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Parameterization of Asian dust (Hwangsa) particle-size distributions for use in dust emission models

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Abstract

An improved dust emission model depending on the particle-size distribution constructed by the sum of three log-normal distributions of particle size of different soil types of Gobi, Sand, Loess and Mixed soil in the Asian dust source regions has been developed and implemented to an intense Asian dust event that has been observed in Korea from 21–23 March 2002. The model has incorporated the concept of the minimally and fully dispersed parent soil particle-size distribution in the source region. The result indicates that the present emission model yields much better spectral-mass concentration distribution compared to those of previously used models of the power law and the log-normal distributions of particle sizes of the soil sampled from Australia in all spectral ranges, suggesting the usefulness of the present parameterization of the spectral dust emission to forecast the Asian dust event in Korea. It also indicates that the accuracy of the spectral-mass concentration largely depends on the availability of high-quality soil particle-size distribution data in the source region.

Keywords: Asian dust aerosol model (ADAM); Dust particle-size; Dust emission model; Hwangsa; Spectral-mass flux of dust

1. Introduction

Asian dust which is called 'Hwangsa' in Korea and 'Kosa' in Japan, is a typical example of mineral aerosol frequently originating in the Gobi desert, Sand desert, Loess plateau and barren mixed soil in northern China and Mongolia during the spring season (In and Park, 2002; Park and In, 2003). In recent years, more intense and frequent dust storms in East Asia have increased with the gradual increase in arid desertification that might be caused by heavy cultivation, overgrazing and lack of precipitation in the source regions (Bai and Zhang, 2001; Park, 2002). Indeed, very severe dust storms were observed in Korea on 21–23 March and 7–9 April 2002. During these periods the observed PM_{10} concentrations were over 1000 $\mu g\, m^{-3}$ at most monitoring sites in South Korea (In and Park, 2003; Park and In, 2003); this was more than 10 times higher than those of the non-dust storm period, thereby causing natural disasters including temporal closing of most of airports and elementary schools in Korea.

These intense Asian dust (Hwangsa) events have been simulated using the three-dimensional eulerian transport model with meteorological outputs of the Regional Data Assimilation and Prediction System (RDAPS) together with the statistically derived dust emission condition using WMO 3-hourly synoptic reporting data for seven spring seasons (March–May) from 1996 to 2002 in East Asia (Park and In, 2003; In and Park, 2003). The simulations showed quite well the observed features in terms of temporal and spatial distribution of dust concentration, the starting and ending times of these events over the Korean peninsula. However, the simulated spectral-mass concentration patterns yielded quite differently compared to measurements in South Korea.

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In simulating the Asian dust event observed in March 2002 in Korea, Park and In (2003) have employed the emitted particle-size distribution of Westphal et al. (1987, 1988). Namely, the spectral-mass flux of dust is proportional to the power of 1.5 of the particle radius

$$\frac{dF_a}{d\log r} \propto r^{1.5}, \qquad (1)$$

where F_a is the dust flux from the surface and r the radius of the dust particle. However, Eq. (1) predicted a significant high concentration in the range of 10–25 μm. To improve this deficiency In and Park (2003) have employed the concept of the minimally and fully dispersed parent soil particle-size distribution (Lu and Shao, 1999; Gomes et al., 1990; Shao et al., 2002) obtained from soil samples in Australia by McTainsh (Shao et al., 2002) to simulated the dust event observed in Korea from 7 to 9 April 2002. The result indicated that a proper parameterization of the soil particle-size distribution could lead to more accurate spectral-mass concentration at the distant regions.

Consequently, the purpose of this study is to improve the spectral-mass concentration distribution observed in Korea using improved functions of minimally and fully dispersed parent soil particle-size distribution based on soil samplings in northern China.

