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Changes in Atmospheric Mercury Concentrations in Seoul, Korea and its Significance: A Case Study Between 1997 and 2002

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Abstract

The concentration levels of gaseous elemental mercury (GEM) in ambient air have been investigated from a monitoring station located in Yang Jae district of Seoul, Korea for a long-term period covering 1997 through 2002. The mean concentration of Hg, if computed based on its hourly measurement data for this six-year period, was 5.32 ± 3.53 ng m^{-3} (N = 27,170). The inspection of the diurnal distribution patterns indicated the presence of notably high concentration levels during nighttime relative to daytime (e.g., the mean hourly value as high as 9 ng m^{-3} in winter nighttime). When divided seasonally, the highest mean of 6.12 ng m^{-3} was also observed during winter followed by spring, fall, and summer. The results of our analysis confirmed the relative dominance of winter (seasonally) or nighttime (diurnally), while exhibiting a complicated trend on a long-term basis. Examination of our data over a different temporal scale consistently indicated that dynamic changes in Hg concentrations occurred through time in line with changes in the strength and diversity of the source processes. It is thus acknowledged that the presence of unusually high Hg levels is the consequence of intense man-made activities, while such signatures can vary in a competitive manner.

Key words : Mercury, Diurnal, Source, Emission, East Asia

1. INTRODUCTION

The record of mercury (Hg) pollution can date back to ancient times when the mercury amalgamation process (e.g., patio) was practiced commonly (e.g., Blanchard, 1980). Likewise, the dominant source of Hg in the context of the global Hg budget estimates was mainly explained by mining activities for gold and silver ores in past centuries. This type of source process is still crucial in certain regions of the globe (e.g., Central and South America: Artaxo *et al.*, 2000; Pirrone *et al.*, 1998), while the nature of the source processes is highly diverse in many industrialized countries and regions (e.g., Kim and Kim, 2002). Investigation of Hg temporal trends indicates a decrease in its concentration levels in certain regions of the globe; this may possibly reflect the fact that its pollution is controllable by the combined effects of several factors such as adm-

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inistrative regulations and advances in control technology (e.g., Slemr and Scheel, 1998). However, the gross trend of Hg is believed to increase largely due to the contribution of rapidly industrializing regions on the globe like China in East Asia (Pirrone *et al.*, 1996).

Although East Asia is expected to exert a great influence on the global Hg budget, there is still a great hiatus on information concerning the mobilization characteristics of Hg in that region (Kim and Kim, 2000). In this respect, the present status of Asia contrasts sharply with that of Europe and America, as its database (DB) in the latter regions is abundant and well-documented. However, much progress has been made in recent years, which allows us to describe Hg distribution patterns in certain sectors of Asia. It has in fact been demonstrated that Hg levels in this region have changed significantly over the past decades. Comparative analysis of Hg in Seoul, Korea indicated a three-fold reduction of Hg concentrations from the late 80s to the late 90s (Kim and Kim, 2002). According to this study, the causes of exceptionally high mean values of around 15 ng m^{-3} seen during the late 80s were mainly ascribable to the peak consumption rate of anthracite coal.

In this work, we attempted to investigate the temporal distribution characteristics of Hg based on our long-term measurements made from a monitoring station located in the Yang Jae district of Seoul between 1997 and 2002. Through compilation of these long-term data sets, we attempted to analyze the behavior and distribution patterns of Hg from various respects. As we conducted a similar type of research using the data sets collected for a considerably limited time period between 1999 and 2000 (Kim and Kim, 2001), the results of our present analysis over this 7 year period may be used to provide more representative figures of Hg behavior in an urban area of the far east Asia.

2. MATERIALS AND METHODS

The atmospheric concentrations of gaseous elemental mercury (GEM: referred hereafter as Hg, unless otherwise specified) were determined from the Yang Jae district of Seoul, Korea for the period covering September 1997 through June 2002. The collection and analysis of Hg samples were made routinely using an on-line analytical system at our monitoring station located at the Seoul Metropolitan Research Institute of Public Health and Environment (SIHE). The general characteristics and all the relevant information of the study site and the surrounding area have been described previously (Kim and Kim, 1999). The site is a dense residential area surrounded by several public parks without any major stationary sources of anthropogenic origin.

