PERGAMON

Atmospheric Environment 34 (2000) 4565–4570

ATMOSPHERIC ENVIRONMENT

www.elsevier.com/locate/atmosenv

Technical note

Dust emission inventory in Northern China

Jie Xuan*, Guoliang Liu, Ke Du

Environment Science Center, Peking University, Beijing 100871, People's Republic of China

Received 11 May 1999; accepted 17 March 2000

Abstract

This paper deals with mineral dust emission inventory from surfaces of Northern China. The inventory was calculated with a US EPA formula by inputting the pre-processed Chinese data of pedology and climatology. Mainly, the emission factor (emission rate) of the dust particles whose diameters are less than 0.03 mm increases from east to west of the area by five orders of magnitude and there are two strong emission regions, one is in Takelamagan desert, Xinjiang Province, and the other in Central Gobi-desert, western part of inner-Mongolia plateau. The maximum rate is at center of the Takelamagan desert, i.e., 1.5 ton ha yr^{-1}. Also, the total annual emission amount of the area is equal to some 25 million tons, and spring is the worst dust-emitting season in the area, which takes more than half of the annual emission amount. The results are in good agreement with the previous calculations using a different US EPA formula (Xuan, J., 1999. Dust emission factors for environment of Northern China. Atmospheric Environment 33, 1767–1776).

Keywords: Mineral dust; Emission factor; Dust emission inventory; TSP; China

1. Introduction

The suspended particulates of the air are not only harmful to the human respiratory system but also effect important atmospheric processes, e.g., the global climate change (Saxena, 1997) and the regional acid rain. For example, in Northern China where calcium ion Ca^{2+} concentration of aerosols is much higher than in Europe, the calcium ions successfully neutralize the acidity of the rainfall though the emission amounts of acid gases SO_2 and NO_x are also very large in the area (Peking University, 1995). A recently published paper on acid rain reports the same result in South Korea (Lee et al., 2000). Those calcium ions are of desert dust origin from Northern China.

Through weather records of sandstorms (Geng, 1985) and chemical analyses of aerosol samples (Zhang et al., 1997), it is well recognized that the major sources for Asian dust lie in deserts of Northern China. However, little information is available on the quantity of dust emissions in the source regions (source strength distribution). It seems that the only paper calculating the dust emission rates in the region was recently published in this journal by the first author of the present paper (Xuan, 1999). Using a US EPA formula (OAQPS, 1977), the author computed both distribution of the emission rates and the total emission amount of the dust smaller than 50 μm in diameter (in short as TSP_{50}) in Northern China, concluding some basic characters for the dust emissions in the area.

For the purpose of comparison and confirmation, we did a similar computation for TSP_{30} using a different US EPA formula (Cowherd et al., 1979), whose results are to be discussed in this paper. It seems that present results are in close agreement with the previous ones. This quantitative agreement can be considered to support the reliability of our calculation results as the two formulae are rather different. It also means that the two formulae are suitable to use in so vast a region.

2. Methodology

The following equation is the EPA formula used for our TSP_{30} calculation, which has been rewritten with

* Corresponding author. Tel./Fax: +86 10 6 2871784.
E-mail address: jiexuan@pku.edu.cn (J. Xuan).

1352-2310/00/$ - see front matter
PII: S 1 3 5 2 - 2 3 1 0 (0 0) 0 0 2 0 3 - X

standard units:

$$Q'_e = 0.2058esf/\mathrm{PE}^2, \quad (1)$$

where Q'_e denotes the annual dust emission rate, ton ha yr^{-1}; e the erodibility index of different soil types, ton ha yr^{-1}; s, the silt content, i.e., the weight percentage of particles smaller than 75 μm (%); f the threshold wind speed ratio, i.e., the time percentage of mean wind speed u higher than a threshold value of 5.4 m s^{-1}; and PE the Thornthwaite's precipitation-evaporation index.

