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Long range transport of fine particle windblown soils and coal fired power station emissions into Hanoi between 2001 to 2008

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A B S T R A C T

Fine particulate matter ($PM_{2.5}$), source fingerprints and their contributions have been measured and reported previously at Hanoi, Vietnam, from 25 April 2001 to 31 December 2008. In this study back trajectories are used to identify long range transport into Hanoi for two of these sources, namely, windblown dust (*Soil*) from 12 major deserts in China and emissions from 33 coal fired power plants (*Coal*) in Vietnam and China. There were 28 days of extreme *Soil* events with concentrations greater than 6 $\mu g\ m^{-3}$ and 25 days of extreme *Coal* with concentrations greater than 30 $\mu g\ m^{-3}$ from a total of 748 sampling days during the study period. Through the use of back trajectories it was found that long range transport of soil from the Taklamakan and Gobi desert regions (more than 3000 km to the north west) accounted for 76% of the extreme events for *Soil*. The three local Vietnamese power stations contributed to 15% of the extreme *Coal* events, while four Chinese power stations between 300 km and 1700 km to the north-east of Hanoi contributed 50% of the total extreme *Coal* events measured at the Hanoi sampling site.

1. Introduction

In a previous publication (Cohen et al., 2010) we used ion beam analysis (IBA) techniques to characterise fine particle air pollution followed by positive matrix factorisation (PMF) methods to identify and fingerprint pollution sources in the Hanoi region. Here we apply these results, for the first time, to study long range transport of two of these sources, namely, wind blown soils and emissions from coal fired power stations into this same Hanoi site.

1.1. Major desert dust sources in the region

Airborne soils and desert dusts can arrive at Hanoi by wind trajectories extending back over inland areas of northern and western China and Mongolia (Hien et al., 2004). They estimated that long range transport accounted for 50%, 34% and 33% of the fine mass in trajectories from the north over inland China, from the north east over the east China sea and from the south west over the Indochina peninsula, respectively.

The Taklamakan desert region is a regular known source of dust storms especially in springtime. Resting in the Tarim Basin, between the mountain ranges of the Tien Shan in the north and the Kunlun Shan in the south, the Taklimakan Desert is one of the world's largest shifting sand deserts, with dunes towering to as much as 200 meters. Dust storms also frequently arise from the Gobi Desert and other desert regions in northern China. The Taklamakan and Gobi Desert regions are shown in Fig. 1. The boxes represent the major desert systems within these two major dust regions (Wang et al., 2008).

Table 1 lists the positions of 12 major desert regions of interest (plotted in Fig. 1) in East Asia after Kim et al. (2007) and their distances to the Hanoi sampling site.

The deserts A to D in Fig. 1 and Table 1 are associated with the Taklamakan desert region, E to I with the Gobi desert region on the China – Mongolia border and J to L with desert regions north of Beijing. The (±) latitude and longitude columns in Table 1 represent the typical extent of each of the identified desert regions. Note each $1^{\circ} \times 1^{\circ}$ grid cell represents approximately 100 km × 100 km in this region of the globe.

Each year there are more than 10 dust storms, occurring mainly during the period March to May, resulting in more than 20 dust events observed at some observational stations in China (Wang et al., 2008). Wang et al. (2008) estimate that about 800 MT of dust is injected into the atmosphere annually from these desert regions. There are any number of publications demonstrating that these dust storms have global impacts (Wang et al., 2005; Lee et al., 2008)

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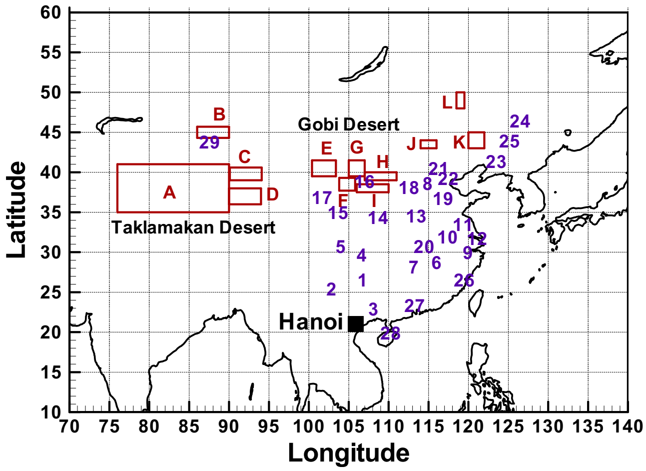

Fig. 1. Location of key deserts (boxes and letters) and major coal fired power plants (numbers) in eastern Asia. Coal fired power stations numbered 30–33 are within the black square marking the Hanoi site and are not shown.

travelling large distances across Korea and Japan (Koo et al., 2008), through southern China to Vietnam and beyond (Hien et al., 2004; Lee et al., 2006) and the severe dust storms even reaching North America (Song et al., 2008).

1.2. Major coal sources in the region

To meet the rapidly increasing demand for electric power while utilizing mainly domestic energy resources, the Vietnamese government is promoting the construction of new coal fired power plants. Apart from hydropower and combined cycle plants, more than ten coal fired power plants are planned with a combined total capacity of 2900 MW by 2010. These projects are outlined in the Master Plan, published by the Ministry of Industry in Vietnam in 2001. Cao Ngan (100 MW) 80 km north of Hanoi was one of the first coal fired plants to go into operation in 2006 during the first step of this Master Plan and as recently as March 2009 a new second generator (300 MW) was announced for the Pha Lai coal fired power plant, 65 km north east of Hanoi. Also in 2007 a new 300 MW coal fired power plant at Uong Bi 100 km east of Hanoi came into operation. Coal fired power plants will eventually account for around 25% of Vietnam's total electricity production (Clough, 2008). Much of the local coal burnt in Vietnam for power is anthracite, this is a difficult fuel with a high ash content of up to 33% but a low sulfur content of between 0.5–0.7% by weight. Hence power production in the region is a significant local source of fine particulate matter as are the gases, CO_2, SO_2 and NO_X, generally associated with coal combustion emissions.