In the course of the present study, we attempted to analyze and to describe the fundamental aspects of Hg behavior over varying time scale such as diurnally, seasonally, and annually. The concentrations of Hg were measured at every hour for the whole study period from the third floor laboratory of SIHE. The hourly Hg concentration data were measured by transferring outdoor air via 2 m long sampling train made of Teflon tubing (30 cm diameter) into an on-line automatic Hg analyzer (AM-2 model, the Nippon Instrument Co., Japan); this system is well-known for its internally combined sampling/detection device. For each hourly interval, Hg was collected by an Au-amalgam trap at a constant flow rate of 1.0 L min^{-1}, desorbed thermally, and detected at a wavelength of 253.7 nm by a non-dispersive double beam, flameless atomic absorption system. The absolute detection limit of the system was found as ca 1 pg of Hg. The precision of individual analytical systems, if evaluated in terms of relative standard error (RSE = mean × 100/SE) of 5 replicate injection data of vapor-phase standards (at three different concentration levels of 1, 2, and 3 ng), generally fell in the range of 0.3 ~ 0.6%. It should be noted that accuracy can be considered to be an important parameter to define the characteristics of the analytical system. However, we are not able to assess it directly owing to the unavailability of certified vapor standards. Hence, as an indirect means to overcome this limitation, the system was calibrated against several NBS standards (e.g.,

NBS-1632a, 1568, and 1575); the results revealed the values of mean accuracy in the 3~5% range.

3. RESULTS AND DISCUSSION

3. 1 The overall picture of Hg distribution in the study area

During the whole study period, our measurements of Hg were made basically on a routine basis except for certain periods; in fact, interruptions were frequent due either to instrumental problems or to the employment of the analytical systems for other study purposes (e.g., gradient measurements using two individual systems) (Kim *et al.*, 2003, 2002; Kim and Kim, 1999). The longest period for which we failed to retrieve the data include one between spring 1988 and spring 1999. Except for such period, we were able to collect a total of 27,170

Table 1. A statistical summary of Hg and relevant environmental parameters determined concurrently during this study period.

	Hg ($ng\ m^{-3}$)	Temp. (°C)	UV ($MJ\ m^{-2}$)	RH (%)	Wspeed ($m\ s^{-1}$)	SO_2 (ppb)	NO (ppb)	NO_2 (ppb)
Mean±SD	5.32±3.53	12.8±10.2	26.0±50.7	62.2±20.0	1.37±0.86	5.62±3.31	42.9±57.6	39.9±18.1
Range	0.03~118	−25.9~35.0	0.00~656	0.00~6.70	0.00~100	1.00~36.0	1.00~570	0.00~146
N	27170	33620	32625	33363	34104	33847	32770	32770

	NO_X (ppb)	CH_4 (ppm)	NMHC (ppm)	THC (ppm)	O_3 (ppb)	CO (ppm)	PM10 ($\mu g\ m^{-3}$)
Mean±SD	82.8±69.1	3.03±4.27	1.52±2.02	3.42±4.95	14.7±16.9	1.26±3.17	58.0±71.5
Range	2.00~678	0.00~59.0	0.00~37.8	0.00~68.0	0.00~155	0.00~47.0	1.00~2946
N	32770	30858	30848	30858	32690	32328	31301

