Monitoring of Ambient Air Particles and Inorganic Elements in China and Korea during an Asian Dust Storm

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ABSTRACT

Concentrations of ambient air particles such as total suspended particulates (TSP), particulate matter (PM)₁₀, and PM_{2.5}, were monitored simultaneously from May to June, 2007, at four locations at Alashan and Beijing in China, and Seoul and Gosan in South Korea. These monitoring sites are in the pathway of Asian dust (AD) storms traveling from China to the Korean peninsula. An AD event was observed in the Korean peninsula on May 25-26. During the sampling period, the average concentrations of TSP and PM₁₀ were each higher than 150 µg/m³ in Alashan and Beijing, but not in Seoul and Gosan. The concentration of TSP in Alashan (where the dust storm originated) on the day of the AD event reached 1824.7 µg/m³, this being the highest concentration of air particles observed during the sampling period. The level was decreased to 15% of this (274.7 µg/m³) in Seoul and to 8.7% (159.0 µg/m³) in Gosan when the AD was observed two days later in Korea. Gosan, a representative background site in East Asia, displayed the lowest concentration of particles, with this maximal TSP concentration of 159 µg/m³. Inorganic element contents in the air particles were also measured, and the concentrations in the four different regions compared. Concentrations of anthropogenically-enriched heavy metals in PM₁₀ and PM_{2.5}, such as lead, arsenic, cadmium, and mercury, were higher in the metropolitan cities of Beijing and Seoul compared to non-industrialized regions of Alashan and Gosan. However, the concentrations of inorganic soil elements including iron, magnesium, aluminum sodium, and manganese, were higher in Alashan compared to those in other sampling sites.

Keywords: asian dust, monitoring, China and Korea, inorganic elements

I. Introduction

Asian dust (AD, also called Yellow Sand) storm

is a seasonal meteorological phenomenon that sporadically affects East Asia. AD storms originate in the deserts of Mongolia and northern China, traverse east China, and reach the Korean peninsula, Japan, Hawaii, and even California.^{1,2)} Hazardous chemicals appear to be present at relatively low levels in AD at the origin because

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AD is derived from alkaline soil or sands. However, AD attracts many different chemicals including gaseous products, heavy metals, and organic compounds when it traverse the region of industrialized eastern China.^{3,4)} Recently, AD storms were found to be increasing in Korea because of rapid desertification in central and northern China and in Mongolia. According to the report of Korea Meteorological Administration (<http://www.kma.go.kr>), fewer AD storms per year had occurred before 1990, but this number has risen to 26 events with 47 dusty days of six spring seasons from 1996 to 2001, and more storms occur in the recent years. It is of interest that the ambient particle concentrations present in AD in Korea have increased.⁵⁾ In addition, the concentrations of hazardous chemicals such as heavy metals also appear to be on the rise in AD due to the rapid industrialization.⁶⁾

Recent epidemiological studies demonstrated that AD storms are associated with a rise in daily mortality in Seoul, Korea^{7,8)} and in Taipei, Taiwan.⁹⁾ AD increased the frequency of cardiopulmonary emergency visits^{10,11)} and daily stroke admissions¹²⁾ in Taiwan; it elevated the number of adverse respiratory symptoms and lowered peak expiratory flow in children with mild asthma.^{13,14)} AD or ambient air particles also increased the incidence of lung inflammation and injury in pulmonary hypertensive rats.¹⁵⁻¹⁸⁾

Based on the potential adverse effects of AD storms on human health, it would be of interest to know the path which an AD storm take and to know whether this may be correlated with higher health risks in individuals exposed to an AD storm. In the present study, we tried to compare the concentration of ambient particles and inorganic elements in different sites including the origin of AD, metropolitan cities in China and Korea.

II. Materials and Methods

1. Sampling sites

Samples were collected at 4 sites (Alashan and Beijing in China, and Seoul and Gosan in Korea) and the locations are shown in Fig. 1. Three-day backward trajectories of AD arriving at Seoul was

Fig. 1. Locations of sampling sites in China and Korea. AL: Alashan, BE: Beijing, SE: Seoul, GO: Gosan. Asian Dust event was observed on May 23 in Alashan, on May 24 in Beijing, from May 25 to 26 of 2007 in Seoul and Gosan.

previously reported.¹⁹⁾ Alashan is a small city in the west of Inner Mongolia, China. The Bardain Jaran Desert, Tengger Desert, and Ulan Buh Desert are close to Alashan County, the districts of which are the main origins of AD in China. Samplers for TSP, PM₁₀, and PM_{2.5} were located on top of a hotel on the west edge of Alashan. The sampling site was considered as a background site because no source of anthropogenic air pollution exists on the west side of the city, which is the border of the Tengger Desert. Sampling in Beijing was conducted on the seventh floor (approximately 20 m high) of a building at Peking University Health Science Center (PKUHSC). The site is near Xueyuan Road, which has heavy traffic in the Haidian District and considered an industrialized location. Sampling in Seoul was conducted on the top of a building at Dongduk Women's University in northern Seoul. Apartment complexes surround this university building, and a 6-lane road is approximately 500 m from the sampling site. Although there are no official data on the traffic density, it is busy with gasoline-fueled passenger cars and diesel-fueled trucks, natural gas-fueled buses, and motorcycles. No other sources of industrial pollution exist in the vicinity. Samplers at Gosan were set on the ground at a site near the

