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On heavy dustfall observed with explosive sandstorms in Chongwon-Chongju, Korea in 2002

Yong-seung Chung[a,*], Hak-sung Kim[a], Jugder Dulam[a], Joyce Harris[b]

[a] *Korea-China Centre for Atmospheric Research, Chongwon, Choongbook 363-891, South Korea*
[b] *CMDL/NOAA, Boulder, CO 80305, USA*

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Abstract

Continuous monitoring of sand and duststorms (SD) and associated heavy dustfall (HD) is made in Korea. In particular, accurate measurements of atmospheric dust loadings have been carried out with the tapered element oscillating microbalance method, and satellite detection of dust clouds is included in the analysis. In 2002, we found three gigantic dust clouds that moved over the Korean Peninsula, and associated HD occurred with PM10 values of 1106–3006 $\mu g\,m^{-3}$. In Beijing, China much higher concentrations were recorded, while in SW Japan measured values were up to 986 $\mu g\,m^{-3}$. Two SD occurred in March and April, while the third one occurred unusually in November. During the year, there were nine cases of reddish-brown sand with 18 dusty days. The intensity of HD was extraordinary for the recent decade. It was observed that with invading SD, the higher the PM10 values the lower the PM2.5 loadings. Also, variations of visibility were more depending on PM2.5 variations than PM10 values. It is shown that satellite detection is a useful technique in monitoring SD and HD.

Keywords: Gigantic sandstorms; East Asian duststorms; Satellite dust detection; PM10 and PM2.5 measurements; Heavy dustfall; Reddish-brown sand

1. Introduction

The formation of large sand and duststorms (SD) cause nuisance as well as air pollution for people in the source region and to those in the remote area several thousand kilometers away. The source area of several deserts and the dry land in northern China and southern Mongolia exceeds 3,500,000 km^2, equal to 1/3 the area of China.

According to recent studies, the frequency of SD increased significantly from the 1960s to the late 1970s. However, from 1980s the frequency of SD occurrence and dusty days in the source regions decreased steadily (Chung et al., 2003; Gao et al., 2003; Sun et al., 2003; Wang et al., 2003). Meanwhile, since 1999, the frequency of dusty days has increased slightly (Gao et al., 2003; Wang et al., 2003).

In 2002, there were many days of heavy dustfall (HD) with the invasion of SD in Korea. In particular, in March, April and November there were three gigantic SD and associated HD produced tremendous social problems in Korea. There were many patients with the environmental diseases including tonsilitis, allergy, asthma, eye irritation, etc. On 22 March, the elementary schools were closed due to HD, and outdoor activities were somewhat restricted with slightly reduced highway traffic.

The purpose of the present study is to describe the observed SD in NW-N China and Mongolia and the associated HD that occurred in Chongju-Chongwon of central Korea. Discussions include data analysis obtained by ground dust monitors including visibility, dust deposits, meteorological maps, and satellite image.

*Corresponding author. Tel.: +1-82-43-233-0002; fax: +1-82-43-232-1100.
E-mail address: kccar1@kornet.net (Y.-S. Chung).

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2. Measurements

Ambient dust loading has been routinely monitored in Chongwon since 1993. The continuous measurements include total suspended particulates (TSP), particulate matter less than $<10\,\mu m$ (PM10) and particulate matter less than $2.5\,\mu m$ (PM2.5). The PM data were measured by tapered element oscillating microbalances, and the method of measurements (R&P) were described elsewhere (Muir, 2000). Meteorological elements were also measured, and in particular, automated measurements of visibility were made with an optical sensor (Belfort instrument).

Fig. 1 shows the measured profiles of PM10 and PM2.5 at Koonghyon (KHN) in central Korea during 2002. In general, observed dust concentrations at KHN and at other Korean sites are higher than the usual values measured in N American and W European sites.