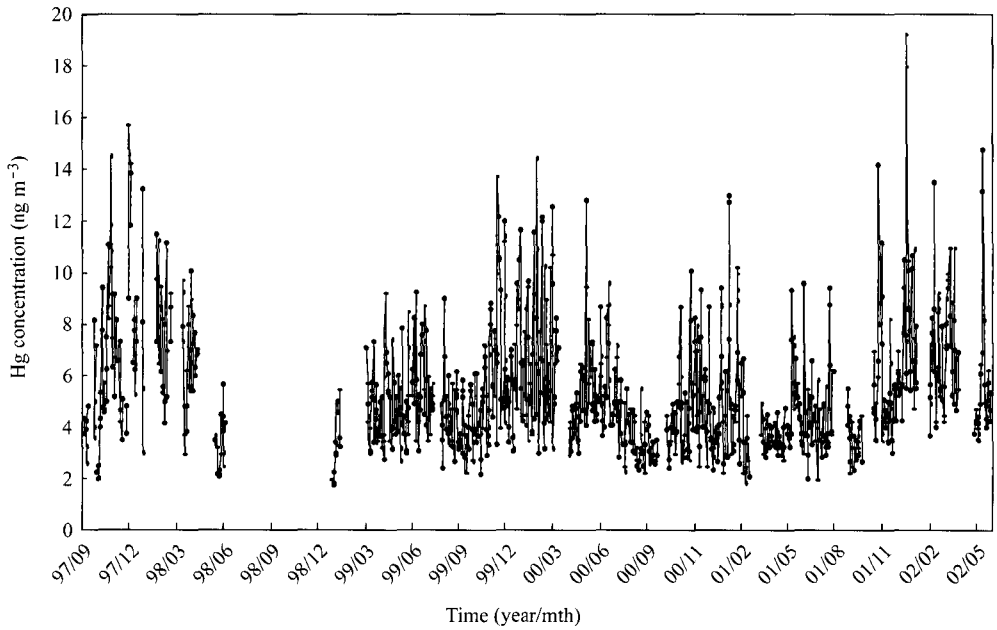

Fig. 1. A plot of day-to-day variabilities of Hg in Yang Jae district of Seoul, Korea during the whole study period between Sep. 1997 and June 2002.