A great difficulty of using the formula exists, i.e., the above input parameters are not available from Chinese climatic and pedological data. For example, the soil parameter e (erodibility index) which scientists and engineers in the United States have precisely tested for different soil types, are still at a very beginning stage of study (Liu et al., 1999). The same situation exists for the climate parameter PE. My previous paper (Xuan, 1999) has described the technical details about how to do pre-processing of the Chinese pedological and climatic data so as to obtain the erodibility index e, the Thornthwaite's precipitation–evaporation index PE and some other parameters.

The other two factors in the present equation are a soil parameter s, named silt content, and a climatic parameter f, named threshold wind speed ratio. According to American soil data, the value of s is ranged between 13.6 and 20 for different soil types, its mean value of 17 was adopted in our calculation. As for f, it needs to be pre-calculated to find the percentage frequency of mean wind speed u at each weather station. Unfortunately, this kind of work has not been done with the huge amount of original wind speed records stored in the Chinese State Meteorological Administration. So, we have to follow the idea of probability distribution of mean wind velocity at a point suggested by Xu (1984) for the f computation, i.e.

$$f = \exp[-(V_c/M)^k], \quad (2)$$

where V_c denotes the threshold wind speed ($= 5.4$ m s^{-1}), and the exponent k is obtained from regression of the mean wind speed u:

$$k = 0.74 + 0.19u. \quad (3)$$

The mode M is calculated from the following equation:

$$M = u/\Gamma(1 + 1/k), \quad (4)$$

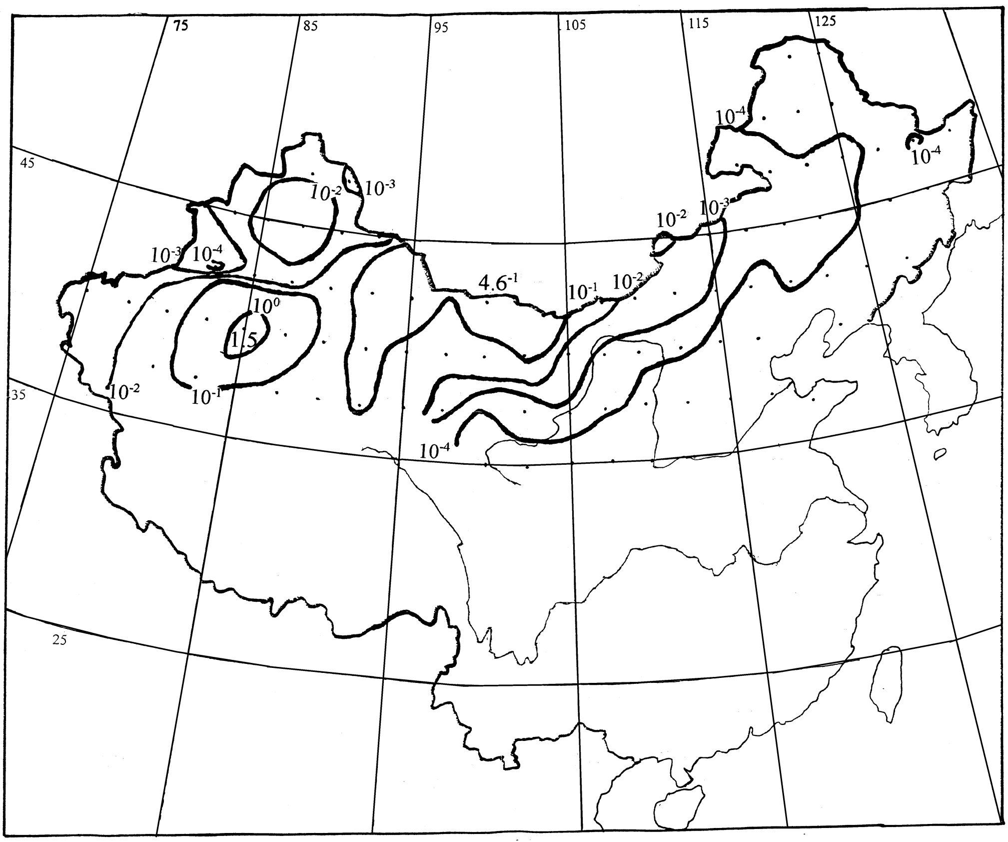

Fig. 1. Annual dust emission rate Q'_e (ton ha^{-1} yr).

