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Original Research Paper

Wavelet packet analysis of particle response to turbulent fluctuation

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ABSTRACT

The fluid–particle synchronous measurements in a boundary layer wind tunnel were conducted to determine the particle concentration response to turbulent velocity fluctuation. Three groups of natural sand samples (diameter of 300–500, 100–125 and 63–80 μm) were employed in the experiments. Consecutive instants of saltating particles were recorded by using a high-speed digital camera at 2000 frames per second and a constant-temperature hot-wire anemometer was used to measure the turbulent fluctuation simultaneously. The particle concentration in the saltation layer was calculated by the dynamic-threshold binarization algorithm. The results confirm that the concentration fluctuation is a fairly typical stochastic process, and the low-frequency variation of particle concentration is closely related to the turbulent fluctuation. Moreover, a method was developed to apply wavelet packet transform to two-phase data analysis from the viewpoint of frequency-domain energy structure. Further analysis shows that the concentration fluctuation is predominant in the low frequency band less than 250 Hz. In addition, the particle concentration response to the turbulent fluctuation is significantly correlated with the particle diameter. For the fine particles (63–80 μm), medium particles (100–125 μm) and coarse particles (300–500 μm), the highest response frequencies of particle concentration variation to the turbulent fluctuation are 60, 40 and 30 Hz, respectively, which demonstrates that an appropriate sampling rate is crucial in saltation measurement. These qualitative and quantitative results are beneficial to understand the fluid–particle interaction mechanism.

1. Introduction

Wind is the essential drive to cause aeolian sand transport and desertization. The blown sand movement is influenced by the magnitude and frequency of wind. Under natural conditions, wind is commonly turbulent and often rapidly fluctuating, giving an inner boundary layer of highly variable properties [1,2]. Complex turbulent flow is inherent to natural aeolian environments. Consequently, almost all kinds of sand-drifting wind account for turbulence with intense fluctuation [3,4]. Turbulent characterization is really important for sediment transport research as instantaneous peaks in velocity components that exceed time-averaged shear velocity above a sand surface may be sufficient to initiate particle entrainment [5,6]. As an instantaneous phenomenon, the startup of a particle is closely related to the instantaneous (turbulent) velocity rather than the mean velocity [7]. In the wind-tunnel experiment by Leenders et al. [8], fairly good correlations between the horizontal wind component and saltation were found, compared to poor correlations between the kinematic stress and saltation. This result is consistent with the conclusion of the field studies conducted by Sterk et al. [4] and Schönfeldt and von Löwis [9]. Consequently, these studies have spurred a move away from the empirical approach of using mean flow properties for analyzing sediment transport toward investigations of high-frequency instantaneous measurements in gas–solid two-phase flow. To determine the frequency requirement of instantaneous measurements, researchers must analyze the fluctuation rule of airflow and saltating sand particles and confirm the response frequency of saltation transport to turbulence. It is an important precondition for realizing the two-phase simultaneous measurement.

Although many laboratory and field results on the response of sand transport to variations in wind velocity have been reported [10–12] and several studies have been directed specifically at the response frequency of saltation transport to airflow [8], considerable uncertainty still remains in existing literatures. Little attention has been devoted to the sampling frequency requirements for the saltation transport measurements. Almost all studies about the response frequency of saltation transport to airflow were derived from the earlier research of Butterfield [13] and Spies et al. [14]. Moreover, the time-domain analysis, including the mass flux ratio between steady and unsteady wind and the cross-correlation

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