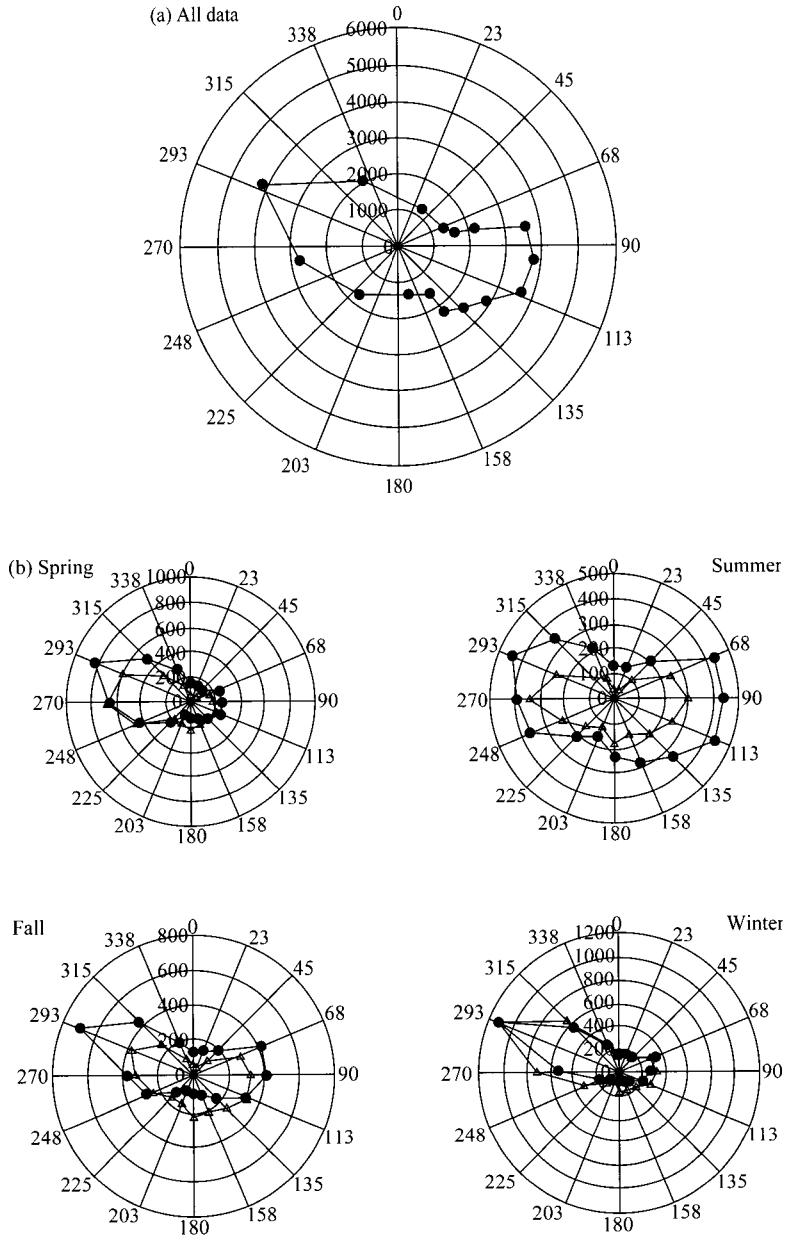

Fig. 2. Comparison of the windrose patterns at the study area using a frequency distribution plot. Comparisons are made by the number of wind occurrences for a given direction: (a) all data sets and (b) both seasonally/diurnally divided data groups. Straight and dotted lines for seasonal patterns represent daytime and nighttime periods, respectively.

individual data points from the whole study period. Fig. 1 depicts the temporal distribution patterns of Hg using its daily mean values. In Table 1, a statistical summary of the Hg measurement data and all

the relevant environmental parameters collected for the whole study period is presented. The results indicate that the meteorological conditions at the site represent those typically seen in a temperate climate zone of mid-latitude. It is found that the average temperature is 12.8°C, while the average wind speed is 1.37 m s^{-1}. In addition, the windrose patterns for the whole study period are compared using the whole data and the seasonally divided data groups (Fig. 2). The results of this analysis indicate that westerly winds rise most dominantly during winter and spring, while both westerly and easterly are important for the rest.

The presence of significantly high Hg levels was commonly found in Seoul during the late 80s (Kim and Kim, 2000) as well as in many Chinese areas at the present time (i.e., rapidly industrialized regions: Tan *et al.*, 2003). The occurrences of those unusually high Hg values have hence been ascribed to strong man-made activities such as the use of anthracite coal. Despite the significant reduction in Hg levels (i.e., near 5 ng m^{-3}) relative to those previous time band, the present time Hg levels in our study site are still clearly distinguished not only from those measured in moderately urbanized regions of the Western countries but also from relatively clean areas in Korea. For instance, Nadim *et al.* (2001), after measuring Hg from eight different locations of Connecticut, USA for a three-year time span, reported its grand mean concentration to be 2.06 ng m^{-3}. They observed the highest mean concentration of 3.76 ng m^{-3} from a highly populated inland site of Waterbury; but the mean concentration levels of most areas were approximately 50% lower than those values. Most importantly, they found the moderately low concentration of 2.1 ng m^{-3} at the Bridgeport site which was selected to represent the most industrialized area of all investigated sites. Similar to this observation, the presence of moderately low Hg concentration levels in urbanized regions has been found more commonly in many Western countries (e.g., Ames *et al.*, 1998) or in rural areas affected by certain anthropogenic activities (Lee *et al.*, 1998). It may be thus reasonable to infer that the Hg levels in many Western countries are controlled in a reasonably efficient manner than in many Eastern countries. In addition, our measurement data at Seoul can be further compared to those results made in a relatively clean area in Korea. In our recent study made in Kang Hwa Island, Korea for the two consecutive spring periods, we observed the mean concentrations of Hg to range from 2.57 (spring 2002) to 3.72 ng m^{-3} (spring 2001) (Kim *et al.*, 2003). It may have to be addressed that the maximum concentration of Hg above 100 ng m^{-3} in the abnormally high concentration range suggests a number of possibilities. Although source processes have changed significantly through time from various respects (in its magnitude or type of sources), there are probably abnormally strong sources that are efficient to influence the observed concentration levels of Hg.