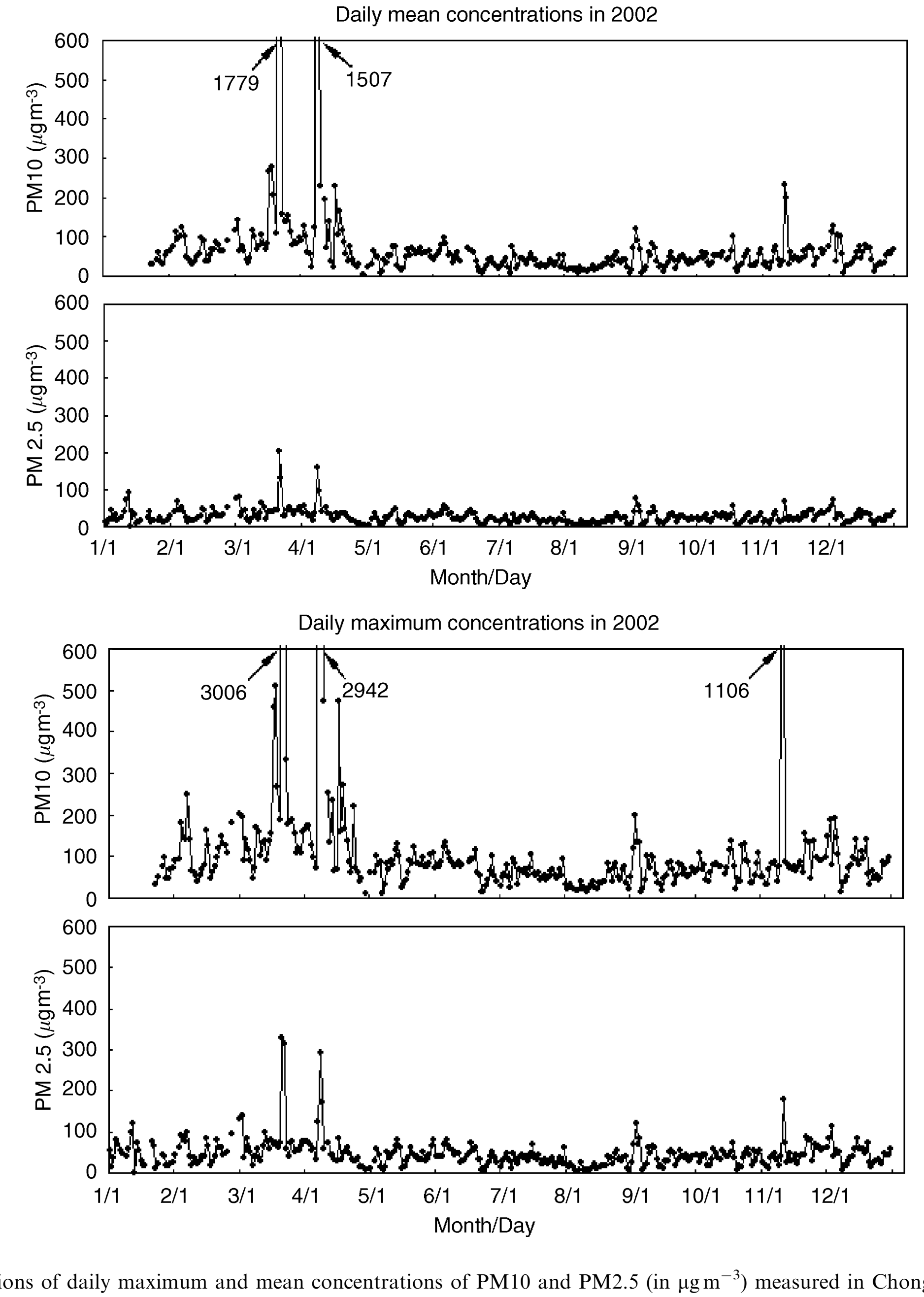

Fig. 1. Variations of daily maximum and mean concentrations of PM10 and PM2.5 (in $\mu g\,m^{-3}$) measured in Chongwon, Korea in 2002.

In particular, dust movements from deserts and dry lands in central and East Asia contribute high annual mean concentrations of PM10 (103 μg m^{-3}) in Korea. As can be seen in Fig. 1, there were a few cases of high concentrations of PM10 and PM2.5. Meanwhile, there is a need for an objective method in selection of reddish-brown sand (RS) days. Previously, RS referred to "yellow" sand, and it was misleading. For the selection of RS days, i.e. HD associated with SD, we have been using threshold values as in Table 1 (μg m^{-3}) (Chung et al., 2003).

In order to avoid the effect of a big bird on inlets or instrument malfunction, steady high values for at least 2 h or more were considered in our case selection of RS. During the 12-month period of 2002 under studies, there were three disastrous episodes of RS days in Korea. Also, there were six minor events which occurred in other periods.

