10 km², with an elevation ranging from 1028 to 1054 m. The area belongs to the typical temperate arid climate zone. The natural vegetation consists primarily of *Populus* L., *Haloxylon ammodendron* (C.A. Mey.) Bunge, and other psammophytes [19-20].

1.2 Methods

1.2.1 Experimental Design The experimental site was established on a typical mobile sand dune (Figure 1). The monitoring system consisted of a sand observation tower and sand collectors. The shelterbelt vegetation comprised *Nitraria tangutorum* Bobr., *Artemisia ordosica* Krasch., *Artemisia sphaerocephala* Bge., and *Agriophyllum squarrosum* (L.) Moq. [20], with a spacing of (2-6) m × (4-8) m and heights of 1.2-3.6 m.

[Figure 1: see original paper]

1.2.2 Data Collection The sand observation tower was constructed with a height of 50 m. Sand collectors were installed at 14 heights: 48, 44, 40, 36, 32, 28, 24, 20, 16, 12, 8, 4, 2, 1, 0.5 m, following the gradient observation method [21]. Horizontal sand flux was measured using BSNE sand collectors with an inlet area of 20 mm × 50 mm. Vertical sand flux was measured at 1.5 cm and 3.0 cm above the surface using specialized vertical sand collectors [22].

Wind speed and direction were monitored using a Windsonic anemometer (Gill Instruments, UK) at heights of 48, 36, 24, 16, 12, 8, 4, 2, and 1 m. The measurement range was 0-60 m・s 1 (0°-359°) with a resolution of 0.01 m・s 1 (1°). Data were recorded continuously at 10-minute intervals. Sandstorm events were identified when wind speed at 12 m exceeded 5 m・s 1 and visibility was less than 1 km [23]. Wind direction was categorized into 16 sectors: N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, WSW, W, WNW, NW, and NNW.

[Figure 2: see original paper]

1.3 Data Analysis

Data processing and statistical analysis were performed using Excel 2010 and Origin 8.5 software. The following formulas were used to calculate sand transport parameters:

(1) **Horizontal sand flux (MH) and vertical sand flux (MV):**

$$MH = \frac{WH}{ab}, \quad MV = \frac{WV}{\pi r^2}$$

where MH is horizontal sand flux (g・m 2), WH is mass of sand collected in horizontal collector (g), a and b are the length and width of the collector inlet (mm), MV is vertical sand flux (g・m 2), WV is mass of sand collected in vertical collector (g), and r is the radius of the vertical collector inlet (cm).

(2) **Sand concentration (C):**

$$C(x) = \frac{Q(x) \cdot V(x) \cdot T}{A}$$

where $C(x)$ is sand concentration at height x (g・m 3), $Q(x)$ is sand flux at height x (g・m 2), $V(x)$ is wind speed at height x (m・s 1), T is sampling duration (s), and A is collection area (m²).

(3) **Data from eight sandstorm events** in 2017 and 2018 were analyzed.

2 Results

2.1 Wind Regime Characteristics

2.1.1 Wind Speed Profiles The wind speed profiles inside and outside the shelterbelt are shown in Figure 3. Both showed increasing trends with height. During sandstorms, the wind speed profile followed a power function relationship: - Inside shelterbelt: $V = 1.49h^{0.37}$ ($R^2 = 0.97$, $P < 0.01$) - Outside shelterbelt: $V = 0.98h^{0.46}$ ($R^2 = 0.99$, $P < 0.01$)

For annual average conditions: - Inside shelterbelt: $V = 3.97h^{0.22}$ ($R^2 = 0.99$, $P < 0.01$) - Outside shelterbelt: $V = 1.89h^{0.38}$ ($R^2 = 0.97$, $P < 0.01$)

Wind speeds ranged from 0.88 to 2.34 m・s 1 inside and 1.12 to 3.56 m・s 1 outside the shelterbelt. The shelterbelt reduced wind speed by 9.26% to 58.70%, with an average reduction of 31.03%. The maximum reduction occurred at 1 m height (58.70%).

[Figure 3: see original paper]

2.1.2 Wind Direction During sandstorms, the prevailing wind directions both inside and outside the shelterbelt were W, WNW, and NE, but their proportions differed significantly (Figure 4). Outside the shelterbelt, the three dominant wind directions accounted for 46.53%, 21.54%, and 15.34% respectively. Inside the shelterbelt, they accounted for 28.59%, 22.99%, and 25.73% respectively. This indicates that the shelterbelt altered wind direction patterns.

[Figure 4: see original paper]

2.2 Sand Flux Characteristics

2.2.1 Horizontal Sand Flux The horizontal sand flux decreased exponentially with height both inside and outside the shelterbelt (Figure 5). The relationship followed:

$$MH = ah^b$$

Outside: $MH = 110.58h^{0.18}$ ($R^2 = 0.92$, $P < 0.01$)
Inside: $MH = 107.88$ to 223.30 g · m ² at different heights

The cumulative horizontal sand flux showed that 78.4% occurred below 24 m outside the shelterbelt, while inside, 53.5% occurred below 24 m. The total horizontal sand flux in the 0-50 m layer was 475.51 g · m ² outside and 177.35 g · m ² inside, representing a reduction of 298.16 g · m ² (62.7% reduction).