3. 2 Short-term variabilities of Hg concentration

To learn more about the factors regulating Hg behavior over short-term interval, Hg concentration data were examined over diurnal scale after being divided into various grouping schemes (Figs. 3 and 4). As a first step, the diurnal patterns were examined by comparing the mean hourly values computed from the whole data set (Fig. 3a). The results of this analysis indicate that diurnal changes occur in the concentration range between 4.5 and 6.5 ng m^{-3} with the amplitude of variability slightly

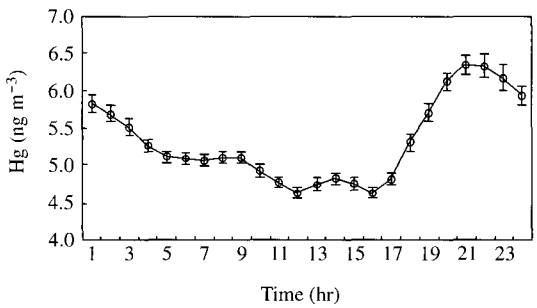

Fig. 3. Diurnal distribution patterns of Hg at the study site are compared using the whole data set collected between 1997 and 2002: Error bars in the figure denote one standard error value.

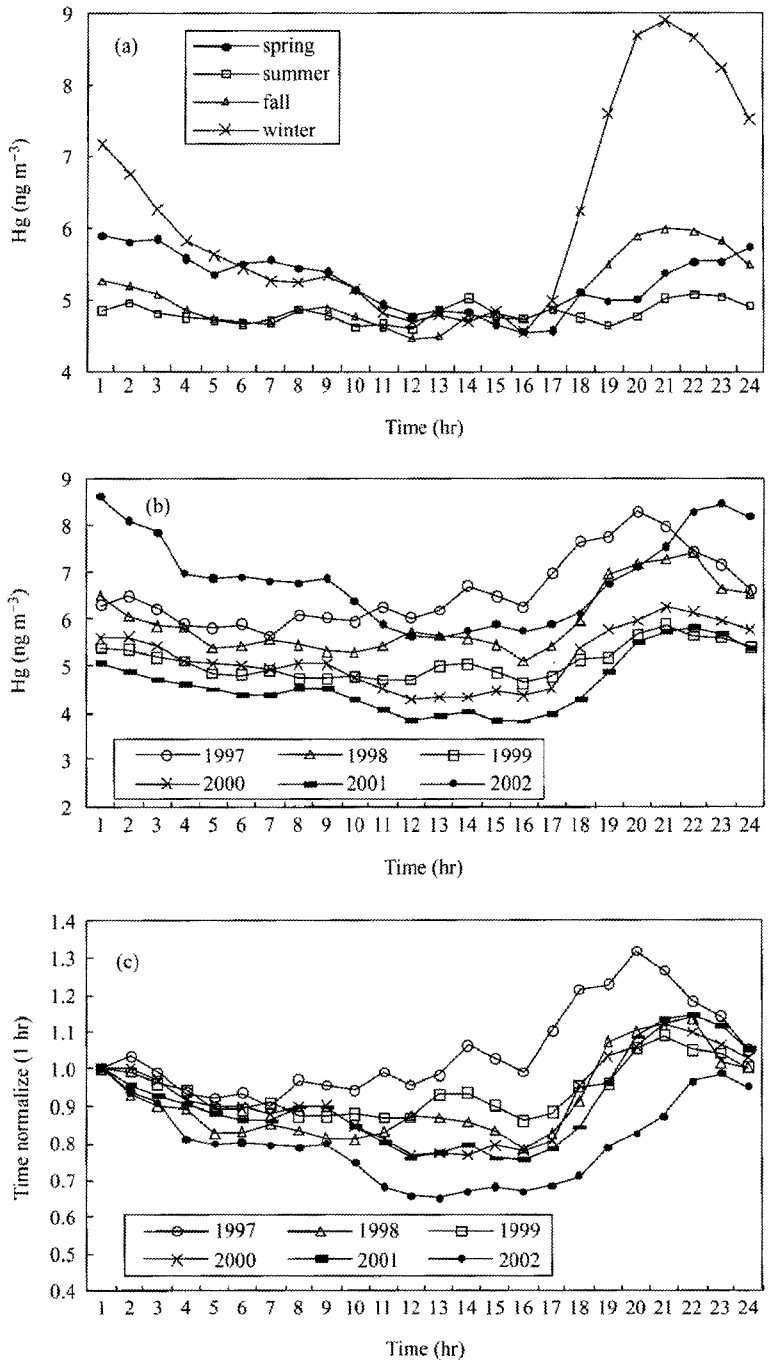

Fig. 4. Comparison of Hg diurnal variabilities between different seasons and years: (a) absolute concentration values for each season; (b) absolute concentration values for each year; and (c) same as (b) but after normalization at 1 AM value for each year.

Table 2. Comparison of Seasonal mean values of Hg and relevant parameters.*

	Seasonal			
	Spring	Summer	Fall	Winter
Hg (ng m^{-3})	5.24±3.31 (7221)	4.81±2.77 (6482)	5.06±3.14 (6382)	6.12±4.46 (7085)
Temp. (°C)	13.2±6.36 (8760)	24.7±3.81 (7713)	14.9±6.76 (7782)	0.88±4.80 (9365)