Yellow Sea. Gosan is located at the western tip of Jeju Island, Korea (33°17'N, 126°10'E, and 70 m Above Sea Level, ASL). It is a small village; at the end of 2006 with a population of 4,000. It is a typical rural area of Jeju Island without any industry or other pollution sources. Gosan is a representative background site in East Asia and has served as a major research location for the long-range transport of ambient air in north-east Asia.^{1,4)}

Sampling was conducted once a day for 20 hrs from May 14 to June 15, 2007 in Alashan, May 17 to June 18 in Beijing, May 8 to June 15 in Seoul, and May 15 to June 18 in Gosan. During the sampling period, AD storm was observed on May 23 in Alashan, on May 24 in Beijing, and on May 25-26 in Seoul and Gosan, Korea. The AD originated in Alashan on May 23, traversed Beijing, and moved to Seoul and Gosan. Meteorological data are shown in Table 1. Three sets of medium-volume air samplers (TH-150 Sampler, Wuhan Tianhong Intelligence Instrumentation Facility, Beijing, China) for TSP, PM10, and PM2.5 were used for collecting the ambient particulate matter (PM) with 10 cm quartz membrane filters (Pal, NY, USA). Samples were collected regularly for 20 hrs/day, from 10:00 a.m. to 6:00 a.m. of the following day. During the break time of 4 hrs, filters were exchanged. Air flow was set at 100 L/

min. After sampling, filters were kept in a desiccator for at least three days to reduce the humidity of the samples, and then the samples were weighed. The sample weight was divided by air volume adjusted to the standardized air condition (20°C, 1 atm).

2. Chemical analysis

For the chemical analysis of inorganic elements in the ambient air particles collected from the 4 different sites, part of each sampling filter (1/8 filter) was cut out and immersed in a mixed acid of 5% HNO₃ (5 ml) and 15% HNO₃ (2 ml) respectively, then diluted up to 10 ml with 1% HNO₃. Filters were immersed overnight at room temperature, and then extracted with a temperature-controlled electrical heater. After acid extraction of the sampling filters, inorganic elements were measured by AFS230E hydride-activating atomic fluorescence spectrophotometer (AFS) (Beijing Haiguang Instrument Co., Beijing, China), AA2610 atomic absorption spectrophotometer (AAS) (Beijing Chaoyang Huayang Pphotic Instrument Co., Beijing, China), and Elan DRC type-II electricity-induced coupling plasma mass-spectrograph (Perkin-Elmer Sciex Co., Waltham, MA, USA). Detection limits (ng/L) are as follows: Al: 90, Cr: 2, Mn: 3, Fe: 900, Ni: 5, Cu: 30, Zn: 60, Cd: 3, Pb: 12, As: 40, Na: 2,000, Mg: 2,000, K: 2,000, Hg: 4, and

Table 1. Meteorological data of sampling sites during AD storms

		May 22	May 23	May 24	May 25	May 26	May 27
AL	Temp. (°C)	17.4	12.6	16.6	20.0	20.9	21.3
	RH (%)	48	35	21	19	15	11
	Rainfall (mm)	0	0	0	0	0	0
BE	Temp. (°C)	17.8	19.2	23.8	24.3	26.2	25.5
	RH (%)	78	88	41	25	35	30
	Rainfall (mm)	33.4	9.4	0	0	0	0
SE	Temp. (°C)	19.7	20.7	19.8	19.7	20.3	22.5
	RH (%)	47.8	48.9	78.4	71.6	50.3	52.0
	Rainfall (mm)	0	0	49.0	1.0	0	0
GO	Temp. (°C)	18.7	20.8	20.3	17.1	20.2	20.2
	RH (%)	58.4	72.4	89.9	92.5	74.0	65.5
	Rainfall (mm)	0	0	14.0	2.5	0	0

Asian Dust storm was observed on May 23 in Alashan (AL), on May 24 in Beijing (BE), from May 25 to 26 of 2007 in Seoul (SE) and Gosan (GO). RH; Relative humidity.

Ca: 500. Quality assurance was conducted by an external expert and no specific issues were found.

3. Statistical analysis

Regression analysis was performed using SPSS (Statistical Package for Social Sciences) for the correlation study of PM 10 and inorganic elements.

III. Results

During the sampling period, the concentrations of TSP, PM10, and PM2.5 were highest in Alashan among the 4 sampling sites (Table 2). The average daily concentration of TSP was 514.5 $\mu\text{g}/\text{m}^3$ and reached 1,824.7 $\mu\text{g}/\text{m}^3$ on May 23, 2007 when an AD storm occurred in the Alashan region. The average daily concentrations of PM10 and PM2.5 in Alashan were 361.7 and 177.6 $\mu\text{g}/\text{m}^3$, respectively. The distribution of PM is shown in Table 2, and it was used to calculate the distribution of particle fraction to TSP. The distribution ranged from 63-70% in the case of PM10 and from 29-36% in the case of PM2.5 at the 4 sampling sites. The PM2.5 ratio to PM10 ranged from 45-57%. The ratio of PM2.5/TSP in Alashan was 34.5%, which indicates that PM2.5 is also a main component of AD.