Table 1
Threshold values used for selection of reddish-brown sand cases

TSP (μg m^{-3})	PM10 (μg m^{-3})	PM2.5 (μg m^{-3})
⩾250	⩾190	⩾85

3. Discussions

3.1. Record breaking heavy dustfall

The previous record of heaviest dustfall in hourly values of Korea was 996 μg m^{-3} PM10 with 1396 μg m^{-3} TSP which occurred during 23–24 March 2000. The record-breaking dustfall in Korea occurred with an SD from Mongolia on 21–23 March 2002. Fig. 2 shows the observed profiles of dust concentrations from the PM10 and PM2.5. The maximum values were 3006 μg m^{-3} for PM10 and 331 μg m^{-3} for PM2.5 at KHN in Chongwon. Meanwhile, daily mean value on March 21 was 1779 μg m^{-3} (Fig. 1). Interestingly, there were heavy deposits of dust over the fender and window of a car in Seoul on 22 March 2002.

Very high values (> 190 μg m^{-3} for PM10) of ambient dust loading occurred from 5 to 7 LST on 21 March and 10 LST on 22 March for at least 43 h. The secondary maximum with 776 μg m^{-3} for PM10 occurred at 17 LST on 22 March, and the third maximum with 358 μg m^{-3} for PM10 at midnight on 22 March.

Fig. 2 also includes the time series of observed visibility and relative humidity (RH). With the arrival of the SD from the Gobi Desert and from Inner Mongolia, observed visibility decreased significantly from 8 LST on 21 March, and visibility of less than

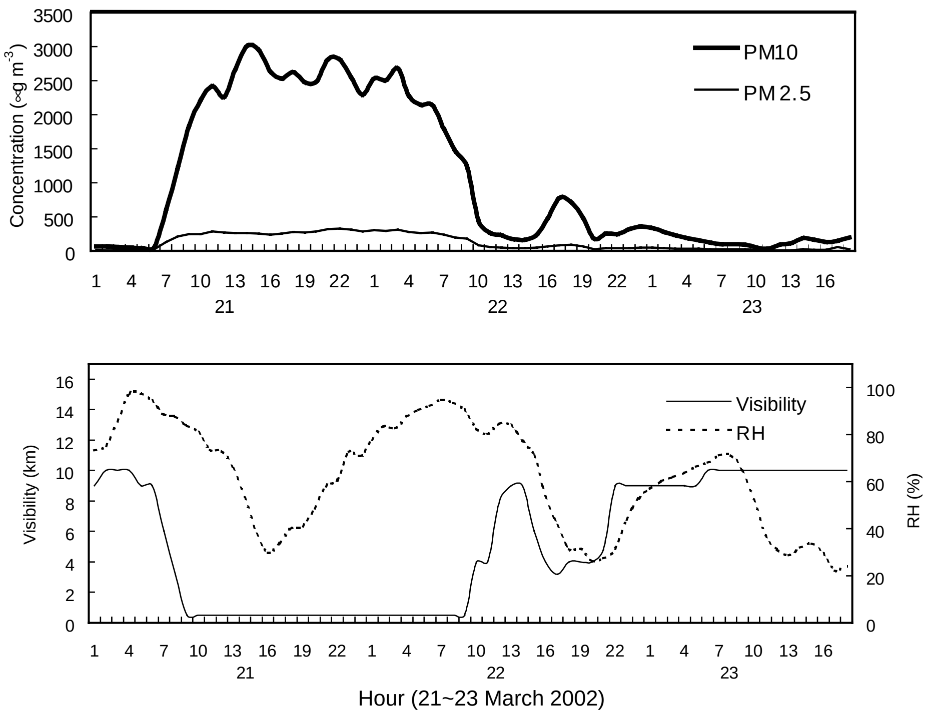

Fig. 2. Variations of hourly values of PM10 and PM2.5 (in μg m^{-3}) with visibility (km) and RH (%) observed in Chongwon during 21–23 March 2002.

1 km was maintained until 9 LST on 22 March. The measured RH decreased below 30% with the dry air from the desert from 14 to 19 LST on 21 March. Also, the low values of RH and visibility observed agreed well with the occurrence of the secondary maximum in PM10 and PM2.5 values on 22 March.

Fig. 3 shows an NOAA satellite image (Chung, 1986) taken at 14 LST on 21 March. The dust cloud was over South Korea. The explosive dust cloud was moving to the SSE direction, and it was 600 km wide and over 2500 km long, covering the area from Vladivostok in far Eastern Russia to Shanghai and the Yangtze delta of China. This dust cloud invaded SW Japan on 22 and 23 March.