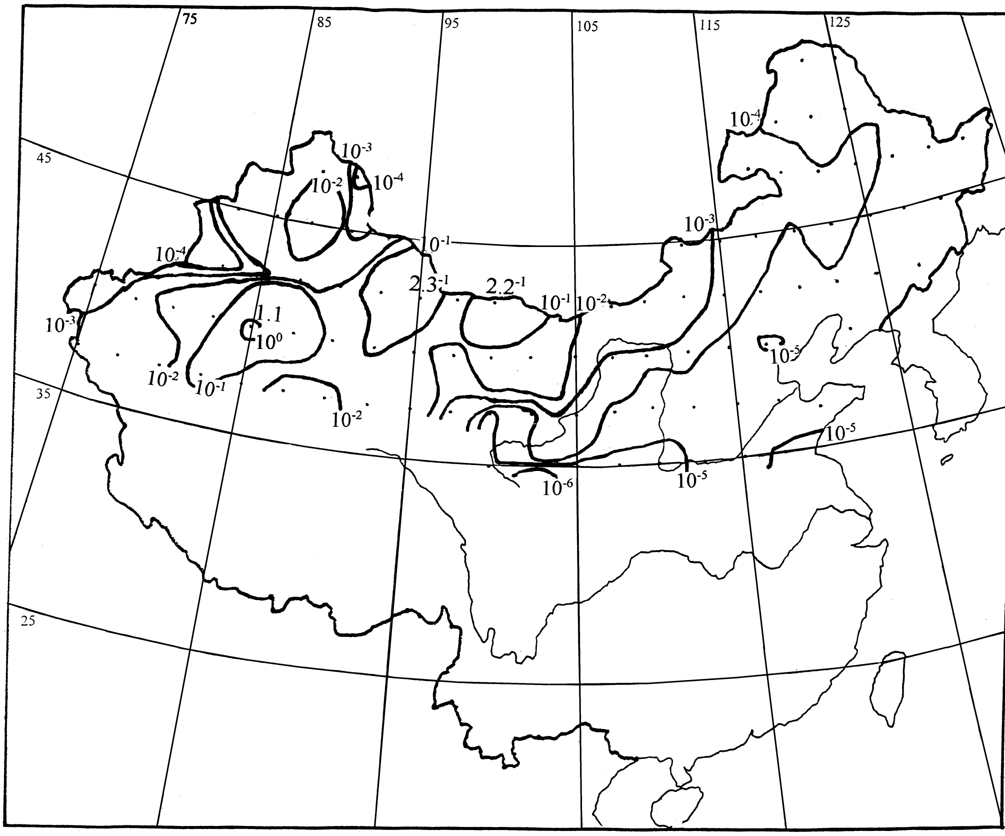

Fig. 2. Dust emission rate in spring Q'_1 (ton ha^{-1} spring).

where Γ is the Gamma function. So, the three Eqs. (2)–(4) were used to obtain the threshold wind speed ratio f with only the data of the mean wind speed u. It has been argued since the very beginning that the threshold wind speed V_c may be of different values for different surfaces. However, we adapted the suggested value of 5.4 m s^{-1} by the author of the formula as no other values seemed more reasonable, and we found the results of the computation rather good.

3. Results and analyses

We calculated the dust emission rates of 92 locations of Northern China. We also divided the annual rates into four seasons, respectively, on its percentage of the seasonal value of the ratio f/PE^2. Fig. 1 shows the contours of the annual dust emission rate Q'_e. Figs. 2–5, respectively, show the contours of the four seasonal dust emission rates: Q'_1 (March–May, spring), Q'_2 (June–August, summer), Q'_3 (September–November, autumn) and Q'_4 (December–February, winter). In all the figures, the highest and second highest emission rates are shown.