UV (MJ m^{-2})	32.4±56.2 (8725)	39.7±73.4 (7296)	21.6±35.4 (7547)	12.5±20.8 (9057)
RH (%)	56.0±21.1 (8776)	73.7±16.7 (7713)	66.3±19.3 (7514)	55.3±16.7 (9360)
Wspeed (m s^{-1})	1.45±0.91 (8779)	1.18±0.69 (7731)	1.25±0.77 (7917)	1.56±0.96 (9677)
SO_2 (ppb)	6.15±3.27 (8708)	3.61±2.23 (7669)	5.09±2.80 (7992)	7.22±3.53 (9478)
NO (ppb)	32.9±46.6 (8579)	21.6±25.5 (7697)	60.2±71.6 (7750)	56.2±65.1 (8744)
NO_2 (ppb)	42.7±18.6 (8579)	35.8±18.3 (7697)	40.9±19.3 (7750)	39.9±15.6 (8744)
NO_X (ppb)	75.6±58.2 (8579)	57.4±36.1 (7697)	101±85.2 (7750)	96.0±77.0 (8744)
CH_4 (ppm)	2.08±0.34 (8464)	2.04±0.40 (7429)	4.94±6.91 (7476)	3.16±4.66 (7489)
NMHC (ppm)	1.41±1.68 (8452)	1.45±1.72 (7429)	1.82±2.69 (7476)	1.42±1.83 (7491)
THC (ppm)	2.29±0.43 (8464)	2.27±0.51 (7429)	5.68±7.89 (7476)	3.58±5.53 (7489)
O_3 (ppb)	20.8±18.3 (8463)	20.5±21.9 (7700)	9.50±11.7 (7761)	8.41±8.51 (8766)
CO (ppm)	0.65±0.46 (8536)	0.42±0.31 (7130)	2.21±4.77 (7826)	1.69±3.79 (8836)
PM10 (μg m^{-3})	77.1±126 (7873)	51.0±36.1 (6035)	50.0±36.7 (7806)	53.2±37.0 (9587)

*Units for each parameter are same as Table 2.

smaller than 2 ng m^{-3}. It is found that relative patterns of its short-term variation, characterized by enhanced Hg levels in the nighttime, are seen quite consistently from almost all types of analyses attempted (Figs. 3 and 4).