In comparison, on 20 March observed daily average concentration of TSP in Beijing was greater than $4000\,\mu g\,m^{-3}$, while hourly maximum value of PM10 exceeded the measuring limit ($1500\,\mu g\,m^{-3}$) of instruments there. Beijing is located ca. 1000 km from KHN. In SW Japan, observed PM10 (SPM) maximum values in Kyushu on 21 March were $986\,\mu g\,m^{-3}$ at Nagashaki University and $414\,\mu g\,m^{-3}$ at Itoshima. In Kyoto city of central Japan, however, the hourly maximum value of PM10 on 22 March was $252\,\mu g\,m^{-3}$. Kyoto recorded about one-tenth of KHN value in central Korea, and the distance between two stations is ca. 800 km.

We also have hourly Geo-stationary Meteorological Satellite image of this storm, and animation of hourly images clearly showed the dust cloud movement from the central Gobi Desert in Mongolia and Inner Mongolia to the western Pacific. As can be seen from satellite image of Fig. 3, the scale of a duststorm was unusually large and dust was well mixed during transport over a thousand kilometers. In other words, the measured values across the entire Korean Peninsula are similar and they are within $\pm 30\%$ range from one site to another. Unfortunately, the TSP monitor was out of order during the episode. According to the former study (Chung et al., 2003), TSP values are usually 30% higher than the measured values of PM10. After the present episode, it was found that most of the dust monitors recorded $1000\,\mu g\,m^{-3}$, the limit of the instruments; in turn, the values higher than limit value were not measured over 60 stations in Korea.

Fig. 4 shows the air-parcel trajectory analysis on 23 March, 8 April and 12 November. The isentropic analysis indicates that dust particles were coming from the NNW direction, i.e from the Gobi and the Inner Mongolian Deserts in 2 days. Clearly, this episode shows the HD problem in Korea, and it is even worse in N China because it is located closer to the source regions.

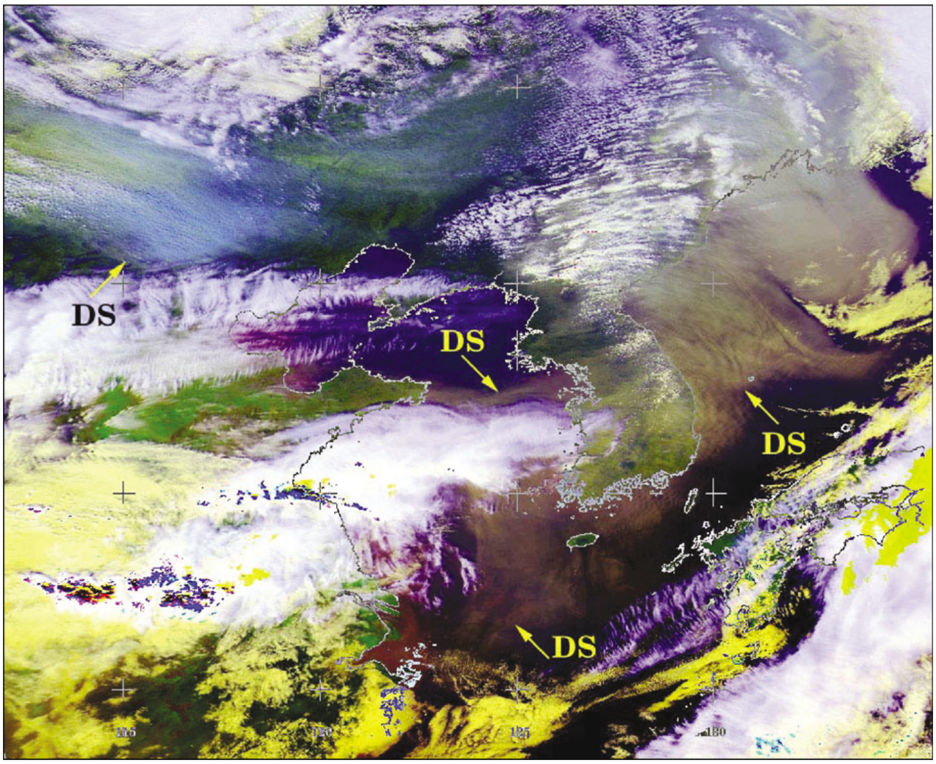

Fig. 3. Satellite image (NOAA 16) taken at 14 LST, 21 March 2002. It shows an elongated giant duststorm (DS) from the Shanghai area via the Yellow Sea—the Korean Peninsula to the Korea East Sea and Vladivostok in Russia.