It can be seen from Fig. 1 that, because of the joint effects of climatic aridity and soil texture, the dust emission rate Q'_e increases from east to west as much as by five orders of magnitude. And, the contours of $Q'_e = 10^{-1}$ ton ha yr^{-1} in the figure show us the two strong emission areas, the first of which is at the center of Takelamagan desert and the second in west part of Inner-Mongolia plateau (the famous Central Gobi-desert). It is in good agreement with the most frequent sandstorm areas observed by meteorologists (Xu and Hu, 1997). The spatial distributions of the four seasonal dust emission rates are of similar patterns. Also, there is a maximum annual emission rate, 1.5 ton ha yr^{-1}, at the center of Takelamagan desert.

The total dust emission amount of Northern China roughly equals 25×10^6 ton yr^{-1}, and the total amounts for four seasons are: 15×10^6 ton in spring, 1.4×10^6 ton in summer, 5.7×10^6 ton in autumn and 2.9×10^6 ton in winter. It seems that spring is the worst season for dust emissions. It accounts for more than half of the annual

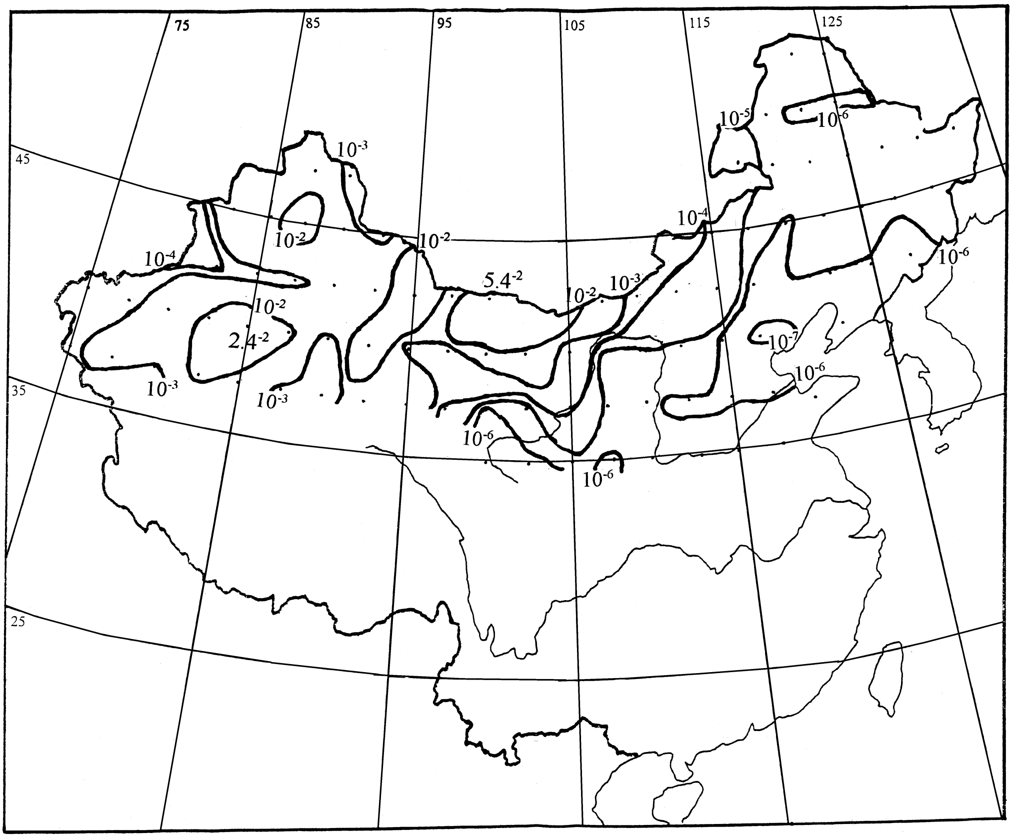

Fig. 3. Dust emission rate in summer Q'_2 (ton ha^{-1} summer).

emission amount. The results are in good agreement with weather records (Xu and Hu, 1997).