2. A model for dust emission

The method for the estimation of total emission amounts of uplifted dust and the conditions for the dust rise in the source regions are given in Park and In (2003). The spectral dust emission may be estimated by Eq. (1) and also by the concept of the minimally and fully dispersed parent soil particle-size distribution. The particle-size distribution suspended in the air is a weighted average of minimally ($P_m(d)$) and fully ($P_f(d)$) dispersed parent soil particle-size distribution (Lu and Shao, 1999; Shao, 2001; Shao et al., 2002) and is given by

$$p_s(d) = \gamma p_m(d) + (1-\gamma) p_f(d), \qquad (2)$$

where $P_s(d)$ is the suspended particle-size distribution and γ the weighting factor. The weighting factor γ is estimated by Lu and Shao (1999) and Shao

Table 1
Parameters for the log-normal distributions to construct minimally ($p_m(d)$) and fully ($p_f(d)$) dispersed particle-size distributions for sand, loam and silty clay (Shao et al., 2002)

Sample	Mode 1			Mode 2			Mode 3		
	w_1	ln (D_1)	σ_1	w_2	ln (D_2)	σ_2	w_3	ln (D_3)	σ_3
$p_m(d)$									
Sand	0.0329	4.3733	0.8590	0.9671	5.7689	0.2526			
Loam	0.1114	4.3565	0.0257	0.4331	5.4092	1.0000	0.4554	5.1674	0.3824
Silty clay	0.1070	4.4539	0.0236	0.3938	2.9319	1.0000	0.4991	4.5062	0.4473
$p_f(d)$									
Sand	0.0338	0.6931	1.0000	0.9662	5.6300	0.2542			
Loam	0.5844	4.6079	0.6141	0.3634	5.2050	0.2897	0.0522	7.0553	1.0000
Silty clay	0.4452	0.6931	1.0000	0.3772	1.8900	0.8966	0.1776	5.6930	1.0000

Table 2
Modified parameters for the log-normal distribution to construct minimally ($p_m(d)$) and fully ($p_f(d)$) dispersed particle-size distributions for sand, loam and silty clay using soil samples from northern China

Sample	Mode 1			Mode 2			Mode 3		
	w_1	ln (D_1)	σ_1	w_2	ln (D_2)	σ_2	w_3	ln (D_3)	σ_3
$p_m(d)$									
Sand	0.0329	4.3733	0.8590	0.9671	5.7689	0.2526			
Loam	0.0514	4.3565	0.0257	0.4931	5.4092	1.0000	0.4554	5.1674	0.3824
Silty clay	0.3000	4.4539	0.0236	0.0500	2.9319	1.0000	0.6500	4.5062	0.4473
$p_f(d)$									
Sand	0.0004	0.6931	1.0000	0.9960	5.6300	0.2542			
Loam	0.3100	4.6079	0.6141	0.5378	5.2050	0.2897	0.1522	7.0553	1.0000
Silty clay	0.0300	0.6931	1.0000	0.7700	1.8900	0.5000	0.2000	5.6930	1.0000

et al. (2002)

$$\gamma = e^{-k(u_* - u_{*t})^n} \quad \text{if} \ (u_* \geqslant u_{*t}), \tag{3}$$

where k and n are constants, u_* the friction velocity and u_{*t} the threshold friction velocity. Eq. (3) indicates that γ approaches 1 for the weak erosion ($u_* \sim u_{*t}$), thereby the suspended particle-size distribution is mainly controlled by the minimally dispersed parent soil particle size, whereas for the strong erosion ($u_* \gg u_{*t}$), γ approaches 0, thereby the fully dispersed parent soil particle-size distribution controls the suspended particle-size distribution.

Table 3
The composition of the soil texture in the dust source region

Source region	Soil texture		
	clay (%)	loam (%)	sand (%)
Gobi region	15	35	50
Sand region	10	10	80
Loess region	20	55	25
Mixed soil region	30	30	40

The minimally and fully dispersed particle-size distribution for a given soil can be expressed as the sum of several log-normal distribution (Gomes et al., 1990; Chatenet et al., 1996; Shao, 2001)

$$p_{\mathrm{m,f}}(d) = \frac{1}{d} \sum_{j=1}^{J} \frac{w_j}{\sqrt{2\pi}\sigma_j} \exp\left(-\frac{(\ln d - \ln D_j)^2}{2\sigma_j^2}\right), \tag{4}$$

where J is the number of modes, w_j the weight for the jth mode of the particle-size distribution, and D_j and σ_j are the parameters for the log-normal distribution of the jth mode.