The concentrations of inorganic elements are shown in Table 3 for PM2.5 and Table 4 for

PM10. In Beijing, concentrations of toxic heavy metals, such as lead (Pb), arsenic (As), and cadmium (Cd) in PM2.5 were higher than in Alashan or in Seoul. In the case of the Pb level in PM10, the average daily concentration in Beijing reached 240.6 ng/m^3 , which is approximately 5-fold higher than that in Alashan. The concentration pattern of inorganic elements in PM2.5 among the 4 sampling sites was similar to that of PM10. The mean concentrations of chromium (Cr) or nickel (Ni) in Alashan were higher than those in other cities (Table 3 and Table 4). The concentrations of inorganic elements that may originate from soil sources such as iron (Fe), aluminum (Al), magnesium (Mg), manganese (Mn), and sodium (Na) were higher in Alashan than those of in Beijing or Seoul. The increased levels of soil-originated elements were attributable to elevated amounts of PM. Based upon regression analysis, the concentrations of anthropogenically enriched elements, such as Pb, As, and Cd were not correlated with the concentration of PM10. The correlation coefficient (R^2) was 0.041 of Pb, 0.004 of As, and 0.028 of Cd. However, the concentrations of possible soil-originated elements, such as Fe ($R^2 = 0.783$), Al ($R^2 = 0.717$), Mg ($R^2 = 0.689$), were significantly correlated with the concentration of PM10. The correlation coefficients of Mn and Na were relatively low compared to other soil-

Table 2. Concentrations of TSP, PM10, and PM2.5

		Mean $\pm$ SD	Min.	25% tile	50% tile	75% tile	Max.
TSP	AL	514.5 $\pm$ 399.4	135.0	269.1	381.8	606.5	1824.7
	BE	330.5 $\pm$ 139.6	109.5	267.9	306.2	373.1	833.6
	SE	99.8 $\pm$ 65.2	30.0	51.7	78.2	135.0	293.2
	GO	51.0 $\pm$ 34.1	15.9	28.0	46.1	59.7	159.0
PM10	AL	361.7 $\pm$ 249.4	115.8	184.0	281.6	454.3	1080.0
	BE	223.1 $\pm$ 114.1	53.7	159.4	205.7	260.0	632.3
	SE	63.6 $\pm$ 45.0	19.1	30.9	50.4	75.5	192.7
	GO	32.5 $\pm$ 22.2	11.1	19.5	24.7	37.7	92.7
PM2.5	AL	177.6 $\pm$ 122.6	29.6	89.4	129.5	250.2	530.1
	BE	106.6 $\pm$ 57.9	33.9	63.1	92.1	128.5	271.5
	SE	36.4 $\pm$ 25.2	11.4	19.0	26.0	44.9	113.7
	GO	14.9 $\pm$ 7.7	8.6	10.8	12.8	15.4	45.9

AL; Alashan, BE; Beijing, SE; Seoul, and GO; Gosan.

