Atmospheric Environment 61 (2012) 56–65

Contents lists available at SciVerse ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Seasonal variations in dust concentration and dust emission observed over Horqin Sandy Land area in China from December 2010 to November 2011

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HIGHLIGHTS

► Seasonal variations in dust concentration and dust emission flux.
► Effects of meteorological and soil conditions on dust emission.
► Evaluation on dynamic and thermal impact of turbulence on dust emission flux.

ARTICLE INFO

Article history:
Received 16 March 2012
Received in revised form
1 July 2012
Accepted 3 July 2012

Keywords:
Horqin Sandy Land area
Dust concentration
Dust emission flux
Friction velocity
Free convective velocity

ABSTRACT

Hourly mean dust concentration observations and meteorological measurements obtained from a sandstorm monitoring station in Horqin Sandy Land area in China from December 2010 to November 2011 were used to investigate the seasonal variations in dust concentration and dust emission flux as well as their relationship with meteorological parameters and soil condition. Based on 14 local dust emission events in spring 2011, the friction velocity (u_*) and free convective velocity (w_*) were calculated, and their correlation with dust emission flux was used to evaluate the dynamic and thermal impact on dust emission by turbulence. Results indicated that dust events occur in every season with peak dust activity in spring. The maximum dust concentration is 1654.1 μg m^{-3} and dust emission flux is 98.4 μg m^{-2} s^{-1}. Freezing of soil in winter effectively decreases soil erodibility and suppresses dust emission. However, soil moisture does not show a significant impact on dust emission in this semi-arid Horqin Sandy Land area. Both friction velocity and free convective velocity could reflect the trend in dust emission flux, but both with obvious underestimation. The thermal impact on dust emission by turbulence is found to be far less than its dynamic impact.

1. Introduction

Each year, an estimated 2000 million tons of dust is emitted into the atmosphere, 75% of which is deposited to the land and 25% to the ocean (Shao et al., 2011a). These dust particles participate in many atmospheric, physical, chemical and bio-geological processes of the Earth system (Xuan, 2004; Shao et al., 2011a,b). Dust particles with diameter less than 20 μm (PM20) can undergo a long distance transport and suspend in the atmosphere for a few weeks, resulting in profound impact on the energy balance of the Earth system via direct and indirect radiative processes and considerable contribution to the exchange of materials such as organic compound and iron on a global scale. Finer dust particles with diameter less than 10 μm (PM10) that are respirable adversely affect human health and cause epidemic diseases (Kampa and Castanas, 2008). Hence, the precise estimation of mineral aerosol emission rate is of primary importance in modeling the dust cycle as well as their effect on climate and human health. So far, the estimation of dust emission rate in modeling still has large uncertainties (Shao, 2001), and the results differ from one model to another (Uno et al., 2006; Todd et al., 2008; Darmenova et al., 2009). Those uncertainties largely lie in the absence of accurate observation of dust emission flux. Observation carried out in field experiments is important to improve the understanding of dust emission processes and to validate dust emission schemes in models (e.g., Mei et al., 2006; Shao et al., 2011b).

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http://dx.doi.org/10.1016/j.atmosenv.2012.07.007

A range of field experiments were carried out over different dust source regions, such as the famous Owens (dry) Lake in California (Lancaster and Baas, 1998; Gillette et al., 1997, 2004), the Sahelian belt in West Africa (Dubief, 1979; Bou Karam et al., 2008; Marticorena et al., 2010), and the Gobi Desert in China (Zhu and Zhang, 2010; Li and Zhang, 2011) and in Mongolia (Park et al., 2010, 2011). These experiments mainly focused on aspects including temporal and spatial variations in dust concentration, meteorological and soil condition changes during dust events, and the estimation of threshold wind or friction velocity for dust emission. For example, Park et al. (2010) indicated that dust (PM10) concentration over Gobi Desert in Mongolia has an evident positive correlation with wind speed ($r = 0.80$) and a weak negative correlation with relative humidity ($r = -0.31$) and NDVI (Normalized Difference Vegetation Index, $r = -0.35$). However, only a few of the experiments focused on the seasonal variations and the characteristics of dust emission.

The dust emission flux is determined by a great number of factors, including atmospheric condition, soil properties and land surface characteristics, etc. Consider the wind shear generated turbulent energy, the power of friction velocity u_* or wind speed U could be used as parameterization for dust emission when they exceed their threshold values, i.e. $u_* > u_{*t}$ or $u > u_t$ (e.g., Gillette, 1977; Gillette and Passi, 1988; Nickling and Gillies, 1989; Tegen and Fung, 1995; Uno et al., 2001). Such simple schemes do not require hard-to-obtain parameters such as soil particle size distribution (PSD) used in physically detailed dust emission schemes (e.g., Shao, 2001, 2004), and therefore are still widely used in some general circulation models and regional simulations (Shao and Dong, 2006; Uno et al., 2006; Ishizuka et al., 2008). However, the thermal effect of turbulence on dust emission flux has seldom been investigated in field experiments. Some parameterization schemes of momentum, heat and moisture fluxes over land under free convective condition proposed the use of a key parameter, the free convective velocity w_* (Sykes et al., 1993; Stull, 1994; Beljaars, 1994). Recently, Park et al. (2011) found that higher convective velocity enhanced the dust concentration of dust events during the cold period from December to March and caused a reduction during the warm period from April to October, because changes in the depth of atmospheric boundary layer would affect the vertical distribution of dust concentration.

