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Size distribution of dust aerosols observed over the Horqin Sandy Land in Inner Mongolia, China

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ABSTRACT

Particle size distributions (psds) of airborne dust (PM_{20}) during different dust emission events are investigated in this study, using data obtained from a dust-event monitoring station in the Horqin Sandy Land in Inner Mongolia, China. The results show that for a weak saltation-bombardment and aggregate-disintegration dust emission (SADE) event ($0.44 < u_* < 0.47$ m s^{-1}) on 7 April 2012, dust aerosols $\leqslant$1 μm in diameter (d) accounted for 80% for all dusts measured. While for a strong SADE event ($0.85 < u_* < 0.89$ m s^{-1}) on the same day, large dust aerosols ($d \geqslant 2.5$ μm) increased significantly, with the largest proportion (40%) located in 4–7 μm, which agreed with the airborne dust psds observed during another two strong SADE events (mean $u_* = 0.78$ and 0.68 m s^{-1}) on 13–14 April 2013. However, for a convective turbulent dust emission (CTDE) event (mean $u_* = 0.31$ m s^{-1}) on 17 April 2013, the mean proportion of dust aerosols <0.45 μm reached 70%, which suggests that only fine dust particles loosely distributed at the surface could be easily uplifted into the atmosphere by convective turbulence. It found that the airborne dust psds at emission move to the larger sizes with the increasing u_*, but they remain unchanged when u_* doesn't change too much. In addition, the dust psds for a non-local dust event on 19 April 2012 appeared smoother because of the mixing of dust aerosols through the processes of dust advection and deposition.

1. Introduction

Dust aerosols can be generated from dust emission in many arid and semi-arid regions in the world and play an important role in many physical, chemical, and biogeological processes in the Earth system (Shao et al., 2011b). They influence the atmospheric radiation balance and even the climate directly by scattering and absorbing various radiation components (Tegen et al., 1996) and indirectly by modifying the optical properties and lifetime of clouds (Mahowald and Kiehl, 2003; Andreae and Rosenfeld, 2008). Dust aerosols of different sizes have profoundly different optical, aerodynamic, and mineralogical characteristics; hence particle size distributions (psds) of airborne dust are very important to precisely estimate the processes of dust emission, transport, and deposition and determine the effects of dust aerosols on climate and human health (Alfaro et al., 1998).

Many field and wind tunnel experiments have been conducted to study the airborne dust psds under different wind speed (U)/friction velocity (u_*) and soil conditions. Gillette et al. (1972) identified a power law, $dN/d(\log d) \propto d^{-2}$, for dust aerosols of 0.3–1 μm in diameter (d) and a flatter curve for larger dust aerosols ($1 \leqslant d \leqslant 6$ μm) at the heights of 1.5 and 6 m in rural Nebraska (USA), with N being the number of dust aerosols counted and d indicating the differential. Gomes et al. (1990) observed a second mass peak of submicron particles in Saharan dust aerosols ($0.1 \leqslant d \leqslant 20$ μm) under strong wind-erosion conditions, which is consistent with the theory that sandblasting process (saltation) is the major mechanism for dust emission (Gillette and Walker, 1977). Alfaro et al. (1997, 1998) used pure quartz particles ($d = 240$ μm) to bombard various surfaces made of kaolin clay, and natural loamy and sandy soils. The results indicated that the dust psd at emission was close to that of the original erodible fractions of the surface soils at a relatively small u_*, whereas at a higher u_*, it had a new peak at a smaller diameter. Consequently, some researchers have believed that size distributions of dust aerosols largely depends on wind speed/friction velocity at emission. However, some findings contradicted this conclusion. Sow et al. (2009) reported that the dust psds appeared to be independent on u_* for a given dust event but differed between various dust

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events (two weak dust events and a strong one), based on the filed observations in Niger. Shao et al. (2011a) observed no significant difference in dust psds under different u_* conditions (i.e., u_* <0.20, 0.20–0.25, 0.25–0.30, . . . , 0.50–0.55 m s^{-1}) in the Japan-Australia Dust Experiment. Kok (2011a) and Mahowald et al. (2014) pointed out that the dust psds observed by different researchers agreed roughly with each other for dust aerosols <5 μm but differed substantially for larger particles (d > 5 μm) mainly due to differences in the soil state and soil psd. Different kinds of size-distributed dependent/independent dust-emission schemes have been developed in dust models (Lu and Shao, 1999; Shao, 2004; Kok, 2011a, 2011b; Ishizuka et al., 2014). However, the characteristics of airborne dust psds at emission under different U/u_* conditions are still needed to be studied in more field experiments.