Table 3. Concentrations of inorganic elements in PM_{2.5} at 4 sampling sites

	Pb	Cr	Ni	As	Cd	Hg	Mn	Fe	Al	Cu	Zn	Ca	Mg	Na	K
Mean	45.8	27.3	5.0	3.7	1.1	13.6	150.1	2341.8	1249.9	30.6	61.4	13008.2	2409.4	1013.8	1056.6
SD	24.3	11.1	2.5	2.2	0.9	6.0	80.0	1341.2	746.7	7.6	31.7	8394.1	1415.7	463.9	656.2
Min.	20.3	0.0	1.1	1.0	0.3	3.8	49.8	612.6	324.5	20.5	20.3	2305.5	455.7	281.0	237.4
AL 25% tile	28.4	23.4	3.4	2.1	0.4	10.1	90.8	1329.0	652.7	24.5	38.0	6445.3	1238.0	685.7	521.1
50% tile	34.3	25.6	4.2	3.2	0.6	12.6	135.1	2034.3	1085.7	29.9	50.4	10689.4	2197.5	906.6	869.9
75% tile	58.3	31.1	6.8	4.7	1.6	16.2	182.9	2963.6	1672.4	34.0	79.8	17307.9	3297.6	1339.9	1461.6
Max.	112.9	52.0	12.0	9.2	4.1	34.2	452.9	6462.6	3814.6	54.2	125.6	36800.4	5740.6	2147.6	2676.6
Mean	194.8	6.0	2.5	43.5	4.1	14.9	76.5	618.6	374.5	62.0	383.9	1858.0	514.0	687.5	4932.4
SD	90.4	3.0	1.1	28.0	2.4	14.4	30.4	523.3	367.2	34.9	172.7	2071.3	649.6	505.4	6846.6
Min.	34.9	0.8	1.2	8.1	0.9	0.4	32.4	180.0	96.2	26.0	126.1	122.0	72.4	267.4	460.8
BE 25% tile	145.4	3.2	1.7	23.8	2.4	4.7	56.5	305.9	162.2	40.8	264.4	506.0	161.8	416.5	1415.0
50% tile	170.5	5.9	2.4	32.6	3.4	12.1	73.8	424.5	255.7	46.5	337.5	882.9	257.8	565.4	2396.2
75% tile	226.9	8.1	2.7	53.7	5.5	21.3	98.3	760.2	457.9	65.8	471.6	2599.2	659.8	774.1	6023.7
Max.	403.2	14.0	6.1	128.0	10.6	62.2	171.0	2674.1	1819.3	187.7	808.3	8847.2	3125.5	3076.0	37390.5
Mean	43.4	21.4	3.5	9.0	1.3	19.6	26.3	299.6	227.5	38.0	115.0	487.1	168.4	248.7	417.9
SD	29.1	14.5	3.9	6.4	0.8	18.2	20.7	219.6	158.2	14.8	77.2	610.5	205.3	235.5	325.0
Min.	10.3	4.2	0.2	1.9	0.2	1.2	7.1	97.5	39.4	4.2	23.6	51.5	17.0	54.4	63.7
SE 25% tile	23.3	12.3	1.9	3.8	0.7	5.6	12.3	158.7	118.2	29.5	60.3	152.3	48.5	103.4	179.0
50% tile	35.9	16.7	2.6	6.2	1.2	14.1	18.9	221.2	190.4	36.9	95.1	238.4	69.6	132.4	275.6
75% tile	61.3	26.5	3.6	13.8	1.8	26.4	30.4	357.9	259.7	46.9	156.9	530.6	185.9	337.5	728.5
Max.	131.9	57.8	24.0	27.0	3.8	68.9	92.0	1077.6	691.3	68.3	361.4	3226.2	838.5	1167.6	1200.2
Mean	22.5	3.9	3.8	1.7	0.6	7.8	17.4	164.5	187.1	25.2	58.4	426.2	253.5	953.4	332.0
SD	23.8	4.2	2.4	1.9	0.9	6.7	19.0	137.1	81.6	14.9	89.5	668.3	470.1	1781.2	334.5
Min.	0.8	0.0	1.1	0.0	0.0	0.6	1.1	0.0	44.9	9.5	2.5	0.0	0.0	126.9	3.9
GO 25% tile	6.3	2.2	2.3	0.8	0.2	1.5	6.3	60.3	158.6	16.2	22.1	163.1	77.8	334.3	86.3
50% tile	14.0	2.7	3.1	1.0	0.3	7.1	12.9	124.8	183.9	20.3	33.4	217.4	114.0	481.7	253.5
75% tile	34.5	4.0	4.8	1.9	0.7	12.5	20.1	239.6	220.3	29.6	52.7	318.6	215.4	708.0	435.4
Max.	100.5	21.4	12.9	8.9	4.3	25.8	91.3	511.5	357.5	72.8	451.2	3324.1	2318.4	9062.7	1527.8

(unit: ng/m³, Hg: pg/m³)