In this study, observations from a sandstorm monitoring station at Naiman downtown in Inner Mongolia of China from December 2010 to November 2011 were used to analyze the temporal variations in dust concentration and dust emission flux, and their relationship with meteorological and soil condition was evaluated in different seasons over Horqin Sandy Land area. The friction velocity (u_*) and free convective velocity (w_*) were calculated in order to explore the dynamic and thermal effect of turbulence on dust emission flux F. The correlation between F and u_* and that between F, u_* and w_* was compared. The paper is organized as follows: in Section 2, details on the experiment site and data used in this paper are described. In Section 3, the variations in dust concentration and dust emission flux as well as their relationship with meteorological and soil condition are being investigated. The friction velocity and free convective velocity are calculated based on 14 local dust events in spring 2011, and their correlation with dust emission flux are also calculated to evaluate the dynamic and thermal impact of turbulence on dust emission. In Section 4, conclusions from this study are drawn.

2. Data and method

2.1. Data from Naiman station

A sandstorm monitoring station with a 20-m observational tower is located about 10 km to the north of Naiman downtown

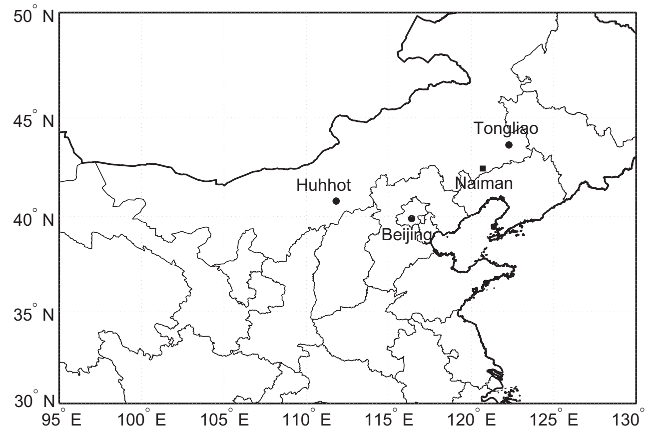

Fig. 1. The geographical location of experiment site in Naiman Banner of China.

(42°27′N, 120°42′E) in Inner Mongolia of China and in the eastern edge of the Horqin Sandy Land area (Fig. 1). This region had a typical semi-arid climate with an annual precipitation rate of 300–400 mm. The surrounding landscape of the station is characterized by gentle undulating, shifting, and semi-shifting dunes and fixed dunes with largely low, open shrub vegetation (Zhao et al., 2007).

The observations at Naiman station include wind direction, four levels of wind speed, air temperature and humidity, radiation components, three depths of soil moisture and soil temperature, precipitation, two levels of dust concentration, and turbulent components of wind and temperature. The detailed descriptions of observations and instruments are listed in Table 1.

All the variables were recorded automatically and continuously with 10-min intervals, and the turbulence measurements were recorded with a response frequency of 10 Hz. A 60-min running average was applied to the data, and then hourly mean data were calculated with the smoothed data (Park et al., 2011). Error records of dust concentration due to beta gauges failure under low temperature or power shortage were discarded. In order to keep

Table 1
Instrumental setting at Naiman station.

Observations	Height/Depth	Instrument Type, Manufacturer	Accuracy
Dust concentration[a]	3 and 18 m	FH62-C14, Thermo	0.1 $\mu g\ m^{-3}$
Wind speed	2, 4, 16, and 20 m	A100LM, Vector Ins.	0.1 $m\ s^{-1}$
Wind direction	20 m	W200P, Vector Ins.	±3
Air temperature	2, 4, 8, and 16 m	HMP45C, Vaisala	0.2 °C
Relative humidity	2, 4, 8, and 16 m	HMP45C, Vaisala	±3%
Short radiation	2 m	LI200X, Li-Cor	±5% maximum
Net radiation	2 m	Nr-Lite, Kipp&Zonen	10 $\mu V\ W^{-1}\ m^{-2}$
Precipitation[b]		Young	2% up to 25 $mm\ h^{-1}$ 3% up to 50 $mm\ h^{-1}$
Soil temperature	5, 20, and 50 cm	107, Campbell	±0.2 °C
Soil moisture content	5, 20, and 50 cm	CS616, Campbell	±2%
Wind fluctuation	8 m	CSAT3, Campbell	±0.01 $m\ s^{-1}$
Temperature fluctuation	8 m	CSAT3, Campbell	±0.01 °C

[a] Dust mass concentration was obtained from beta gauges operating at a flow rate of 1000 $L\ h^{-1}$.
[b] Precipitation was measured by a tipping-bucket rain gauge with a resolution of 0.1 mm.