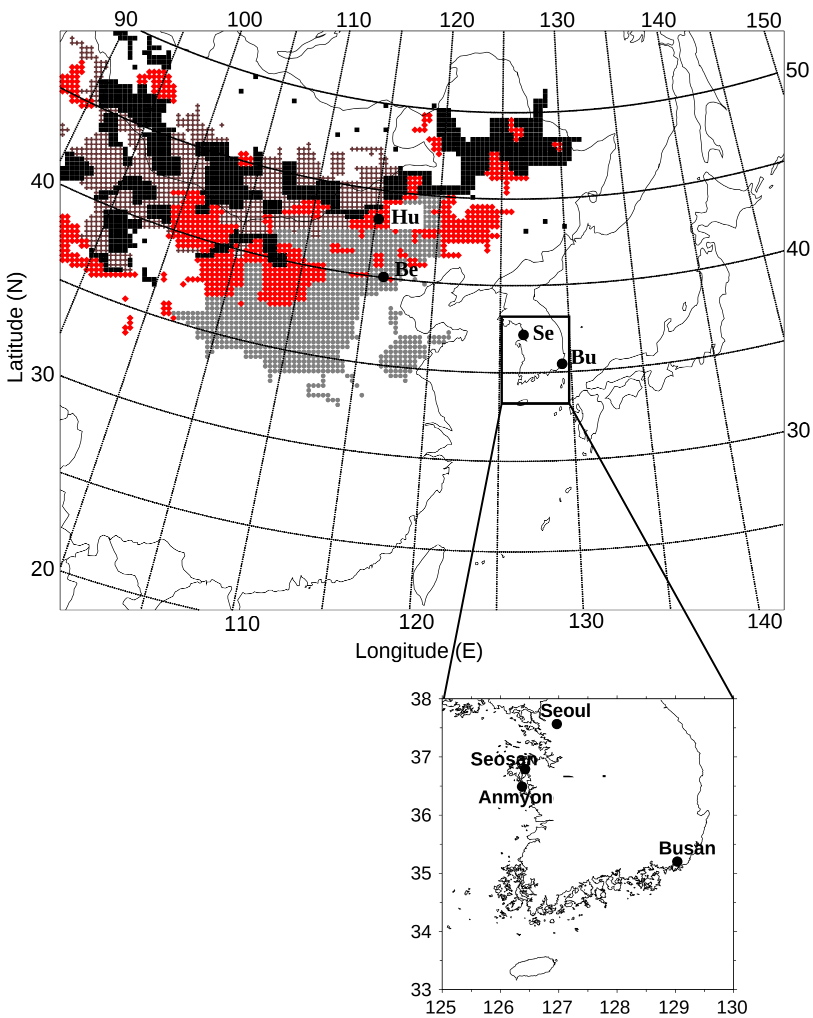

Fig. 1. The model domain and Asian dust source regions (+ + Gobi, ◆◆ Sand, ●●Loess and ■■ Mixed). The enhanced map shows South Korea with locations of several monitoring sites. The letters of Hu, Be, Se and Bu represent the locations of Hunsendake, Beijing, Seoul and Busan, respectively.

In doing so, the particle-size distribution should be specified using a small number of parameters that can be applicable to a particular soil type. However, the soil particle-size distribution in the Asian dust source regions is not available yet. Therefore, we have taken two sets of parameters for the log-normal distributions to test their usefulness for the spectral-mass concentration distribution observed in Korea. One is taken from Shao et al. (2002). The other is a modified form of Shao et al. (2002) based on the soil samples collected in northern China.

Table 1 shows the parameters for the log-normal distributions that are used to construct minimally and fully dispersed particle-size distributions for sand, loess and silty clay used by Shao (2001) and Shao et al. (2002). These parameters were estimated with soils samples collected in Australia. Table 2 shows presently developed soil particle-size distributions with soil samples obtained from northern China (Park, 2002).

In the Asian dust source regions, soil types are composed of Sand, Gobi, Loess and Mixed soil (Park and In, 2003; In and Park, 2002). The composition of the soil texture at each source region in Table 3 is approximated from 37 soil samplings taken from each soil type in northern China (Park, 2002). The modified model given in Park and In (2003) with the soil particle-size distributions in Table 2 and the soil types in Table 3 is hereafter called as the Asian Dust Aerosol Model (ADAM).