Table 4. Concentrations of inorganic elements in PM10 at 4 sampling sites

	Pb	Cr	Ni	As	Cd	Hg	Mn	Fe	Al	Cu	Zn	Ca	Mg	Na	K
Mean	51.2	22.2	10.1	5.4	1.3	14.2	245.3	4545.4	2430.4	33.2	88.8	28996.0	4936.5	2053.3	1697.7
SD	26.7	7.4	6.3	3.0	1.0	5.2	126.9	2839.0	1509.0	7.5	41.2	17820.7	3455.9	1332.7	909.5
Min.	24.2	13	2.5	1.1	0.3	2.9	95.3	1166.2	644.9	22.4	37.2	6448.9	1000.8	484.4	459.9
AL 25% tile	30.2	17.4	6.4	3.5	0.5	11.1	187.3	2796.5	1643.8	28.7	56.4	16271.0	2735.2	1129.1	1035.7
50% tile	43.2	22.0	8.6	4.9	0.8	13.6	211.4	3639.3	2077.4	32.3	80.8	25171.5	4064.1	1618.3	1617.7
75% tile	67.5	24.3	12.4	7.4	1.8	16.7	275.7	5386.4	2863.5	35.9	114.6	36013.9	6267.8	2892.5	2420.6
Max.	126.5	47.7	26.9	12.4	4.4	26.4	649.8	11680.9	7305.8	61.4	190.6	73038.3	15519.4	5624.7	3946.1
Mean	240.6	20.8	6.4	61.8	5.1	25.6	161.7	1961.1	1297.2	110.9	612.8	9614.1	2174.3	1229.6	6171.5
SD	138.1	12.0	3.0	49.7	3.3	18.9	77.4	1247.1	943.8	59.2	385.7	5308.3	1516.0	764.7	7448.1
Min.	39.9	2.1	3.2	10	0.7	6.5	71.7	425.7	259	59.3	151.4	871	295.5	463.8	857.8
BE 25% tile	164.1	13.0	4.2	33.5	3.0	12.3	114.2	1254.7	832.0	76.2	394.2	6515.2	1280.2	695.3	2314.1
50% tile	215.8	19.5	5.8	42.9	4.2	20.9	135.3	1631.2	929.3	86.8	530.2	8293.5	1820.7	1069.6	3031.2
75% tile	267.8	25.6	7.3	72.4	6.6	31.1	181.5	2184.4	1643.3	120.7	696.7	11611.5	2378.1	1456.9	8440.9
Max.	795.1	25.7	7.3	73.4	6.6	33.0	186.0	2129.5	1435.5	123.4	698.3	11188.3	2301.1	1457.4	8459.8
Mean	65.6	14.9	4.9	34.4	1.8	24.0	54.5	662.7	636.8	66.3	215.6	2340.6	1011.5	1564.9	746.2
SD	51.7	8.4	3.9	58.9	1.4	18.4	53.3	619.7	801.0	30.8	213.8	3492.7	1657.7	2717.5	840.3
Min.	11.3	1.6	0.6	2.8	0.3	1.2	9.6	156.4	114.5	7.2	29.4	97.8	63.5	81.7	71.8
SE 25% tile	30.2	9.3	2.3	5.0	0.9	11.4	21.0	297.3	195.9	47.0	75.0	526.8	126.2	167.7	224.0
50% tile	46.2	13.1	3.5	8.7	1.5	17.3	31.7	412.8	252.6	63.4	135.7	800.9	188.0	284.7	372.5
75% tile	90.9	18.7	7.1	21.1	2.1	32.2	54.4	682.0	539.3	82.6	246.6	1650.3	699.9	994.5	818.7
Max.	229.9	37.0	18.7	216.4	6.2	67.7	208.8	2586.8	3129.3	138.8	905.9	14542.1	5540.1	8995.0	3355.4
Mean	25.2	5.0	3.3	2.4	0.6	3.8	23.3	301.4	234.7	41.8	60.2	790.4	426.8	1706.6	429.6
SD	25.6	2.2	1.3	2.0	0.6	4.0	20.3	239.4	143.8	31.6	44.2	814.7	382.1	1272.2	374.8
Min.	1.6	1.1	0.9	0.2	0.1	0.0	1.3	14.7	50.2	5.6	10.6	56.1	45.6	289.2	24.0
GO 25% tile	6.8	3.5	2.4	1.1	0.2	0.6	6.7	107.5	128.7	24.5	28.1	167.6	173.4	918.1	142.1
50% tile	16.1	5.1	3.3	2.1	0.4	2.3	17.3	218.2	193.2	31.6	46.2	411.0	243.3	1483.0	294.2
75% tile	35.4	6.4	4.5	2.7	0.7	6.6	37.3	489.8	348.5	48.2	88.8	1403.4	650.4	1865.0	685.8
Max.	91.1	10.4	5.7	6.8	2.0	11.6	62.3	795.1	553.0	145.3	161.5	2704.9	1631.7	5306.6	1299.9

(unit: ng/m³, Hg: pg/m³)

Fig. 2. Regression analysis for the correlations of PM10 and inorganic elements.

The continuous lines represent the regression lines. Total number of PM10 samples in this analysis was 123, which collected from Alashan, Beijing, Seoul and Gosan during the sampling period.

originated elements. The R-square values of Fe and Al were very high when they were compared to those of other elements, which seemed to be indicators of soil concentration in ambient air

(Fig. 2) The same pattern was also shown in PM2.5 using regression analysis (data not shown).

During the approximate 30 days of sampling period from May to June, an AD storm occurred

in Seoul and Gosan from May 25 to May 26. The AD originated in Alashan on May 23, traversed Beijing on May 24, and arrived in Seoul and Gosan on the afternoon of May 25, lasting to the morning of May 26. Before and after the AD storm, ambient particle concentrations of TSP, PM₁₀, and PM_{2.5} at 4 sampling sites are shown in Table 5. The TSP concentration on May 23 was 1824.7 $\mu\text{g}/\text{m}^3$ in Alashan, 144.4 $\mu\text{g}/\text{m}^3$ in Beijing, 86.2 $\mu\text{g}/\text{m}^3$ in Seoul, and 39.1 $\mu\text{g}/\text{m}^3$ in Gosan. Exceedingly high concentrations of TSP in Alashan on May 23 revealed that the AD event occurred in Alashan. On May 24, TSP concentration in Alashan significantly decreased to 483.6 $\mu\text{g}/\text{m}^3$, but TSP concentration in Beijing rose to 833.6 $\mu\text{g}/\text{m}^3$, which indicated that the AD storm travelled from Alashan to Beijing. Particle concentrations in Seoul and Gosan were not measured on May 24 due to rain. In the afternoon of May 25, AD was observed on the Korean peninsula, such that the concentrations of TSP in Seoul and Gosan increased markedly to 274.7 and 159 $\mu\text{g}/\text{m}^3$, respectively. The AD storm occurred in the afternoon in Korea and lasted until the morning of May 26. As shown in Table 5, PM_{2.5} which belongs to the class of fine particles, also increased during the AD event on May 23 in Alashan, on May 24 in Beijing, and from May 25 to May 26 in Seoul and Gosan. When

