Atmospheric Environment 140 (2016) 420–431

Contents lists available at ScienceDirect

Atmospheric Environment

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

A parameterization of dust emission (PM_{10}) fluxes of dust events observed at Naiman in Inner Mongolia using the monitored tower data

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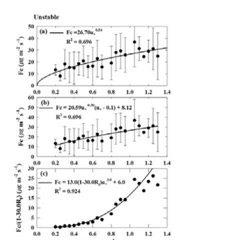
HIGHLIGHTS

- The Naiman tower data are used for the dust emission flux (F_c) of dust events.
- Dust events are defined with the mean dust concentration and the standard deviation.
- 317 dust events are identified from March 2013 to November 2014 at the Naiman site.
- F_c is parameterized with the friction velocity (u_*) and the flux Richardson number (R_f).
- The good estimation of F_c requires both u_* and R_f rather than u_* only.

GRAPHICAL ABSTRACT



The optimal regression equations with R^2 values of the PM_{10} emission flux (Fc) parameterized by u_* only, by u_* and u_{*t} and by u_* and R_f are shown in (a), (b) and (c) respectively.

ARTICLE INFO

Article history:
Received 16 January 2015
Received in revised form
2 June 2016
Accepted 6 June 2016
Available online 7 June 2016

Keywords:
Asian dust monitoring tower
Convective velocity
Dust emission flux
Flux Richardson number
Gradient method
Naiman
Optimal regression equation

ABSTRACT

The optimal regression equations for the dust emission flux parameterized with the friction velocity (u_*) only, the friction velocity with the threshold friction velocity (u_{*t}) and the friction velocity together with the flux Richardson number (R_f) in the dust source region are derived using the sonic anemometer measured momentum and kinematic heat fluxes at 8 m height and the two-level (3 m and 15 m height) measured PM_{10} concentrations from a 20-m monitoring tower located at Naiman in the Asian dust source region in China for the period from March 2013 to November 2014. The analysis period is divided into three sub-periods based on the Normalized Difference Vegetation Index (NDVI) to eliminate the effect of vegetation on the dust emission flux. The dust event is identified as a peak half hourly mean dust concentration (PM_{10}) at 3 m height exceeding the sub-period mean dust concentration plus one standard deviation of the sub-period. The total of 317 dust events is identified with the highest number of dust event of 18.8 times a month in summer. The optimal regression equations of the dust emission flux (F_c) for dust events parameterized with u_* and R_f are found to simulate quite well the dust emission flux estimated by the observed data at the site for all periods especially for the unstable stratification, suggesting the potential usefulness of these equations parameterized by u_* with R_f rather than those by u_* only and u_* together with u_{*t} for the estimation of the dust emission flux in the Asian dust source region.

1. Introduction

Asian dusts, which are a typical example of mineral aerosol, frequently originate in the sand desert, Gobi desert, Loess plateau

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http://dx.doi.org/10.1016/j.atmosenv.2016.06.004
1352-2310/

and mixed barren soil area in northern China and Mongolia. These occur all year around with a maximum frequency in spring (In and Park, 2002; Park and In, 2003; Park and Lee, 2004; Park et al., 2010a,b) and often tend to cause serious adverse consequences to humans and their environment not only in the source regions but in the far downwind regions (Hagen and Woodruff, 1973; Buritt and Hyers, 1981; Goudie, 1977; Gao et al., 1992; Park et al., 2010b). Some of severe dust storms occurred in the Asian dust source region were reported to be transported to the western parts of USA across the Pacific Ocean (Husar et al., 2001; Clarke et al., 2001; Grousset et al., 2003; VanCuren, 2003; Hsu et al., 2006).

East Asia is a major source of natural (Asian dust) and anthropogenic aerosols over the northern hemisphere due to the rapid economic development in many Asian countries. Asian dust, which is called Hwangsa in Korea and Kosa in Japan, that originates in northern China and Mongolia in the arid and semi-arid regions will experience pollutants emitted from the industrialized regions that are heavily concentrated in the eastern parts of China during long-range transport of dust. Consequently, a significant transformation of chemical composition of the dust is expected (Saxena and Seigneur, 1983; Gao et al., 1991; Kang and Sang, 1991; Perry et al., 1997; Kim and Park, 2001; Arimoto et al., 2004; Park et al., 2005; Park and Joeng, 2008).

The Korean peninsula that is located in the downstream region of the Asian dust source regions, is often affected by severe dust storm events, especially in spring with the observed PM_{10} concentration over 1500 $\mu g\ m^{-3}$ at most monitoring sites in Korea (KMA, 2014), causing serious social impacts including temporal closing of most airports and elementary schools in Korea (Park and Lee, 2004). These series of dust events have motivated to develop the Asian Dust Aerosol Model (ADAM) to forecast Asian dust events in Korea. Since the ADAM model was developed as an operational forecasting model in Korea Meteorological Administration (Park and In, 2003; In and Park, 2003) in 2002, the model has been revised several times to the ADAM2 model (Park and Lee, 2004; Park et al., 2008, 2010a,b). The ADAM2 model was implemented to simulate Asian dust events observed in Korea and found that the model had great potentials for the use of an operational Asian dust forecast model in the Asian domain (Park et al., 2010c). However, more accurate prediction of the dust concentration required further study on proper parameterizations of dust emission processes in the source region (Park et al., 2010c).

