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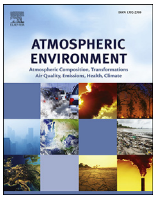

Short communication

Meteorological constraints on characteristics of daily dustfall in Xi'an

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ABSTRACT

Dust deposition is a crucial link of dust cycle that is less constrained in model studies. This study acquired profiles of flux and size distribution of daily dustfall from 2012 to 2013 in Xi'an on the southern Chinese Loess Plateau. On this basis, we made quantitative estimates of dust contribution from particular sources and processes, which provides important boundary conditions for model studies. Regrouping the data into transport- and source-limited deposition scenarios, we revealed that besides precipitation extreme wind speed and average relative humidity are the primary meteorological constraints in the transport- and source-limited scenarios, respectively. Stronger extreme wind speed promotes higher flux and deposition of dust >16 μm, corroborating previous interpretations of variation of flux and grain size of aeolian deposits. However, higher average relative humidity favors lower flux and deposition of dust <16 μm, which is a deposition process not recognized before, and is possibly due to hygroscopicity of mineral dust or the influence of water vapor on air convection. Elucidating this process in future studies might substantially improve model performance on dust deposition.

1. Introduction

Dust cycle has been recognized as an important process connecting lithosphere with atmosphere, hydrosphere, and biosphere (Knippertz and Stuut, 2014; Shao et al., 2011), which impacts on the geomorphology, air conditions, cloud formation, precipitation, solar radiation budget of the earth system, and many geochemical and biogeochemical processes in terrestrial, atmospheric, and aquatic systems (Creamean et al., 2013; Jickells et al., 2005; Liu, 1985; Mahowald and Kiehl, 2003; Pye, 2015; Tegen et al., 1996; Uno et al., 2009; Zhao et al., 2008; Zhuang et al., 1992). Dust activities are extremely variable both temporally and spatially, causing difficulties in evaluating their regional and global impacts. Various dust models had thus been devised to fulfill the task. Robust model evaluations rely on accurate characterization of the dust properties in dust emission, transportation and deposition processes, including most importantly the mass, size distribution, and composition of airborne dust. In comparison, dust deposition is the least understood process of dust cycle (Knippertz and Stuut, 2014; Mahowald et al., 2014; Shao et al., 2011).

Dry deposition and wet deposition are the two paths for dust removal from the atmosphere. Various dust models adopted a fairly standard physical scheme for describing dry deposition (Seinfeld and Pandis, 2006), deriving the deposition flux from the multiplication of the dust concentration and deposition velocity. However, diverse physical schemes for wet deposition were applied (Giorgi and Chameides, 1985; Rasch et al., 2000). The simplest scheme among them, for example, is assuming the dust scavenging amount proportional to that of the precipitation (Tegen and Fung, 1994). Different parameterizations of wet deposition schemes and the deposition velocity in the dry deposition scheme in various models produced considerable differences among their estimates (Huneeus et al., 2011; Mahowald et al., 2014; Shao et al., 2011; Schulz et al., 2012). There had been, however, few field deposition measurements to constrain the uncertainties in model estimates.

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Sporadic measurements of the deposition flux of dust had been partially compiled in Huneeus et al. (2011) and Shao et al. (2011), covering sites from the dust sources to remote oceans around the globe. The measured flux varies from less than 1 g to thousands of grams per square meter every year. Many of these measurements had no subsequent or parallel studies to corroborate, while measurements from overlapping oceanic areas in a few studies show significant differences from each other and model estimates (Shao et al., 2011). The scarce size-distribution measurements of deposited dust in various areas also show large discrepancies with theoretical expectations (Betzer et al., 1998; Maring et al., 2003; Ryder et al., 2013). This inconsistency between field measurements and theoretical estimates suggests that the physical schemes applied in present models still need significant improvements.

Field measurements are the most important approach to reveal meteorological constraints on dust deposition. Due to difficulties in sampling, most previous studies provided flux and size distribution variations of deposited dust on a coarse time resolution, ranging from a few days to months (Offer and Goossens, 2004; Yan et al., 2015a; Zhang et al., 2010). Since dust deposition and atmospheric parameters vary on synoptic or shorter timescales, long-term measurements are not suitable to reveal the natural constraints on dust deposition. This study presents flux and size distribution profiles of daily dustfall in Xi'an on the southeast of the Chinese Loess Plateau covering four seasons from early 2012 to early 2013. By comparing with daily meteorological parameters, this study focuses on revealing meteorological constraints on dust flux and size distribution.