we compared the concentrations of anthropogenically enriched heavy metals along the sampling sites data demonstrated that the concentration of anthropogenically enriched elements were higher in the metropolitan areas. As shown in Table 6, in which anthropogenic elements and natural soil element were compared, the concentrations of As, Pb, and Cd in PM₁₀ and PM_{2.5} were always higher in Beijing and Seoul than those in Alashan and Gosan during the AD storm. The Alashan PM₁₀ level was 1,824.7 $\mu\text{g}/\text{m}^3$ on May 23 when the AD event was observed. The Beijing PM₁₀ level was 144.4 $\mu\text{g}/\text{m}^3$ on May 23 when the AD event was not observed. The PM₁₀ level in Alashan was 12.6-fold higher than in Beijing (Table 5). However, the As levels were 8 ng/m^3 in Alashan and 32.9 ng/m^3 in Beijing (Table 6). When the As concentration was calculated by weight of the particles, it was found that it was approximately 4.4 ng/mg -particle in Alashan, but 235 ng/mg -particle in Beijing. Results indicate that concentration of As in PM₁₀ collected in Beijing was 53-fold higher than in Alashan. The concentrations of the inorganic compounds Al, Mg, Na, Mn, and Fe in PM₁₀ and PM_{2.5} increased with the elevated levels of particle concentrations during the AD storm (Tables 5 and 6).

Table 5. Concentrations of ambient air particles during an AD storm

		May 22	May 23	May 24	May 25	May 26	May 27
TSP	AL	748.5	1824.7	483.2	156.9	234.7	160.1
	BE	109.5	144.4	833.6	300.7	401.1	312.1
	SE	83.7	86.2	-	274.7	203.0	172.0
	GO	26.6	39.1	-	159.0	131.8	105.0
PM ₁₀	AL	397.8	1055.4	287.5	118.9	205.8	121.0
	BE	103.1	96.3	632.3	211.7	250.5	224.7
	SE	49.9	56.9	-	192.7	163.7	142.5
	GO	18.9	27.8	-	84.6	92.7	82.8
PM _{2.5}	AL	120.6	323.3	62.0	29.6	81.1	55.9
	BE	96.1	33.9	153.8	76.3	82.1	55.0
	SE	19.0	37.2	-	65.8	113.7	100.6
	GO	10.4	20.4	-	24.1	45.9	23.9

(unit: $\mu\text{g}/\text{m}^3$)

Asian Dust storm was observed on May 23 in Alashan, on May 24 in Beijing, from May 25 to 26 of 2007 in Seoul and Gosan. “-” ; sampling was not done due to rain.

Table 6. Daily concentrations of inorganic elements during the Asian dust storm at the 4 sampling sites