The spectral particle-mass concentration distribution in the source region is estimated by averaging the log-normal distribution functions in Tables 1 and 2 with the weighting factor of the fractional coverage of the soil type in each grid cell.

3. Spectral-mass concentration distributions for the Asian dust event observed on 21–23 March in Korea

A severe Asian dust (Hwangsa) event was observed in Korea for the period of 21–23 March 2002. Park and In (2003) have simulated this event using Eq. (1) for the spectral-mass distribution of dust in the source regions. This case has been simulated with the ADAM model to examine the performance of each parameterization of the dust particle-size distribution against the field measurement at Anmyondo in Korea (Fig. 1). Three different parameterizations of the particle-size distribution in the source regions are tested. One is to use Eq. (1) that has been used in Park and In (2003) and the other two are to use parameters for the log-normal distribution given in Tables 1 and 2 with Table 3.

Fig. 1 shows the model domain, the dust source region delineated by four different soil types (Gobi, Sand, Loess and Mixed soil) and several air quality monitoring sites in Korea. The Model simulation has been performed in a horizontal grid of $30 \times 30\,km^2$ and 25 vertical layers up to 50 hPa level for the period from 19 to 24 March 2002 using the same model employed in Park and In (2003) for each parameterization of the particle-size distribution in the source region.

4. Results

Comparisons of the modeled and observed spectral-mass concentration distribution are shown in Fig. 2. The spectral number concentration measured at Anmyondo (Fig. 1) by the optical particle counter (OPC, HIAC/

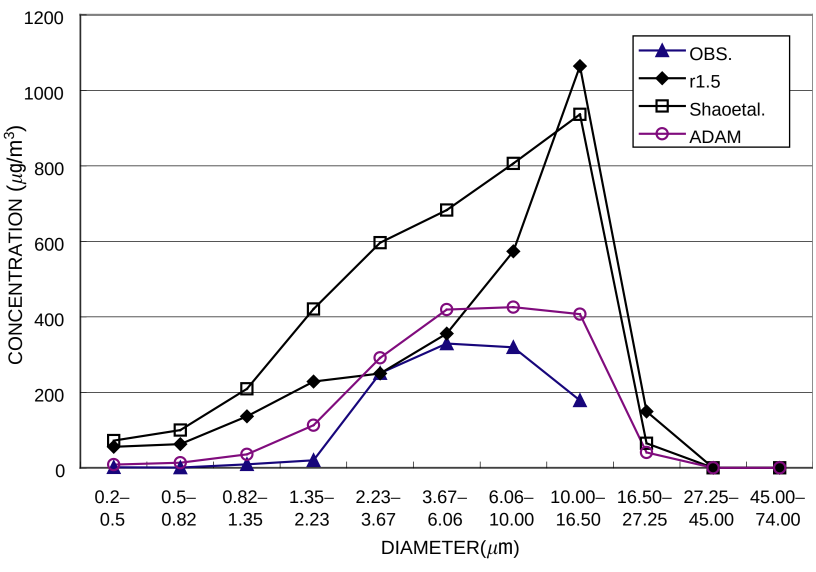

Fig. 2. Spectral-mass concentration distributions obtained from observation (-▲-), power law (-◆-), log-normal size distributions function of Shao et al. (-□-) and ADAM (-○-).