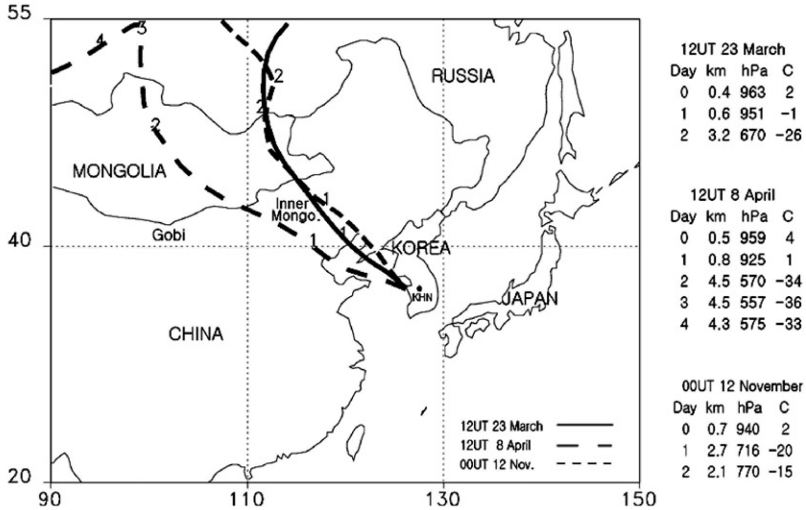

Fig. 4. Isentropic air-parcel trajectories arriving at the west coast of central Korea on 23 March 2002. Numbers indicate days to reach to Korea; km altitude; hPa pressure and C in temperature. KHN is the rural site in central Korea.

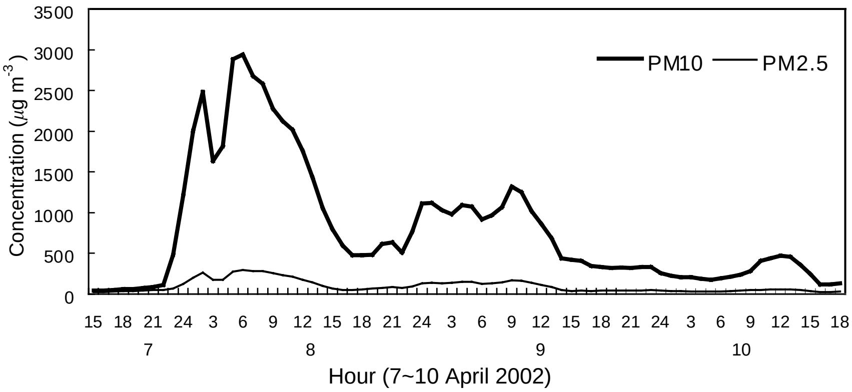

Fig. 5. Variations of hourly values of PM10 and PM2.5 (in $\mu g\,m^{-3}$) observed in Chongwon during 7–10 April 2002.

3.2. Second highest record of heavy dustfall

Fig. 5 shows observed time series of PM10 and PM2.5. This episode has the second highest values observed in Korea after the dust monitors were installed 10 years ago. Prior to 21 LST, 7 April 2002, PM10 values were less than $100\,\mu g\,m^{-3}$. However, at 23 LST they increased to over $500\,\mu g\,m^{-3}$ and maintained that level until 17 LST, 8 April. The highest PM10 value observed during this event was $2942\,\mu g\,m^{-3}$, while highest PM2.5 value was $294\,\mu g\,m^{-3}$. Daily mean value of PM10 on 8 April was as high as $1507\,\mu g\,m^{-3}$. During the 7-h period from 16–22 LST, 8 April, PM10 values were lower at about $500–600\,\mu g\,m^{-3}$. However, PM10 values increased to over $1000\,\mu g\,m^{-3}$ for the duration of 14 h on 9 April. Thereafter dust loadings decreased steadily, with a jump to $472\,\mu g\,m^{-3}$ for PM10 at mid-day on 10 April.

Fig. 6 includes a satellite (NOAA-12) image at 17 LST, 8 April. It clearly shows an explosive dust cloud covering N and central Korea and the Korea East Sea. The variation in intensity of SD over the sea indicates the variation in atmospheric loadings. During the period of 7–10 April there were 63 h of PM10 values above $190\,\mu g\,m^{-3}$.