To the north, China also burns large quantities of coal and bio-fuel (IEA, 2002), and is generally recognised as a major global anthropogenic source for fine particle pollution (Cao et al., 2006). According to Arndt et al. (1998) China produces around 11 MT year^{-1} of sulfur emissions but only 6.1 MT year^{-1} are deposited in China itself the rest is transported out of the region. The UNEP (2008) report estimates that black carbon emissions from South Asia and India have increased from 0.17 MT year^{-1} in 1950 to 0.55 MT year^{-1} in 2000, and SO_2 emissions have increased from 1 MT year^{-1} to 7 MT year^{-1} over the same period, while for east Asia and China the black carbon emissions have increased from 0.25 MT year^{-1} to 1.3 MT year^{-1} and SO_2 emissions have increased from 2 MT year^{-1} to 20 MT year^{-1} (again for the same period). Coal-fired power plants have been considered as a very important source of regional air pollution (Zhao et al., 2008). For China, SO_2 emission from coal-fired power plants in 2005 was estimated to be 16.1 MT, approximately 53% of the national emissions. Grided coal-fired power emissions of SO_2, NO_x and particulate matter in 2005 for China were estimated by Zhao et al. (2008) and it was found that the eastern region with nearly one-third of total coal-fired power emissions had the highest emission intensity for all the species, followed by central and southern, north-eastern and northern regions. In Table 2 we list the major coal fired power plants in eastern China (1–29) together with the four significant coal fired power stations in North Vietnam (30–33) within 150 km of the sampling site at Hanoi. These are the coal combustion sources we will consider here when investigating possible long range transport

Table 1
Latitude and longitude of 12 major desert regions in east Asia after Kim et al. (2007) and their distance to the Hanoi sampling site.

#	Deserts	Latitude	±Lat	Longitude	±Long	Dist to Hanoi (km)
A	Taklamakan desert	38.0	3.0	83.0	7.0	3000
B	Gurban Tonggut desert	45.0	0.7	88.0	2.0	3120
C	Kumtaq desert	39.8	0.8	92.1	2.0	2420
D	Qaidam desert	37.0	1.0	92.0	2.0	2190
E	Badain Jaran desert	40.5	1.0	101.9	1.5	2170
F	Tengger desert	38.5	0.8	104.8	1.0	2120
G	UlanBuh desert	40.5	1.0	106.0	1.0	2140
H	Qubqi desert	39.5	0.5	109.0	2.0	2070
I	Mu Us sandy desert	38.0	0.5	108.0	2.0	1880
J	Otindaq sandy desert	43.5	0.5	115.0	1.0	2630
K	Horqin sandy desert	44.0	1.0	121.0	1.0	2900
L	Hulun Buir sandy land	49.0	1.0	119.0	0.5	3290

Table 2
Latitude and longitude of 33 major coal fired power plants in east Asia. The Chinese sites (1–29) are after Zhao et al. (2008). Their percentage $PM_{2.5}$ and SO_2 emissions, relative to the totals for the 29 Chinese sites, are also listed.

#	Coal fired power stations	Lat	Long	% $PM_{2.5}$ emissions	%SO_2 emissions	Dist to Hanoi (km)
1	Guizhou	26.58	106.71	2.1	5.8	670
2	Yunnan	25.04	102.70	2.0	1.7	560
3	Guangxi	22.81	108.31	1.4	2.1	325
4	Chongqing	29.55	106.55	1.1	1.3	960
5	Sichuan	30.66	104.08	5.2	5.8	1090
6	Jiangxi	28.68	115.90	1.4	2.3	1325
7	Hunan	28.20	112.98	3.3	2.7	1090
8	Hebei	38.05	114.49	6.6	7.9	2070
9	Zhejiang	30.27	120.16	8.0	3.9	1760
10	Anhui	31.86	117.28	2.7	2.0	1650
11	Jiangsu	32.05	118.77	8.4	7.2	1770
12	Shanghai	31.22	121.48	2.5	3.1	1920
13	Henan	34.76	113.65	9.2	8.2	1710
14	Shaanxi	34.26	108.95	4.4	4.2	1520
15	Gansu	36.07	103.75	0.7	1.2	1680
16	Ningxia	38.47	106.27	1.4	1.8	1950
17	Qinghai	36.61	101.79	0.1	0.0	1780
18	Shanxi	37.87	112.57	2.2	7.6	2000
19	Shandong	36.67	117.01	8.7	11.8	2050
20	Hubei	30.57	114.29	4.4	4.2	1360
21	Beijing	39.91	116.40	0.5	0.6	2340
22	Tianjin	39.10	117.25	1.3	1.3	2290
23	Liaoning	41.80	123.41	6.2	4.1	2850
24	Heilongjiang	45.74	126.64	4.6	1.1	3340
25	Jilin	43.89	125.32	4.5	1.2	3120
26	Fujian	26.08	119.30	2.0	1.3	1500
27	Guangdong	23.12	113.26	3.7	4.4	800
28	Hainan	20.03	110.35	0.1	0.2	480
29	Xinjiang	43.79	87.61	1.3	0.7	3060
30	PhaLai	21.12	106.30			50
31	UongBi	21.04	106.79			100
32	CaoNgan	21.62	105.82			70
33	NaDuong	21.70	106.97			140