[Figure 5: see original paper]

2.2.2 Vertical Sand Flux Vertical sand flux decreased significantly with height, following a power function relationship (Figure 6): - Outside: $MV = 4.88h^{-0.40}$ ($R^2 = 0.93$, $P < 0.01$) - Inside: $MV = 4.11h^{-0.45}$ ($R^2 = 0.76$, $P < 0.01$)

The cumulative vertical sand flux showed that 80% occurred below 28 m outside the shelterbelt. The total vertical sand flux in the 0-50 m layer was 2.22 g · m ² outside and 1.85 g · m ² inside, a reduction of 0.37 g · m ².

[Figure 6: see original paper]

2.2.3 Sand Concentration Sand concentration decreased exponentially with height (Figure 7): - Outside: $C = 65.50e^{-0.05h}$ ($R^2 = 0.92$, $P < 0.01$) - Inside: $C = 21.95h^{-0.20}$ ($R^2 = 0.76$, $P < 0.01$)

The average sand concentration was 37.24 mg · m ³ outside and 14.76 mg · m ³ inside, a reduction of 60.4%. The maximum concentration occurred at 1 m height outside (83.79 mg · m ³) and inside (25.16 mg · m ³).

[Figure 7: see original paper]

3 Discussion

3.1 Wind Speed Variation

The study demonstrates that wind speed profiles in the near-surface layer (0-50 m) follow power function relationships during sandstorms, consistent with previous research [22, 25]. The shelterbelt significantly reduced wind speed by an average of 31.03%, with maximum reduction (58.70%) at 1 m height. This vertical gradient in wind speed reduction is crucial for understanding sand transport mechanisms and shelterbelt effectiveness [5, 25-29].

3.2 Sand Flux Variation

The horizontal sand flux followed exponential distributions with height, with 78.4% of total flux occurring below 24 m outside the shelterbelt. This concentration of sand transport in the near-surface layer highlights the importance of ground cover and low-height vegetation in wind erosion control [22]. The shelterbelt reduced total horizontal sand flux by 62.7% (298.16 $\text{g} \cdot \text{m}^{2}$), demonstrating significant protective effects.

Vertical sand flux also showed height-dependent patterns, with 80% occurring below 28 m. The reduction of vertical flux by 0.37 $\text{g} \cdot \text{m}^{2}$ indicates that the shelterbelt effectively decreased saltation activity and dust emission [24].

3.3 Shelterbelt Effects

The comprehensive analysis reveals that shelterbelts in the Ulan Buh Desert margin provide substantial protection against sandstorms: 1. **Wind speed reduction**: Average 31.03% decrease, with peak reduction at low levels 2. **Horizontal sand flux reduction**: 62.7% decrease (298.16 $\text{g} \cdot \text{m}^{2}$) 3. **Vertical sand flux reduction**: Significant decrease (0.37 $\text{g} \cdot \text{m}^{2}$) 4. **Sand concentration reduction**: 60.4% decrease (22.48 $\text{g} \cdot \text{m}^{3}$)

These results underscore the critical role of shelterbelt systems in desert ecosystem management and sandstorm disaster mitigation. The findings provide scientific basis for optimizing shelterbelt structure and configuration in arid regions [14-15, 31-33].

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Abstract: This paper analyzes data of horizontal and vertical sand-dust flux and annual wind speed and direction during eight sandstorms, collected from the sand watchtower near the surface layer (0-50 cm) of Inner Mongolia Dengkou Desert Ecosystem National Observation and Research Station. The purposes were to analyze variations of sand-driving wind regime, distribution of wind-blown sand, and the effect of shelterbelt on sandstorms on small scale in the northeastern marginal zone of the Ulan Buh Desert. The results were as follows: The average wind speed inside and outside the shelterbelt increased with height; the wind speed profiles during sandstorms could be expressed by power exponential functions. The prevailing wind directions inside and outside the shelterbelt were W, WNW, and NE, but their proportions were different. The horizontal sand-dust flux and sand-dust concentration outside the shelterbelt decreased with height. The distribution of wind-blown sand accorded with exponential functions. The horizontal sand-dust flux and sand-dust concentration inside and outside the shelterbelt increased slowly with height, and the distribution of wind-blown sand accorded with power exponential functions. The vertical sand-dust flux inside and outside the shelterbelt decreased significantly with height, and the distribution of wind-blown sand accorded with power exponential functions. When sandstorm passed through the shelterbelt system, the wind speed was significantly decreased with an average reduction of 31.03%, while the horizontal and vertical fluxes of wind-blown sand were reduced by 298.16 $\text{g} \cdot \text{m}^{2}$ and 0.37 $\text{g} \cdot \text{m}^{2}$ respectively, and the concentration of wind-blown sand was decreased by 22.48 $\text{g} \cdot \text{m}^{2}$.

Keywords: shelterbelt; wind speed; sandstorm; horizontal flux; vertical flux; wind-blown sand concentration; Ulan Buh Desert

Note: Figure translations are in progress. See original paper for figures.

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