	May 22			May 23			May 24			May 25			May 26			May 27		
	PM10	PM2.5		PM10	PM2.5		PM10	PM2.5		PM10	PM2.5		PM10	PM2.5		PM10	PM2.5	
As*	AL	6.2	3.4	8.0	3.9	3.4	4.7	3.4	3.4	2.0	1.0	3.5	2.1	4.0	2.8			
	BE	36.6	24.7	32.9	21.3	19.0	33.5	19.0	34.9	23.0	23.0	39.8	27.1	35.0	25.0			
	SE	6.7	3.6	6.3	4.5	-	-	-	26.1	15.2	15.2	19.4	14.2	19.2	13.7			
	GO	1.3	0.8	1.3	0.5	-	-	-	6.5	4.4	4.4	4.6	3.4	2.8	2.3			
Pb*	AL	43.4	32.8	38.7	27.0	32.9	29.9	32.9	25.0	21.0	21.0	26.7	21.4	37.9	32.4			
	BE	184.8	146.7	124.8	102.0	61.3	79.6	61.3	134.9	120.2	120.2	205.2	180.3	164.1	145.4			
	SE	39.9	27.7	106.6	28.6	-	-	-	126.6	91.0	91.0	99.9	83.9	120.8	62.4			
	GO	20.3	19.0	5.2	5.9	-	-	-	62.8	51.5	51.5	45.3	40.5	28.5	28.6			
Cd*	AL	0.7	0.5	0.6	0.3	0.4	0.5	0.4	0.5	0.3	0.3	0.4	0.3	0.8	0.6			
	BE	2.5	1.8	1.8	1.3	0.9	1.3	0.9	2.6	2.1	2.1	4.2	3.4	3.3	2.8			
	SE	1.5	1.0	1.8	1.5	-	-	-	2.8	1.8	1.8	2.6	1.9	1.9	1.5			
	GO	0.4	0.3	0.2	0.2	-	-	-	1.0	0.8	0.8	0.8	0.7	0.6	0.6			
Al	AL	4189.7	2076.2	5150.7	2343.1	1856.1	2843.1	1856.1	879.2	324.5	324.5	1278.6	591.2	1718.3	974.2			
	BE	259.0	164.9	2420.3	953.6	1819.3	4987.1	1819.3	3243.1	1145.0	1145.0	1801.2	457.9	1865.1	617.2			
	SE	254.0	82.0	352.3	121.0	-	-	-	1685.4	505.7	505.7	1113.2	410.5	1062.3	515.1			
	GO	197.3	170.0	440.6	357.5	-	-	-	419.0	211.6	211.6	489.7	278.1	553.0	336.0			
Mg	AL	10200.9	4248.7	15519.4	5740.7	4320.0	8055.1	4320.0	1545.7	455.7	455.7	2734.6	1205.0	3407.0	2124.5			
	BE	295.5	72.4	4010.5	1533.9	3125.5	8402.2	3125.5	5229.9	1904.2	1904.2	2538.4	659.8	2733.9	902.0			
	SE	241.4	49.0	209.2	55.4	-	-	-	3044.9	838.5	838.5	1690.9	532.4	1164.7	477.8			
	GO	120.8	59.8	168.4	82.0	-	-	-	703.9	221.9	221.9	810.6	342.7	905.4	452.4			
Na	AL	3812.3	1535.7	5624.7	2022.0	1602.3	3010.4	1602.3	756.4	281.0	281.0	1585.1	671.9	1651.6	1007.8			
	BE	485.9	326.5	1819.8	774.1	1277.8	3448.1	1277.8	2116.2	887.4	887.4	977.8	489.7	824.7	473.9			
	SE	526.7	116.1	391.5	162.5	-	-	-	1761.7	508.9	508.9	1452.4	477.7	949.5	391.8			
	GO	497.5	225.4	962.9	320.2	-	-	-	1817.6	467.2	467.2	1537.1	481.2	1260.5	482.3			
Mn	AL	379.4	234.1	471.3	254.4	211.3	281.4	211.3	126.2	49.8	49.8	161.8	82.8	189.0	124.6			
	BE	71.7	44.4	230.6	103.9	171.0	426.5	171.0	309.6	136.4	136.4	222.5	101.1	206.2	98.3			
	SE	39.4	17.4	38.4	20.3	-	-	-	194.4	71.6	71.6	139.5	60.7	98.5	48.4			
	GO	15.0	10.5	19.1	14.8	-	-	-	62.3	30.5	30.5	60.4	33.5	58.2	35.7			
Fe	AL	8359.5	4003.9	11509.5	4901.5	3838.3	6214.9	3838.3	1666.3	612.6	612.6	2562.2	1270.3	3266.4	1997.9			
	BE	425.7	239.8	3465.7	1400.4	2674.1	7084.4	2674.1	4580.0	1756.0	1756.0	2501.6	820.6	2498.8	973.9			
	SE	488.0	160.0	610.2	322.2	-	-	-	2586.8	817.7	817.7	1702.8	576.0	1117.0	546.0			
	GO	232.9	123.0	462.3	218.3	-	-	-	630.4	271.0	271.0	717.7	355.0	795.1	428.2			

(unit: ng/m³)

Asian Dust storm was observed on May 23 in Alashan (AL), on May 24 in Beijing(BE), from May 25 to 26 of 2007 in Seoul (SE) and Gosan (GO).
 “-”; sampling was not done due to rain, - ; sampling was not done because of rain. *; anthropogenically enriched inorganic elements.

IV. Discussion

The concentrations of TSP, PM₁₀, or PM_{2.5} in Alashan were markedly higher compared with those in other cities.²⁰⁻²²⁾ It is interesting to note that the ratio of PM_{2.5}/TSP in Alashan was not significantly different from those of Beijing or Seoul because it has been known that distribution of PM_{2.5} is relatively low in non-polluted areas.²³⁾ PM_{2.5} collected in Alashan did not originate from anthropogenic sources but from natural soil. However, PM_{2.5} distribution during the AD in Alashan may be higher than expected based on the ratio of PM_{2.5}/TSP.

Daily PM₁₀ concentrations of Beijing exceeded 150 µg/m³, which is the current National Ambient Air Quality Standard (NAAQS) of the U.S. Environmental Protection Agency (EPA). During the 32 days of the sampling period, the daily PM₁₀ concentration in Beijing exceeded the NAAQS for 27 days. During the 36 days of sampling, the daily PM₁₀ concentration exceeded NAAQS for only 2 days in Seoul. The 24-hr average of NAAQS for PM_{2.5} in the 1997-standards of the U.S. EPA was 65 µg/m³, but was changed to 35 µg/m³ in the EPA's 2006-standard. All days except one in Alashan, and two in Beijing exceeded the 2006 NAAQS for PM_{2.5}. In Seoul, 35% of the sampling days exceeded the PM_{2.5} standards. However, only one day exceeded the PM_{2.5} standard in Gosan, which was the day of the AD event. Chuersuwan *et al.*²⁴⁾ reported measuring the ambient particle concentrations of the Bangkok Metropolitan Region (BMR) during 2002-2003. According to this study, average daily concentrations of PM₁₀ and PM_{2.5} at the traffic site were 108.1±35.5 µg/m³ and 69.0±28.8 µg/m³, respectively. Particle concentrations in Beijing in 2007 were 2-fold higher than those of the BMR in 2003. Compared with the cities of Europe, Beijing showed higher concentrations of ambient PM.^{25,26)}