We have compared the results with our previous calculation for TSP_{50} (Xuan, 1999), in which a different US EPA equation was used (Cowherd et al., 1979)

$$Q_e = ecCKLV \quad (5)$$

where Q_e denotes the annual dust emission rate of TSP_{50}, ton ha yr^{-1}; c the TSP content, i.e., the weight ratio of particles smaller than 50 μm in diameter to total erodible soil particles; C the climatic factor, $C = 0.504\,u^3\,\mathrm{PE}^{-2}$; K the surface roughness factor, 1 or 0.5 for smooth or rough surfaces, respectively; L the unsheltered field width factor, 0.7 or 1.0 for fields of width 300 m (and less) or 600 m (and more); V the vegetation cover factor, 1.0 if no vegetation. It is very encouraging to find that the main characters for TSP_{30} and TSP_{50} emission rates agree with each other, though computed with different equations. For example, the two strong emission areas are nearly the same for both TSP_{30} and TSP_{50} and the total emission amounts of TSP_{30} and TSP_{50} are compatible: the latter amounts are 43×10^6 tons annually, 25×10^6 tons in spring, 2.5×10^6 tons in summer, 8.6×10^6 tons in autumn and 7.4×10^6 tons in winter. Furthermore, the maximum dust emission rates are comparable too: 1.5 ton ha yr^{-1} for TSP_{30}, and 1.8 ton ha yr^{-1} for TSP_{50}. The good agreement seems to support the reliability of our calculation results.

The two equations are different in some aspects. The Thronthwaite's precipitation–evaporation index is the same. Also, the soil factors are the same in the two equations, except for the TSP definitions: TSP_{30} for the factor s in Eq. (1) or TSP_{50} for the factor c in Eq. (5). The main difference between the two equations is in the function of the mean wind speed u, the principal factor affecting dust emission processes. The factor f in Eq. (1) suggests that the dust emission rate is proportional to the time percentage of wind speed u which is higher than a threshold value of 5.4 m s^{-1}, while the factor C in Eq. (5) means that the rate is proportional to the third power of mean wind speed u^3. Both the above rules are well recognized; however, it should be pointed out that