For this purpose a 20-m monitoring tower at Naiman (42° 27′N and 120° 42′E, 367 m) in Inner Mongolia in the Asian dust source region was installed in 2007 (Fig. 1). The Naiman site is located in one of the major pathways of dust storms that occur in central northern China and southeastern Mongolia to the Korean peninsula. The occurrence of the dust storm in the Horqin desert affects severely the Korean peninsula due to its nearness to Korea. From 2002 to 2012, about 60% of the dust events observed in Korea (annual average of 8.9 times) have their pathways through the Horqin desert where the Naiman site is located but that has been increased to 70% for the last two years of 2013 and 2014 (KMA, 2014).

The dust concentration observed at a site in a source region is primarily determined by the advection, emission and deposition of dust. Most of dust emission models use the surface features and the threshold friction velocity which is related to the momentum flux (Gillette, 1979; Marticorena and Bergametti, 1995; Park and In, 2003; Tegen and Fung, 1994; Helgren and Prospero, 1987; Westphal et al., 1988; Shao, 2004; Park et al., 2010a, 2010b; Gillette and Passi, 1988). Therefore the dust emission fluxes in many studies are usually parameterized by the wind shear generation of turbulent energy (friction velocity) only without considering thermal turbulence induced by the temperature difference between the surface soil and the air near the ground. Since the ground surface in the dust source region is usually dry and little vegetated, the temperature difference undergoes a remarkable diurnal variation thereby affecting dust emission intensity through diurnally varying sensible heat flux. However, sensible heat fluxes from the ground have been excluded in the parameterization of dust emission in the dust source region in most dust models including Asian Dust Aerosol Models (ADAM). Recently Park et al. (2011b) parameterized the dust concentration in terms of friction velocity and the convective velocity using the monitored data at the Erdene site located in the southeastern part of Mongolia. They showed that the dust concentrations can be driven by the thermal turbulence (convective velocity) as well as mechanical turbulence (friction velocity). Park et al. (2011a) showed that dust emission fluxes for the local dust emission cases at the Naiman site in Inner Mongolia can be enhanced by the convective velocity for both the stable and unstable stratifications in winter.

The purpose of this study is to estimate dust emission (PM_{10}) fluxes by parameterizing the dust emission flux in terms of the friction velocity and the convective velocity scale during the dust event periods with the use of monitored data from the tower installed at Naiman (Horqin desert) in Inner Mongolia, China.

2. Monitoring site and instrumentations

Naiman county is located about 500 km to the north-east of Beijing, the capital city of China, and located in the eastern edge of the Horqin desert (Fig. 1) that is severely affected by overgrazing and overcutting (Imagawa et al., 1997). The Naiman tower (42° 56′N, 120°42′E, 367 m) is located about 10 km to the north of Naiman downtown and to the south-eastern edge of the Horqin desert with many sprawling sand dunes (Fig. 1b). The main dust source region is extended toward the west and the north of the tower. The surface soil at the tower site is a mixed soil mainly composed of sandy and clay soils, and severely affected by desertification.

The annual mean temperature of the Naiman site is 6.4 °C and the annual total precipitation is 372 mm (Imagawa et al., 1997) with the annual mean potential evaporation of 1935 mm (Zhao et al., 2007). The landscape is characterized by gently undulating, shifting and semi-shifting dunes and fixed dunes (Fig. 1b). The vegetation at the tower site consists largely of low, open shrub dominated by Caragana microphylla, Salix gordejevii and Artemisia halodendron (Zhao et al., 2007).

The Naiman monitoring tower is a 20-m triangular lattice mast equipped with a sonic anemometer (CSAT3, Campbell Scientific Inc.) to measure turbulent momentum and sensible heat fluxes at 8 m height, the vertical profiles of air temperature and relative humidity at 2, 4, 8 and 16 m height and of wind speed at 2, 4, 16 and 20 m height, soil temperature and soil moisture sensors at 5, 20, 50 cm depth, radiation and air pressure sensors at 2 m height, and precipitation at the surface, and PM_{10} concentration measurements (FH62C14, Thermo Scientific) with the resolution of 0.1 $\mu g\ m^{-3}$ at 2 levels (3 m and 15 m height) (Fig. 1c). The inlet of the FH62C14 at the 3 m height is the part of the β-gauge but that at the 15 m height is extended using a teflon tube that is attached to the tower so as to minimize the flow disturbance due to the tube. These two Beta gauges are operating at a flow rate of 1000 l h^{-1} and calibrated at the site every 6 months.

3. Data and methodology

The measured data for the period from March 2013 to November 2014 are used for the parameterization of the dust emission flux. Three component wind speeds (u, v, w) and a sonic temperature (T)