2. Sampling and methodology

2.1. Sampling

Detailed sampling information and procedures had been reported by Yan et al. (2015a, b). They are briefly stated as follows. Xi'an situates on the southern Chinese Loess Plateau, the world's famous dust sink. It is around 500 km downwind to the southeastern edge of the world's second largest dust emission center, Chinese deserts and Gobi deserts. The sampling site situates on a four-storied building at the Institute of Earth Environment, Chinese Academy of Sciences, in the southwestern Xi'an, which is surrounded by commercial and residential districts. Water surface was adopted to collect insoluble dustfall. Four glass samplers with water covering the bottom were placed at around 1 m above the roof. Samples were collected at 14 O'clock every day. The sampling campaign was conducted throughout the spring in 2012 and half a month each in the subsequent summer, autumn and winter. With a few samples missing due to incidents in sampling, a total of 131 samples at March 8 - June 1, July 10–24, and November 5–19, 2012, and January 24 - February 8, 2013 (without February 6) were collected. No obvious pollution from around the samplers was observed during the sampling campaign.

2.2. Measurements

Collected samples were sifted through a 100 mesh sieve to remove fallen leaves and insects, dried at 40 °C, and weighed. Dust flux was calculated following:

$$\mathrm{Flux} = \mathrm{weight}/(\mathrm{area} * \mathrm{time})$$

here weight is in g, area is in m^2, and time is in day.

Samples with enough mass, a total of 121 samples, were subjected to size distribution measurements. Following the procedures of Lu and An (1998), samples were treated with 30% hydrogen peroxide (H_2O_2) to remove organic matter, and then with 10% hydrogen chloride (HCl) to remove carbonates and iron oxides. Before measurements, the residues were dispersed by adding 10% sodium hexametaphosphate ($(NaPO_3)_6$) while oscillating in an ultrasonic vibrator. Size distribution measurements were conducted using a Malvern Mastersizer 2000 in the sedimentology laboratory at the Institute of Earth Environment, Chinese Academy of Sciences. Results were reported as volume percentages in 100 size-bins from 0.02 to 2000 μm.

2.3. Deposition scenarios

Previous studies had demonstrated that dustfall in Xi'an is usually a mixture of dust from various sources, including dust of long-range transport from Chinese deserts and Gobi deserts, regional dust from surrounding human habitats, and local dust from Xi'an itself (Yan et al., 2015a, b). Among them, contribution from anthropogenic local dust, such as fugitive dust from roads and construction dust, is less constrained by meteorological factors. In addition to varying dust supply from different sources, this would obscure correlation between dust characteristics or indices and meteorological parameters. As an important meteorological factor, precipitation could efficiently remove dust aerosols from air masses. In the meantime, it increases moisture of local soil/loose sediment, reinforces interparticle forces, and therefore increases the erosion threshold of soil/loose sediment and decreases local dust emission (Knippertz and Stuut, 2014). Different deposition scenarios can thus be discerned based on local precipitation records to make possible relationships between dust indices and meteorological factors more prominent.

We therefore regrouped the dataset into four deposition scenarios, including initial dry, initial wet, consecutive dry, and consecutive wet deposition scenarios. The underlying rationale is that: given precipitation has negligible influence on dust of long-range transport (precipitation is rare in deserts and Gobi deserts), on the first day of precipitation (initial wet), dust deposition has composite influence from all sources, while the influence of resuspension and contribution from local sources (and maybe some regional sources depending on the rainfall area) are lessened; dust deposition is further exempt from those on the following rainy days (consecutive wet); after the rain stops, it takes a few hours to days for soil/loose sediment to dry out, dust deposition suffers serious shortage of local dust (and maybe some regional dust) on the first day (initial dry); on the following clear days (consecutive dry), soil/loose sediment is more likely to have dried out, and dust deposition is influenced by dust contribution from all sources. Dust deposition in initial dry and consecutive wet deposition scenarios are therefore more source-limited, while they are more transport-limited in consecutive dry and initial wet deposition scenarios.

We investigated the correlation among the dust flux, grain size proxies, and a series of meteorological parameters, including wind speed (extreme, maximum, and average wind speeds), wind direction, temperature, pressure, water vapor pressure, sunshine duration, relative humidity (average and minimum relative humidity), and precipitation. Among them, grain size proxies refer to the mean grain size and percentages of four size ranges, i.e. less than 5.5, 5.5–16, 16–44, and larger than 44 μm, which are important in studies of paleo-climatic reconstruction (Újvári et al., 2016; Vandenberghe et al., 1997). The extreme wind speed is the maximum instantaneous wind speed, while the maximum wind speed is the maximum 10-min-average wind speed. All meteorological data come from the national daily dataset of surface weather profile provided by the National Meteorological Data Center (http://data.cma.cn/).