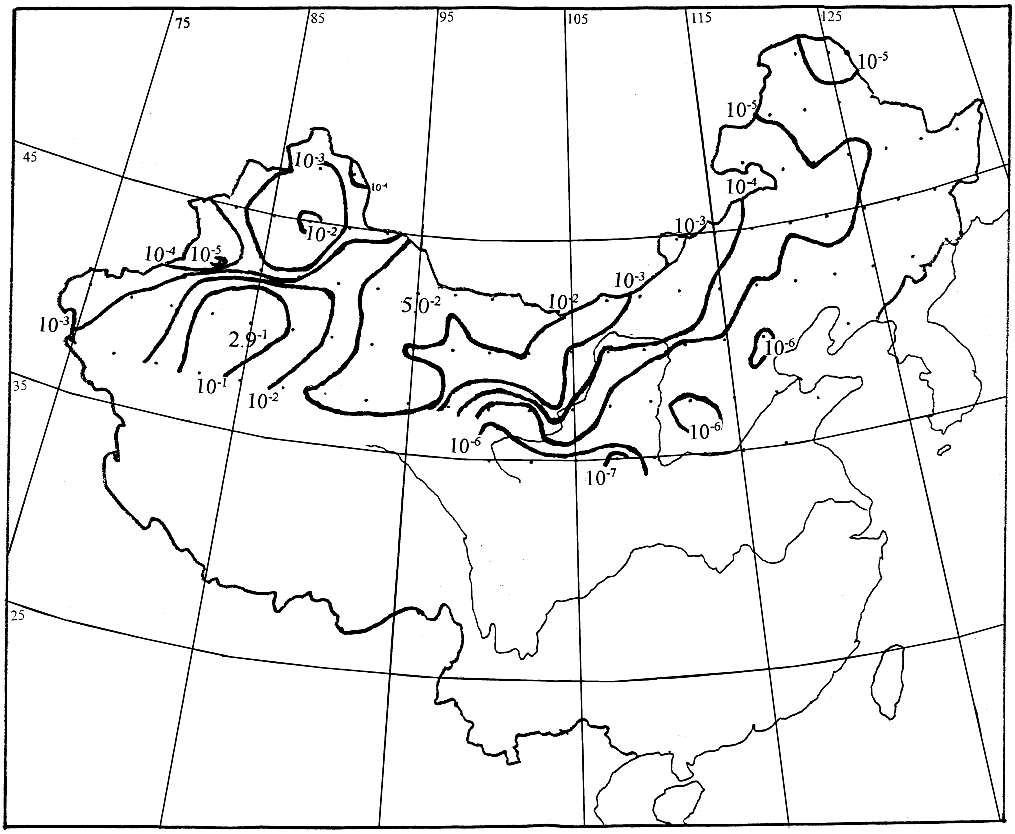

Fig. 4. Dust emission rate in autumn Q'_3 (ton ha^{-1} autumn).

the threshold wind speed ratio f in Eq. (1) depends also on soil conditions because the threshold wind speed V_c is a soil factor. There is still one more difference that the three surface parameters in Eq. (5), K, L and V, are not included in Eq. (1). In spite of the differences, calculations with the two equations have given very similar results, the agreement strongly supports our calculation results. In reality, the results are also compatible with the previous Saharan data (Junge, 1979), i.e., the total dust (TSP_{50}) emission amount from Sahara desert is estimated to be between 60 and 200 million ton yr^{-1} while for global emissions it is between 100 and 500 million ton yr^{-1}.

There exists significant error in dust emission estimation because of the investigation difficulties, e.g., the uncertainty factor for previous Saharan dust emission data is usually 2–3 (Junge, 1979). I am also unable to quantify the total error because some formulae and data used in my calculating procedure were officially published with no error information on them. However, at most an error of 100% should be supposed when one uses the calculation results.

4. Conclusions

(i) The mineral dust (TSP_{30}) emission rate in Northern China increases from east to west as much as by five orders of magnitude. A maximum rate appears in central Takelamagan desert, equaling some 1.5 ton ha yr^{-1}, and the total amount of the dust emitted into the air every year in the region is estimated to be some 25 million tons.

(ii) There are two strong emission areas in the region: the first one is in Takelamagan desert and the second in the western part of the Inner-Mongolia plateau.

(iii) Spring is the worst season for dust emissions. Its emission amount is about 15 million tons, more than half of the annual amount.

(iv) The two US EPA formulae are suitable for computing dust emission rates from surfaces so vast in area.

(v) Among others, the soil factors, e (erodibility index), c (TSP content) and s (silt content), and the climatic factor PE (Thronthwaite's precipitation–evaporation index) are the principal determinant factors to dust emission computing. The mean wind speed u is