In general, the concentrations of inorganic elements in PM were increased as the increase of concentration of PM₁₀ or PM_{2.5}.²⁷⁻²⁹⁾ However, there was a regional difference in concentrations of anthropogenic metals. When the concentrations were compared among the 4 sampling sites, the concentrations of possible anthropogenically enriched

elements, such as Pb, Cd, Hg, As, Cu, and Zn, were higher in the metropolitan cities of Beijing and Seoul compared to Alashan (Table 4). As indicated previously, particle concentrations of PM₁₀ and PM_{2.5} in Alashan were higher than those in other sampling sites, but total concentrations of anthropogenically enriched elements were greater in Beijing or Seoul than in Alashan. Data thus indicate that there are many sources of environmental pollution in metropolitan cities. The mean concentration of Cr or Ni was greater in Alashan than Beijing or Seoul. Previous reports suggested that Cr and Ni reflect soil sources³⁾. However, when the metal concentrations were calculated by particle mass (ng metal/mg weight of particle), not by total ambient air volume, the concentrations of Cr and Ni were higher in Beijing and Seoul compared to Alashan. It seems that Cr or Ni released from industrial sources or other environmental pollution sources was also attached to the particles in the metropolitan cities of Beijing or Seoul. The concentration of soil originated inorganic compounds such as Al, Mg, Na, Mn and Fe was elevated on the day of AD and well represented the change of particle concentration. However, it seemed that the anthropogenic compound including As, Pb and Cd did not always represent the particle concentration (Table 6).

A recent study on the source identification of metals included size-fractionated airborne PM suggests that high loadings on Fe, Mn, and Cr reflect soil sources.³⁰⁾ Particles collected in central Taiwan during an AD event in the spring of 2000 also showed a high loading of the crustal elements Ca, Mg, Al, and Fe.³¹⁾ The samples collected in Alashan displayed the highest concentration of soil-derived inorganic elements^{32,3)} and may be indicators of an AD storm, as shown in Table 4. The changes of the particle concentration of PM₁₀ and PM_{2.5} were almost the same as those of TSP at the sampling sites. Several reports also indicated that PM_{2.5} increased during AD storms.³³⁻³⁵⁾

In summary, AD storm originating in Alashan attracts anthropogenically enriched heavy metals as the storm traverses the region of industrialized eastern China. PM_{2.5} as well as PM₁₀ and TSP, is predominant components of AD which originate in Alashan as reflected by the ratio of PM_{2.5}/TSP.

The hazardous heavy metals in AD were higher in metropolitan area, Beijing and Seoul than those in Alashan and Gosan.

V. Conclusion

The concentrations of the ambient particles TSP, PM10, and PM2.5 were monitored simultaneously at four different locations on the AD pathway: Alashan and Beijing in China, Seoul and Gosan in Korea. Sampling was done from May to June 2007 for about 30 days and an AD event was observed during the period. Inorganic elements, including hazardous heavy metals, were also measured in the collected particles to know the changes of metal concentrations, when the AD passed over metropolitan cities.

1. During the sampling period in Alashan and Beijing, the average particle concentrations of TSP, and PM10 were higher than $150 \mu\text{g}/\text{m}^3$, but not in Seoul and Gosan. The concentration of TSP in Alashan on the day of AD event reached $1824.7 \mu\text{g}/\text{m}^3$. The level was decreased to 15% ($274.7 \mu\text{g}/\text{m}^3$) in Seoul and 8.7% ($159.0 \mu\text{g}/\text{m}^3$) in Gosan when the AD was observed in two days later in the Korean peninsula.

2. The concentrations of anthropogenic compounds, such as Pb, Cd, Hg, As, Cu, and Zn, were higher in the metropolitan cities of Beijing and Seoul than those in Alashan and Gosan. The concentrations of inorganic elements which may originate from soil sources such as Fe, Al, Ca, Mg, and Na, were higher in Alashan than those in Beijing or Seoul.

3. When we compared the concentrations of anthropogenic heavy metals along the sampling sites from Alashan to Beijing and then to Seoul and Gosan, it was found that the anthropogenic elements (Pb, As, Cd) were not correlated with the AD concentration by regression analysis. However, the concentrations of inorganic elements Al, Mg, and Fe bound to PM10 and PM2.5 were correlated with the concentrations of PM10 and PM2.5 during the AD event.

4. The fractional distribution of AD originated in Alashan in May was as follows: PM10/TSP 63%-70%, PM2.5/TSP 30%-34%, and PM2.5/PM10 46%-57%, which means that fine particles are also

major component of AD originated in the Alashan region.

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