If the analysis of the diurnal patterns is made among different seasons, the patterns for wintertime are distinguished most clearly from all seasons compared at the same basis. In the case of the winter season, the nighttime concentration increases noticeably more so than its counterpart. Such nighttime dominance tends to diminish across fall, spring, and summer. As a result, differences in Hg concentration levels between day and night time periods become the least distinguishable in the summer season. It is generally accepted that enhanced Hg levels during winter are due to the strong man-made activities (such as enhanced fuel consumption and household heating) under unfavorable conditions of atmospheric mixing. In addition, the possibly important role of other sources such as long range transport of Hg from strong source areas (like China) may be speculated. It is hence reasonable to infer that reduced diurnal variations of Hg in the summertime may reflect the influences of relatively weak source activities under favorable mixing conditions. Our analysis was further extended to examine the diurnal patterns of Hg at annual intervals (Fig. 4). When compared in terms of relative sense (i.e., after normalization), the results exhibit strong consistency in that the diurnal patterns are dramatically stable enough with highly systematic patterns through the years.

The overall results of our diurnal pattern investigations indicate that short-term variabilities of Hg in urban areas (like our study site) can be characterized by strong consistency, at least in the relative sense. Although information concerning the detailed emission inventory of the study area is unavailable, the observed short-term patterns indicate that Hg levels in the study area can be affected most sensitively by such factors as the use of coals as major fuels. The significance of coal as the dominant anthropogenic source of Hg has been documented in our previous studies (Kim and Kim, 2000); the clear trend of such signature was seen persistently from various locations of Seoul during the late 80s. The overall results of the short-term trend study in which relative enhancement in nighttime Hg levels is phenomenal appear to be highly comparable to those of Lee *et al.* (1998). These authors reported nighttime dominance of Hg consistently through the seasons from their routine measurements made in a rural region of England and ascribed it to the

general differences in meteorological conditions over a diurnal scale.

3. 3 Seasonal and annual variabilities of Hg concentration

To account for the temporal variability of Hg across the seasons, the magnitude of seasonal mean concentrations was compared. As seen in Table 2, the seasonal mean values decreased noticeably on the descending order: winter, spring, fall, and summer. Consequently, differences in the mean seasonal values between the highest (6.12 in winter) and lowest (4.81 ng m^{-3} in summer) appear to be rather significant. If we examine the seasonal trend of Hg using the secondary criteria (such as diurnal grouping), the patterns are found to contrast between daytime and nighttime (Fig. 5). Thus, the result of this comparison, wherein no seasonal patterns are apparent in the daytime data sets, indicate that seasonal patterns of Hg may be affected most significantly by the differences in the nocturnal source processes. It should, however, be addressed that the seasonal patterns in Seoul are quite contrary to those observed from other continents, Europe or America. For instance, according to the studies of Slemr and Sheel (1998), the Hg levels peaked during spring/summer and reached the lowest value during the winter months. The observed differences in relative seasonal patterns between different regions thus confirm the common

Table 3. Comparison of monthly mean values of Hg concentration (ng m^{-3}) for the study period of 1997~2002.[1)]

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual mean	[Max-Min]	Amplitude of seasonal change
1997									3.94	4.75	8.14	7.95	6.19	4.20	67.8
1998	8.05	7.42	8.55	6.38	3.47	3.42							6.21	5.13	82.6
1999	3.38		4.85	4.77	4.45	5.86	5.16	4.52	4.08	4.30	7.07	6.74	5.02	3.68	73.4
2000	5.99	6.64	7.51	4.38	5.71	5.91	4.47	3.41	3.12	4.03	5.03	5.33	5.13	4.39	85.7
2001	4.57	6.11	3.49	3.71	3.55	5.03	4.15	4.68	3.76	3.38	6.24	5.07	4.48	2.86	63.9.
2002	8.14	5.58	7.01	7.38	4.17	6.19							6.41	3.97	62.0
Mean	6.03	6.43	6.28	5.32	4.27	5.28	4.59	4.20	3.72	4.11	6.62	6.27			

1) Monthly mean was derived by the hourly data sets collected for each specific month.
2) Amplitude of seasonal change was computed by the ratio: (maximum-minimum)/annual mean value.