Asian dust, which is a typical example of a dust aerosol, frequently originates in the sand desert, Gobi desert, the Loess Plateau, and the mixed barren soil in northern China and Mongolia when meteorological and soil surface conditions combine to create conditions suitable for dust rise (Zhu and Zhang, 2010; Li and Zhang, 2012). The changes in dust psds during long-range transport of Asian dusts have been studied (e.g., Zhang et al., 1998; Maring et al., 2003; Kobayashi et al., 2007), whereas it is rare to investigate dust psds during dust emission caused by different mechanisms, i.e., saltation-bombardment and aggregate-disintegration dust emission (SADE) and convective turbulent dust emission (CTDE), because of the lack of psd data in field experiments. Note that CTDE is mainly caused by convective turbulence aided by the mechanical turbulence (u_*) and occurs under non-saltation conditions. Although dust emission flux during an individual CTDE event is usually of orders of magnitude smaller than that during an individual SADE event (Klose and Shao, 2013), CTDE flux is considerable and important to the background dust concentration and dust cycles from the view of an annual or even longer time scale because CTDE events occur more frequently than SADE events (Li et al., 2014).

A comprehensive long-term dust event experiment has been conducted since 2007 in the Horqin Sandy Land in Inner Mongolia of China, which is a typical Asian dust source region. The mass-related size distribution of dust aerosols ($0.1 \leqslant d \leqslant 20$ μm) was measured by a widely-used 10-stage quartz crystal microbalance (QCM) cascade impactor (e.g., Kompalli et al., 2014) at a 3 m height. Using the QCM-measured psd data and the micrometeorological data obtained from the Horqin site during two intense observation periods (IOP) in April 2012 and 2013, the characteristics of airborne dust psds during different dust events (three local SADE events, a local CTDE event, and a non-local dust event) under different u_* conditions were studied. The data and methods used in this study were introduced in Section 2, and the characteristics of dust psds for different dust events were analyzed in Section 3. The conclusion were drawn and discussed through comparing the present results with previous relevant studies in Section 4.

2. Experiment and methods

2.1. Experiment in the Horqin Sandy Land

The experimental site is located at the eastern edge of the Horqin Sandy Land (42°56′ N, 120°42′ E) in Naiman Qi of Inner Mongolia, China. The annual mean precipitation in this semi-arid region is about 300–400 mm. The landscape of the Horqin site is gently undulating and dominated by shifting, semi-shifting, and fixed dunes, and the vegetation around the site consists largely of low open shrubs (Zhao et al., 2007), as shown in Fig. 1.

Fig. 1. Photo of the experimental site in the Horqin Sandy Land in Inner Mongolia, China.

A 20-m observational tower was built at the Horqin site. The observations included that (1) micrometeorological parameters, such as wind speed (010C, Met One Instruments Inc.) at heights of 2, 4, 16, and 20 m, air temperature and humidity (HMP45C, Campbell Sci. Inc.) at heights of 2, 4, 8, and 16 m, wind direction (020C, Met One Instruments Inc.) at a 20 m height, shortwave radiation (LI200X, Li-Cor Co.) and net radiation (Nr-Lite, Kipp&Zonen) at a 2 m height, precipitation (52202, R. M. Young Co.), and air pressure (PTB110, Vaisala Co.) at the surface; (2) soil parameters, such as soil temperature (CS107, Campbell Sci. Inc.) and soil moisture content (CS616, Campbell Sci. Inc.) at depths of 5, 20, and 50 cm; (3) turbulence of wind and temperature (CSAT3, Campbell Sci. Inc.) at a 8 m height; and (4) dust parameters, such as dust (PM_{10}) mass concentration measured by beta-gauges (FH62-C14, Thermo Co.) at heights of 3 and 18 m, saltating sand particles (d > 50 μm) detected by wind eroding mass sensors (H11B, Sensit™) at heights of 0.20, 0.50, and 0.75 m, and dust (PM_{20}) mass concentrations of different sizes observed at a height of 3 m by a 10-stage quartz crystal microbalance (QCM) cascade impactor (PC-2HX, California Measurements Inc.), for which the lower size cutoff diameters for each stage are 10, 7, 4, 2.5, 1.4, 0.7, 0.45, 0.3, 0.2, and 0.1 μm.

Sensit wind eroding mass sensor has been widely used in wind-erosion research (Stockton and Gillette, 1990; Van Pelt et al., 2009). Electrical charges can be produced by the deformation of the Sensit piezoelectric sensor as saltating particles strike on it. The Sensit then responds linearly to the impacting kinetic energy of saltating particles. The QCM cascade impactor has a reference crystal and a sensing crystal in each stage. The frequency change (dF) between the two crystals increases with the increasing mass of particles collected on the sensing crystal. Once dF in any one of the stages reaches a preset value, a QCM sampling ends. The mass concentration in each stage can be calculated by the micro-processor in the control unit according to the dF at the same stage and the sampling time duration (Park and Park, 2014).