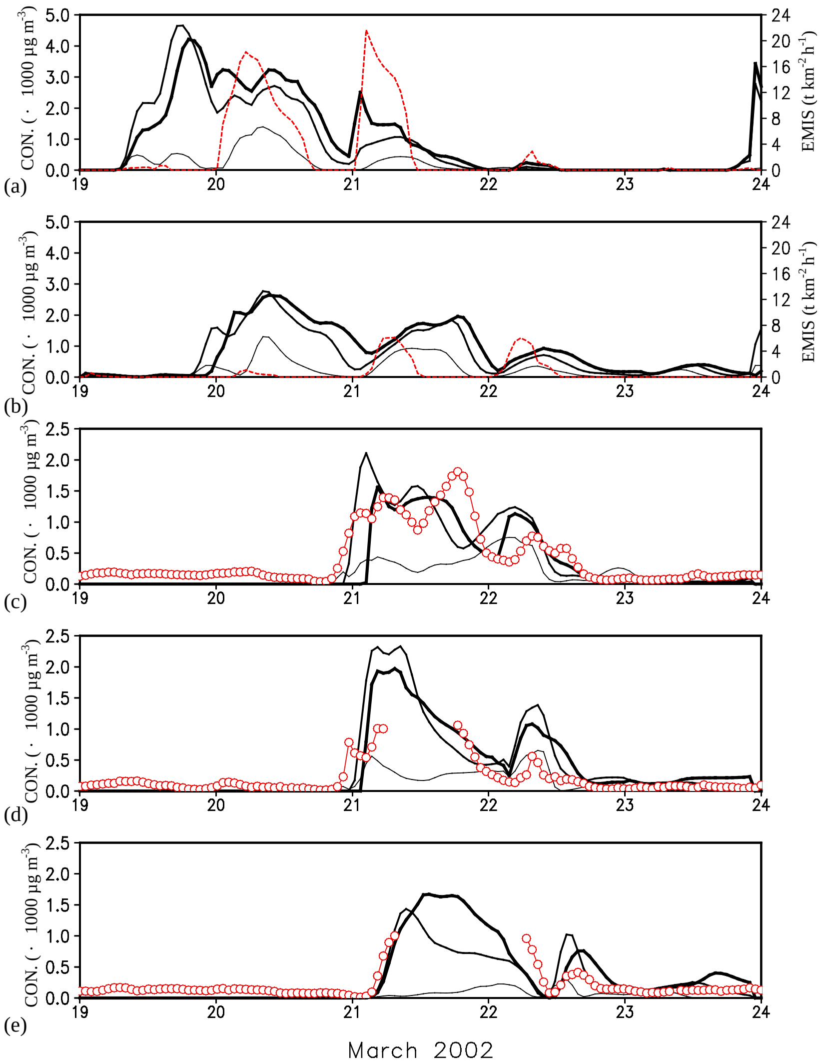

Fig. 3. Time series of modeled mean PM_{10} concentration ($\times$ 1000 μg m^{-3}) averaged for the layers of surface to 100 m (—), 100–1500 m (—), above 1500 m (—) with emission rates (- - - -, t km^{-2}h^{-1}) and observed surface PM_{10} concentrations (-○-○-○-) at (a) Husendake, (b) Beijing, (c) Seoul, (d) Seosan and (e) Busan using the power law of the spectral emission model.

ROYCO 5230) is averaged for 12 h during the period of high dust concentration. The averaged spectral number concentration is converted to the spectral-mass concentration assuming a spherical shape of a particle with a constant density of 2600 kg m^{-3} (Park and In, 2003; In and Park, 2003). The simulated spectral-mass concentration is also averaged for the same time period at Anmyondo. The simulated spectral dust concentration estimated by using the power law shows 2–5 times higher dust concentration than that of the observation, especially in the range of larger than 6.0 μm in diameter. On the other hand that estimated by using the data in Table 1 (Shao et al., 2002) yields a significant high dust concentration in all spectral range with a maximum concentration difference in the diameter range of 10–16 μm.

However, the ADAM model (Table 2) yields a quite similar spectral dust concentration distribution compared with the observation. However, the model simulates slightly overestimates, suggesting the importance of soil particle-size parameterization in the source region for the proper spectral-mass concentration distribution away from the source region.

Figs. 3–5 show the time series of modeled PM_{10} concentrations averaged for the layers of below 100, 100–1500 m and above 1500 m above the ground at five sites (Fig. 1). These PM_{10} concentrations are obtained from three different spectral emission models using the