Trajectory analysis of Fig. 4 suggests that air parcels were arriving in W Korea from the NW direction; Inner Mongolian Desert. In fact, a SD generated over the northern Gobi Desert on 5 April. According to analyses of trajectories, meteorological maps and satellite imagery, the dust cloud was invading the Korean Peninsula in one and half days after travelling over 1900 km. On

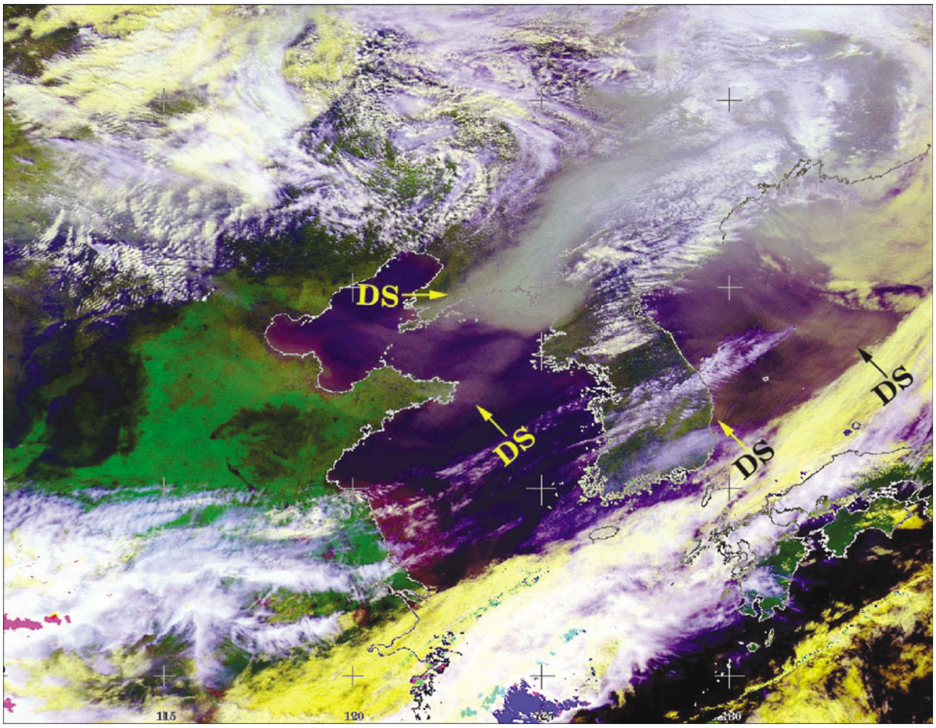

Fig. 6. Satellite image (NOAA-12) of 17 LST, 8 April showing a gigantic dust cloud (DS) over N and central Korea and over the Korea East Sea.

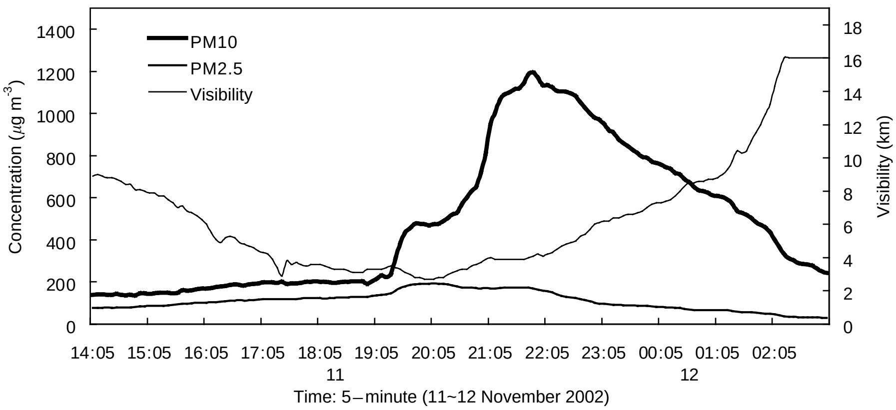

Fig. 7. Variations of 5-min average of PM10, PM2.5 and visibility measured in Chongwon (KHN) during 11–12 November 2002.

6 April, the SD was occurring in an area of at least 1000 km × 1000 km over the Gobi Desert.

3.3. The unusual autumn episode

SD occur in all seasons (Chung et al., 2003). It is known that severe SD occur usually from March to May, while only weak duststorms (DS) occur in summer. This is due to weak circulation and ground conditions in summer, e.g. weeds and moisture.