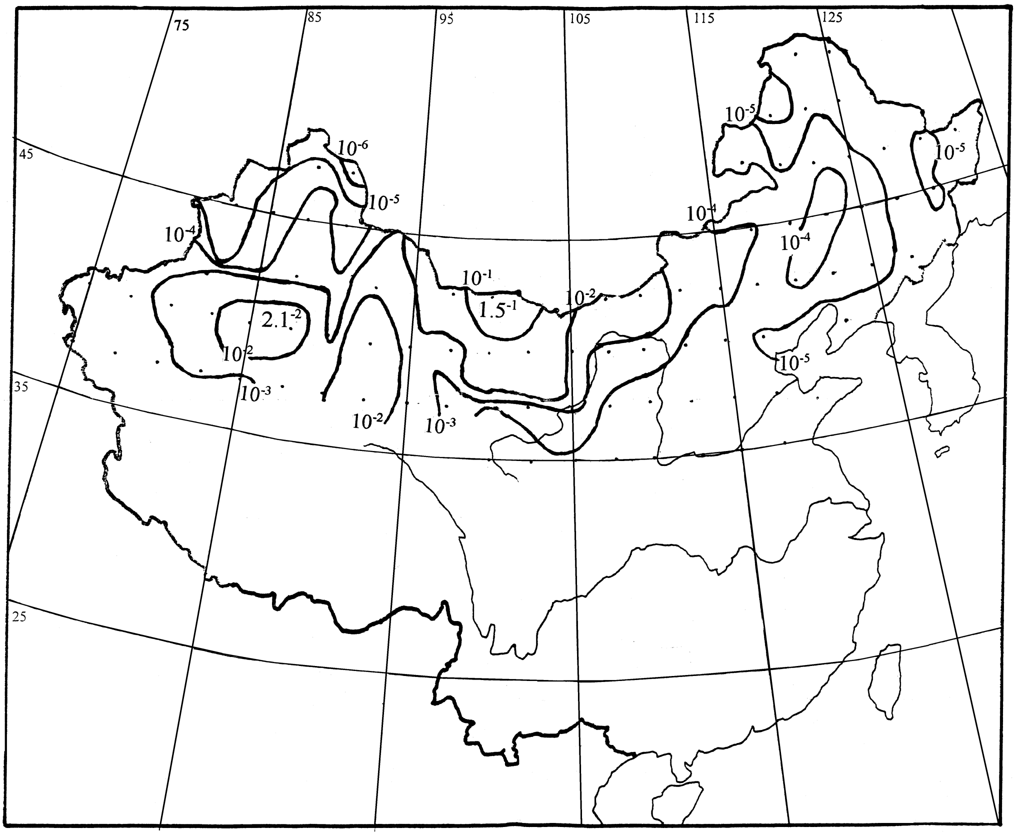

Fig. 5. Dust emission rate in winter Q'_4 (ton ha^{-1} winter).

also a principal determinant factors, however, it produces close results in our case to take into consideration its third power u^3 or its threshold wind speed ratio f.

Acknowledgements

The research is financially supported by the National Natural Science Foundation of China (NSFC) with the Project No. 49775277. Also, thanks to Professor Peter Brimblecombe and Dr Jill Austin, the editors of the journal, for correcting my poor English.

References

Cowherd, C., et al., 1979. Iron and steel plant open source fugitive emission evaluation. EPA-600/2-79-103.

Geng, K., 1985. Characteristics of aerolian-sand climate of China arid lands. In: Zhao, S. (Ed.), Physical Geography of China Arid Lands. Science Press, Beijing.

Junge, C., 1979. The importance of mineral dust as an atmospheric constituent. In: Morales, C. (Ed.), Saharan Dust. Wiley, New York (Chapter 2).

Lee, B., et al., 2000. Chemical composition of precipitation and wet deposition of major ions on the Korean peninsula. Atmospheric Environment 34, 563–575.

Liu, L., et al., 1999. Effects of gravel mulch restraining soil deflation by wind tunnel simulation. China Deaert 19, 60.

OAQPS (EPA), 1977. Guideline for Development of Control Strategies in Areas with Fugitive Dust Problems. EPA-405/2-77-029.

Peking University, 1995. The effects of particles and gases on acid depositions and parameterization. Technical Report of State Key Project No. 85-912-01-04-05.

Saxena, V.K., et al., 1997. Impact of stratospheric volcanic aerosols on climate: evidence for aerosol short-wave and long-wave forcing in the southeast US. Atmospheric Environment 31, 4211.

Xu, Q., Hu, J., 1997. Features of spatial and temporal distributions of the dust storms in North–West China. In: Fang, Z., et al. (Eds.), Studies of China Sandstorms. Meteorology Press, Beijing.

Xuan, J., 1999. Dust emission factors for environment of Northern China. Atmospheric Environment 33, 1767.

Zhang, X., et al., 1997. Dust emission from Chinese desert sources linked to variations in atmospheric circulation. Journal of Geophysical Research 102, 28041.