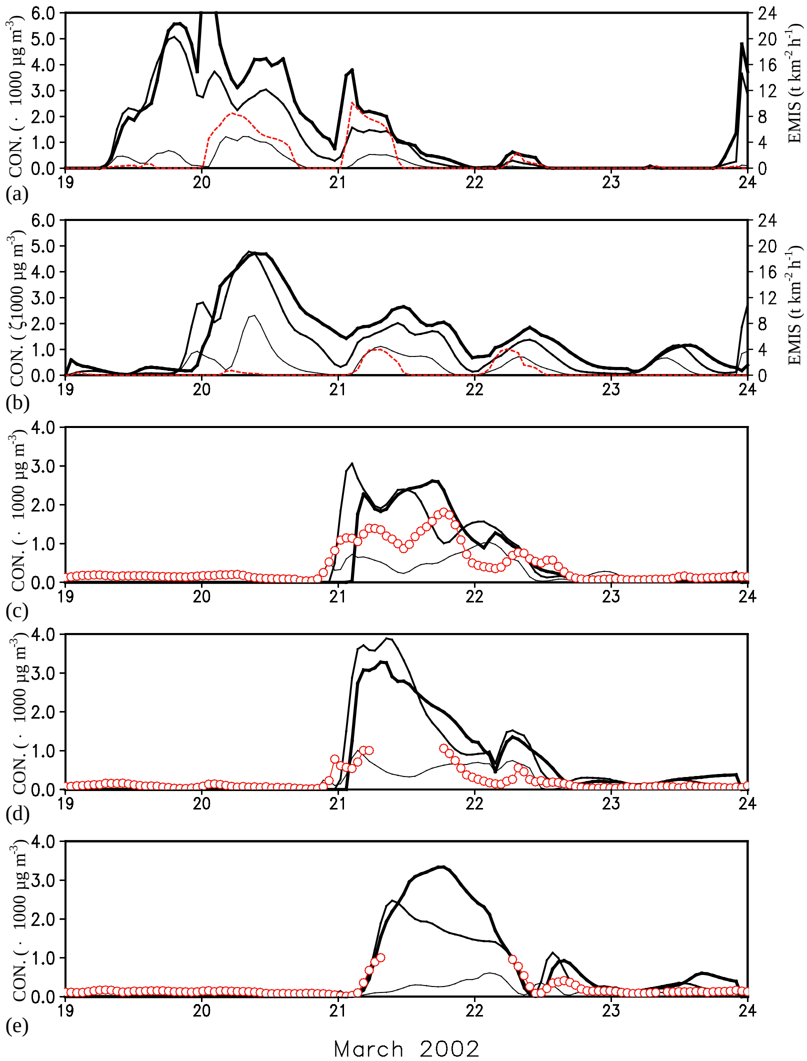

Fig. 4. The same as in Fig. 3 except for using the spectral emission data of Shao et al.

data in Tables 1 and 2. The estimated emission rates at the source site (Hunsendake) and Beijing while the observed PM_{10} concentrations at Seoul, Seosan and Busan in Korea (Fig. 1) are shown in Figs. 3–5. All chosen spectral emission models simulate quite well the starting, ending and dust peak appearing times of the dust storm at Seoul, Seosan and Busan in Korea. However, each spectral emission model yields different PM_{10} concentration. The simulated PM_{10} concentration using the power law of the spectral emission model (Fig. 3) is a little lower than the observed one for the first peak but is a little higher for the second peak at Seoul (Fig. 3c). However, the model slightly overestimates the observed PM_{10} concentration at Seosan (Fig. 3d) and Busan (Fig. 3e). Dust concentrations tend to increase in the middle layer (100–1500 m layer) first rather than in the lowest layer away from the source regions (Figs. 3c–e), whereas the highest concentration occurs in the lowest layer in the source region, especially in the regions where dust is emitting (Figs. 3a and b).

The model used the log-normal distribution of soil particle size data in Table 1 (Shao et al., 2002) and overestimates the observed PM_{10} concentration significantly at all sites (Fig. 4). However, the ADAM model (Fig. 5) simulates quite well the observed PM_{10} concentration at Seoul, Seosan and Busan (Figs. 5c–e), suggesting the importance of soil particle-size distribution in the source region.