A DS and intense HD occurred unusually during the period 11–12 November. The measured values of PM10 and PM2.5 are shown in Fig. 7. In this case, the hourly maximum PM10 value observed was 1106 $\mu g\,m^{-3}$, while that of PM2.5 was 181 $\mu g\,m^{-3}$. A 5-min average value of 1194 $\mu g\,m^{-3}$ occurred at 21:50 LST. During the event, PM10 values greater than 190 $\mu g\,m^{-3}$ occurred for 17 h,

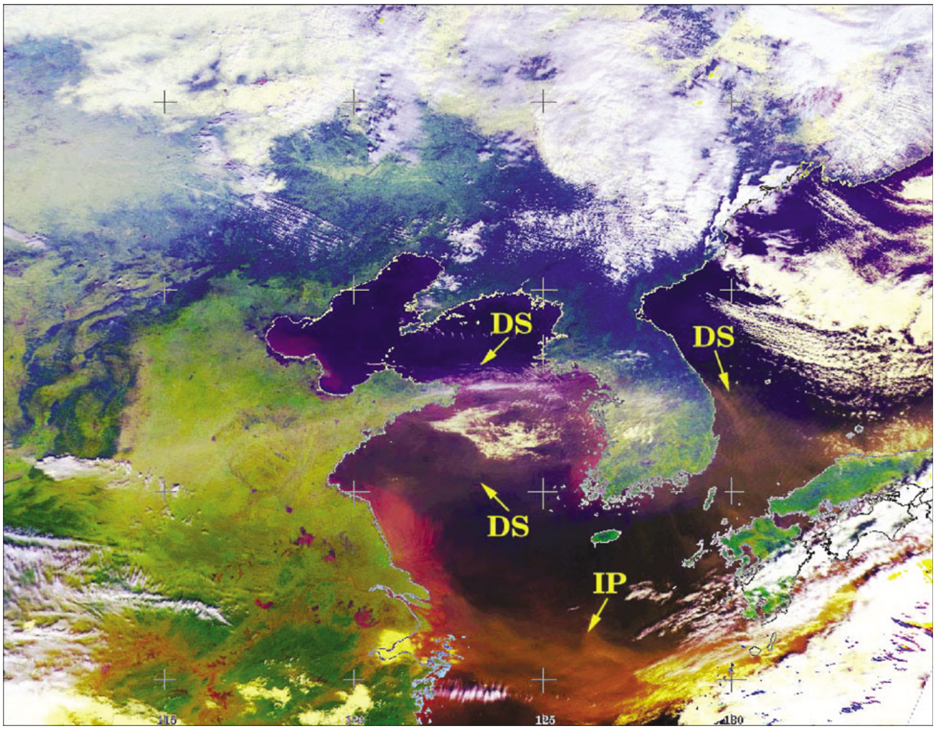

Fig. 8. Satellite image (NOAA-17) of 11 LST, 12 November 2002 showing an elongated dust cloud (DS) over the Korean Peninsula. The dust cloud extends to the Shantung Peninsula, China and to SW Honshu Island, Japan. Another elongated (IP) plume from the Shanghai area of China to the south of Kyushu Island, Japan is of industrial origin in China.

while PM2.5 values greater than $85\,\mu g\,m^{-3}$ occurred for 9 h.

The satellite image (NOAA-17) in Fig. 8 shows that an elongated dust cloud was situated from the Shantung Peninsula of China via the Yellow Sea and S Korea to SW Japan. The dust originated in the Inner Mongolian Desert (Fig. 4), was approximately 500 km wide and 2000 km long. Interestingly, there was another mass of air pollutants from Shanghai and the surrounding area to the East China Sea and southern Kyushu of Japan. This was a typical mass of air pollutants transporting from China. The magenta color over lakes in eastern China also suggests the massive loadings of industrial pollutants (Chung, 1986). On 9 April, observed levels of CO, NO_X, O_3, and SO_2 at Chongwon-Chongju were relatively high with the industrial plumes that were transported from central and E China.

Fig. 7 includes a detailed analysis of 5-min mean values of PM10, PM2.5 and visibility. There was a phase lag between the PM10 and the PM2.5, with the period of highest PM10 concentrations being delayed compared to high PM2.5 values. The minimum value in visibility occurred in the period of low PM2.5 values. From that time visibility steadily increased even when PM10 values increased. This suggests that reduction in visibility is more dependent upon the loadings of fine dust particles. The visibility improved significantly with PM10 values of less than $300\,\mu g\,m^{-3}$.

