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An observational study of saltation and dust emission in a hotspot of Mongolia

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ABSTRACT

We conducted field observations from April 2012 to June 2013 on the desert steppe of Mongolia to investigate saltation and dust events and to examine the effect of surface conditions on dust emissions. The desert steppe of Mongolia is a major source of dust and has the highest frequency of dust events in East Asia. Our results indicate that saltation and dust events were caused mainly by westerly winds, particularly from April to June. Saltation and dust concentrations were substantially lower in 2013 than in 2012 because soil temperatures were lower and snow events more frequent in 2013. Increased dust concentrations in summer were likely caused by transported dust, rather than local dust. Saltation and dust emissions rarely occurred when soil moisture was greater than 6%. However, the threshold wind speed did not correlate well with soil moisture, but decreased with increasing soil temperature. Dramatic decreases of threshold wind speed occurred in both 2012 and 2013 after large dust events, even though there was little change in soil moisture and vegetation cover. These variations of threshold wind speed during dust-emitting periods likely reflect changes of soil structure, possibly related to the freeze–thaw cycle.

1. Introduction

Asian dust is a serious environmental problem in arid and semiarid regions of East Asia. The main source regions of Asian dust are the Taklimakan Desert, Gobi Desert, and Loess Plateau regions (Shao and Dong, 2006; Bian et al., 2011). Dust produced in these regions increasingly affects human and livestock health, air pollution, agriculture, and local ecosystems and not only in the source regions but also in downwind regions (Willis et al., 1980; Betzer et al., 1988; Chung et al., 2003; Yuan et al., 2004). Asian dust can affect the source area, surrounding areas, and the global climate (Zhang et al., 2003; Wesche and Retzer, 2005; Chimgee et al., 2010). The effect of dust in areas surrounding the source is much less severe than in the areas of origin in Mongolia and China, where strong dust storms occur.

Most dust emission models include parameters to account for the effects of land-surface conditions such as soil particle size distribution, soil-surface characteristics, vegetation cover, and the roughness frontal area index. The frequency of dust occurrences is dependent on surface conditions that affect the affect the wind speed threshold for erosion, such as vegetation cover (Kimura et al., 2009), surface soil water content (Ishizuka et al., 2005; Kimura et al., 2009), and snow cover (Kurosaki and Mikami, 2004). Therefore, it is important to gain a better understanding of the physical relationships between surface conditions and dust outbreaks and thus improve the accuracy of early warning and monitoring systems. A better understanding of these relationships, combined with weather forecasts including wind speed, will be helpful for developing strategies that seek to mitigate or prevent serious environmental damage caused by dust storms.

Previous studies have examined modeling and prediction of dust storms to understand and quantify the processes that lead to dust events, and their impact on the environment and climate (Han et al., 2004; Hara et al., 2006; Shao and Dong, 2006; Zhao and Zhao, 2006; Liu et al., 2011). However, the field measurements are essential for understanding wind-erosion processes and for verifying wind-erosion models and the relationship between

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surface conditions and dust outbreaks remains unclear, and the number of field observations that include land-surface data, soil particle size distributions, soil-surface characteristics, vegetation cover, and the roughness frontal area index are inadequate for defining these relationships. With this in mind, an intensive field observation was conducted on the steppe in Mongolia (Shinoda et al., 2010; Abulaiti et al., 2013; Kimura, 2013). For example, these intensive field observations indicated that the threshold wind speed increased as the vegetation cover increased, and the particle in the size range from 124 to 645 μm were effectively trapped by vegetation. The frontal area was strongly correlated with the effective shelter length on sand transport in both short grasses and shrubs. However, the threshold wind speed, saltation flux and soil particles size distributions likely change with surface conditions, therefore, more information should be obtain under natural conditions in the field.

Much of Mongolia is covered by desert plains, and southeastern Mongolia is part of the Gobi Desert. Over these vast areas, dust storms are frequent and sometimes severe. Cyclones and their accompanying cold fronts often generate the strong surface winds required to raise soil particles into the atmosphere and to produce severe dust storms (Natsagdorj et al., 2003; Jugder et al., 2004). An analysis of meteorological observatory data showed that the frequency of dust storms in East Asia was highest at Tsogt-Ovoo on the northern desert steppe of Mongolia (Kurosaki and Mikami, 2007). Tsogt-Ovoo lies in a shallow valley; topographic depressions such as this, and dry lakes, are known to be significant sources of dust (Engelstaedter et al., 2003). However, there is a lack of data on parameters such as threshold wind speed, saltation flux, dust concentration, vegetation cover and soil properties in this area. We undertook field measurements at Tsogt-Ovoo from April 2012 to June 2013 to investigate saltation and dust events and the effect of surface conditions on dust emissions in this very active source region.