5. Conclusion

Three different dust emission models depending on the particle-size distribution have been implemented to a

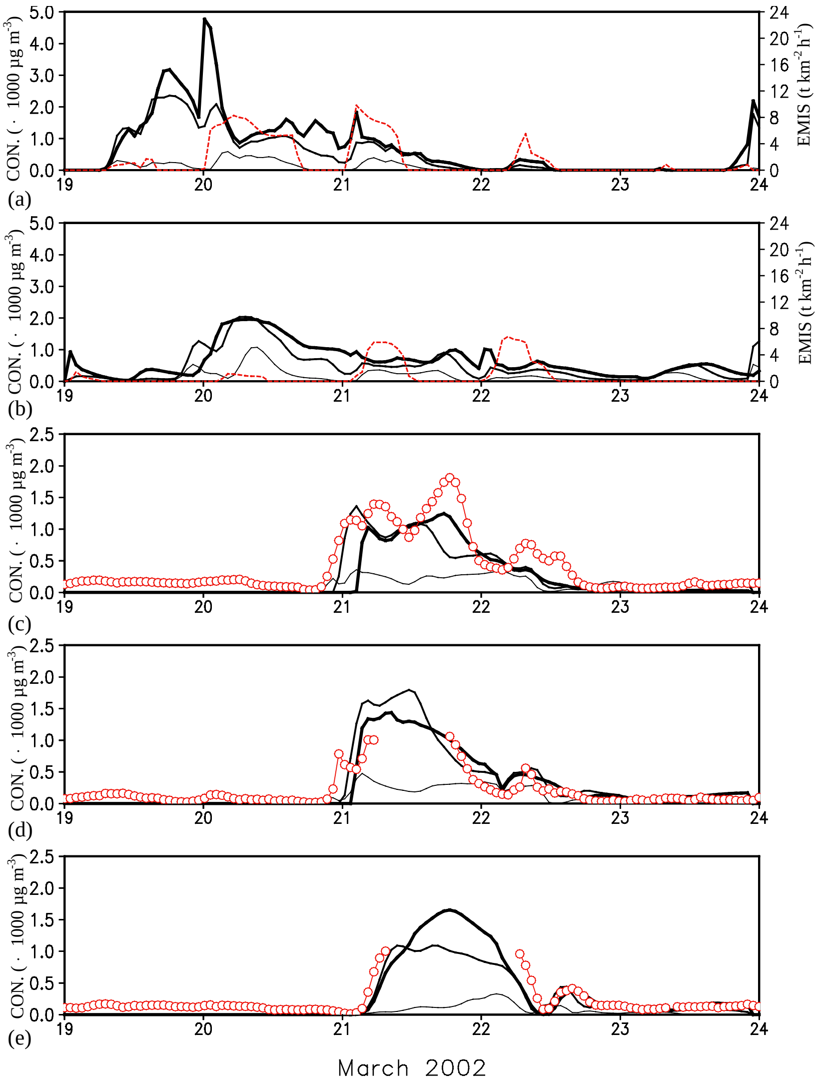

Fig. 5. The same as in Fig. 3 except for the result of ADAM.

severe Asian dust (Hwangsa) event observed in Korea in the period of 21–23 March 2002 to examine the performance of each emission model for the simulation of the spectral-mass concentration distribution observed at Anmyondo in Korea. The used spectral dust emission models are the spectral-mass flux following a power of 1.5 of the dust particle radius as by Westphal et al. (1987), and an additive form of several log-normal size distributions for soils with the minimally and fully dispersed particle-size distribution function in Table 1 (Shao, 2001; Shao et al., 2002) and the modified log-normal size distributions in Table 2 with observed soil types in northern China.

The results indicate that all three parameterizations of the spectral dust emission simulate quite well the starting, ending and the dust peak appearing time compared with those observed in Korea, suggesting the importance of meteorological model for arriving and ending times of the Asian dust event observed in Korea. However, these models produce the spectral-mass concentration distribution differently.

The power law overestimates the spectral-mass concentration in the range of larger than 10 μm in diameter. The emission model used the data in Table 1 (Shao, 2001; Shao et al., 2002) and also overestimates the spectral-mass concentration in all spectral range. However, the ADAM model simulates quite well the spectral-mass concentration distribution observed in Korea, suggesting the proper parameterization of the soil particle-size distribution in the source region being important for more accurate spectral-mass concentration distribution at the distant regions.

This study clearly indicates that the minimally and fully dispersed particle-size distributions in the source regions have great potential to simulate more accurate spectral-mass concentration away from the source regions. This requires the detailed soil textures of different soil types in northern China and Mongolia.

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