3.4. Other cases and summary

The fourth highest PM10 value was $508\,\mu g\,m^{-3}$ with PM2.5 values of $86\,\mu g\,m^{-3}$. The dust cloud in the satellite image (not shown) on 17 March was clearly over Korea and adjacent seas. The dust cloud was covering from S Manchuria, China and the Korean Peninsula to SE Japan. The Yellow Sea and the Korea East Sea were also under the influence of the huge DS.

Three satellite images shown clearly support the results of dust monitors at the ground measurements in air quality qualitatively and quantitatively. Other remaining cases listed in Table 2 are not included for detailed description.

Fig. 9 shows three cases for comparison. It illustrates the difference in duration, strength and mode of the maximum values of dust concentrations. Two cases in March and April were gigantic with triple modes in 3 days, while the November episode lasted for 1 day with a single mode. The giant SD consists of higher PM10 concentrations. Table 2 summarizes the HD observations at KHN with RS.

Table 2
Heavy dust loadings observed in Chongju-Chongwon in 2002 with duststorms from NW-N China and Mongolia

Case and date (nine cases, 18 days)	PM10 max ($\mu g\, m^{-3}$)	Duration (h) ($\geqslant$190)	PM2.5 max ($\mu g\, m^{-3}$)	Duration (h) ($\geqslant$85)
7 February	250	3	97	3
28–30 March	202	3	140	15
17–19 March	508	40	86	3
21–23 March	3006	43	331	37
7–10 April	2942	63	294	31
17 April	474	11	85	6
19 April	270	8	—	—
3 September	199	3	121	11
11–12 November	1106	17	181	9
Mean	995.2	21.2	166.9	14.4

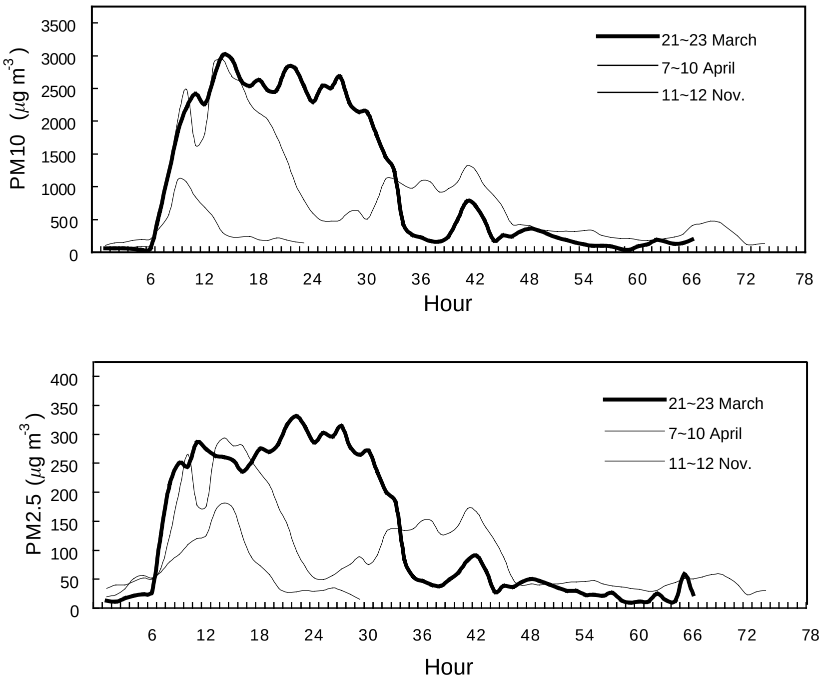

Fig. 9. Comparison of three duststorm events with PM10 and PM2.5 measurements.

4. Concluding remarks

We have been monitoring SD in the source regions and HD in Korea. During the year 2002, there have been nine cases of SD with 18 HD days, and on average each episode in Korea prevailed for about 2 days.

The average maximum concentrations were PM10: 995.2 and PM2.5: 166.9 $\mu g\, m^{-3}$. The three cases were the record-breaking episodes, which occurred on 21–23 March, 7–10 April and 11–12 November. These dust clouds produced HD with maximum PM10 concentrations of 3006, 2942 and 1106 $\mu g\, m^{-3}$, respectively.

Because of very high concentrations of airborne dust with invading SD affecting human health, we suggest that dust reduction devices should be installed and operated in most indoor environments including automobiles. Also, there is a need for the improvement in our knowledge of duststorms.

Acknowledgements

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