2. Observation methods

2.1. Study site and experimental method

The observational station at Tsogt-Ovoo is within the northern desert steppe of Mongolia (44°23′04″N, 105°16′59″E) (Fig. 1). Data were collected from April 2012 to June 2013. The instrumented site has been fenced (30 m × 30 m) since 19 March 2012 to keep herders and animals out; vegetation conditions inside the fence have been maintained similar to those outside.

The observation site is in a region where the temperature during the period 1986–2005 ranged from −10.1 °C to 14.2 °C. Mean annual precipitation is 118 mm. Average snow cover from mid-October to the end of April is 1.5 cm, and the local sandy loam soil freezes to a depth of 1.6–1.7 m (Nandintsetseg and Shinoda, 2013). At the observation site, the soil contained 77% sand, 12% silt, and 11% clay. Vegetation at the site is dominated by the desert shrubs *Reaumuria soongolica* and *Salsola passerina*, and vegetation cover was less than 5% (Ishizuka et al., 2012).

The meteorological parameters measured were air temperature and humidity (Vaisala; HMP-155D-10; instrument height 1.98 m), precipitation (OTA; CTKF-1; instrument height 0.65 m), and wind speed and direction (R.M. Young; YG-5103 sensor; instrument height 3 m). Volumetric soil moisture content was measured with amplitude domain reflectometry probes (Delta-T; ML2x) that were set at horizontal intervals of 0.02 m. Soil temperature at 0.01 m depth was measured with a platinum resistance thermometer (C-PTG-10). PM_{10} dust concentration (mg m^{-3}) was measured with a TSI Dust Trak Model 8533 at a height of 1.42 m above ground. Instantaneous measurements were taken at intervals of 1 s for saltation, PM_{10}, wind speed and direction, and at intervals of 5 s for air temperature, humidity, and pressure, and recorded by a data logger (Campbell Scientific; CR1000); all data were averaged over 1-min intervals.

A piezoelectric sensor (Sensit Co., Portland, ND, USA) used to measure saltation was mounted at 0.059 m above ground. This sensor can falsely record rain drops and splash as saltating sediment, so saltation data for days when rain or snow were recorded were not used in the subsequent analysis.

2.2. Estimation of threshold wind speed for saltation

We determined the threshold wind speed (u_t; 3 m above ground) for saltation by using the following equation (Shinoda et al., 2010), which is similar to that proposed by Owen (1964) for threshold friction velocity:

$$SN = D \cdot u(u^2 - u_t^2) \quad u \geqslant u_t, \tag{1}$$

where SN is saltation number (counts per minute), D is an empirical coefficient (g s^2 m^{-5}) that is dependent on sand particle size, u is wind speed (m s^{-1}) at 3 m height, and u_t is threshold wind speed (m s^{-1}). We solved for D and u_t through successive approximations of Eq. (1) using observed saltation numbers.

2.3. Wind energy

For estimations of the ability of wind to cause erosion (erosivity), the most important factor is wind speed. We used wind power density per unit area to quantify wind conditions. Wind power density Ushiyama (2002) was calculated as:

$$WPD = \frac{1}{2}\rho u^3, \tag{2}$$

where WPD is wind power density (W m^{-2}) during a half-hour interval, ρ is air density (kg m^{-3}), and u is the half-hourly averaged wind speed (m s^{-1}) measured 3 m above ground.

Wind energy (WE, J m^{-2}) for a period of N hours was calculated as:

$$WE = \sum_{i=1}^{N}(WPD \times 1800). \tag{3}$$

3. Results and discussion

3.1. Wind characteristics

Frequency distributions of wind direction (Fig. 2) show that winds from the W to WNW, E to ENE, and NNE were predominant, and that the most frequent and strongest winds (>10 m s^{-1}) were from the W and WNW (Fig. 2a). Winds during saltation and dust (PM_{10}) events were predominantly from the W to WNW (Fig. 2b). Wind energy was higher in spring than in other seasons (Fig. 2c). Both easterly and westerly winds were predominant from January to March and from October to December; however, winds were mainly westerly (>5 m s^{-1}) from April to June, and mainly easterly (<5 m s^{-1}) from July to September (Fig. 3).

These observations indicate that wind directions for both strong and light winds were similar from January to March and from October to December, and strong winds dominated from April to June. Therefore, the frequency of dust events was related mainly to westerly winds in this region, particularly in spring.

3.2. Saltation and dust emission activity

Both saltation and dust concentration increased with increasing wind speed in spring in both 2012 and 2013, and then decreased