Table 4. Comparison of annual mean values of Hg and relevant parameters determined at the Yang Jae site.

Year	1997*	1998*	1999	2000	2001	2002*
Hg (ng m^{-3})	6.60±3.89 (1781)	5.96±3.42 (1627)	5.09±3.01 (6851)	5.16±3.26 (7249)	4.61±3.13 (6843)	6.87±5.10 (2819)
Temp. (°C)	9.50±6.82 (2251)	9.26±8.44 (3060)	13.8±10.5 (8525)	13.7±10.3 (8410)	14.3±11.2 (7054)	10.9±9.01 (4320)
UV (MJ m^{-2})	9.75±14.8 (2133)	15.4±23.8 (2869)	30.2±53.1 (8120)	40.1±68.6 (8388)	17.1±39.8 (6795)	19.9±34.6 (4320)
RH (%)	51.0±18.2 (2253)	52.8±20.5 (3060)	64.8±18.2 (8427)	64.6±19.4 (8257)	64.1±19.3 (7046)	62.1±22.1 (4320)
Wspeed (m s^{-1})	1.61±0.95 (2253)	1.50±1.02 (3060)	1.54±0.90 (8534)	1.47±0.86 (8603)	1.07±0.68 (7334)	1.16±0.69 (4320)
SO_2 (ppb)	7.46±3.69 (2244)	7.60±3.00 (30250	5.80±3.51 (8449)	5.44±2.96 (8607)	4.59±2.71 (7226)	5.03±3.48 (4296)
NO (ppb)	85.5±91.7 (2244)	42.8±53.9 (3066)	46.5±59.9 (8495)	37.6±49.5 (8114)	35.0±47.6 (6624)	35.7±49.6 (4227)
NO_2 (ppb)	45.7±19.5 (2244)	43.6±18.2 (3066)	42.7±19.2 (8495)	38.6±16.8 (8114)	35.3±17.0 (6624)	38.3±16.6 (4227)
NO_X (ppb)	131±107 (2244)	86.4±66.1 (3066)	89.2±72.2 (8495)	76.2±60.4 (8114)	70.3±58.3 (6624)	74.0±57.4 (4227)
CH_4 (ppm)	18.9±6.69 (1795)	2.22±0.47 (2084)	2.10±0.41 (8186)	1.91±0.26 (8068)	2.03±0.32 (6814)	2.14±0.29 (3911)
NMHC (ppm)	2.70±2.13 (1795)	1.35±1.13 (2084)	3.07±2.61 (8174)	1.45±1.53 (8068)	0.25±0.24 (6814)	0.19±0.18 (3913)
THC (ppm)	21.6±8.17 (1795)	2.35±0.53 (2084)	2.41±0.58 (8186)	2.17±0.37 (8068)	2.28±0.50 (6814)	2.33±0.42 (3911)
O_3 (ppb)	7.73±8.54 (2241)	16.1±15.2 (3066)	16.6±19.4 (8495)	17.0±18.7 (8171)	11.6±13.4 (6821)	14.1±15.4 (3896)
CO (ppm)	9.82±7.92 (2245)	0.87±0.50 (2538)	0.88±0.56 (8288)	0.52±0.44 (8462)	0.39±0.35 (6532)	0.50±0.32 (4263)
PM10 (μg m^{-3})	53.4±37.1 (2237)	53.3±32.4 (3037)	57.9±38.1 (8469)	47.8±34.3 (8426)	54.6±41.2 (4904)	88.2±167 (4228)

*Cases with limited measurement data not to represent a full-year trend.
**For each case, mean±SD and N are provided.

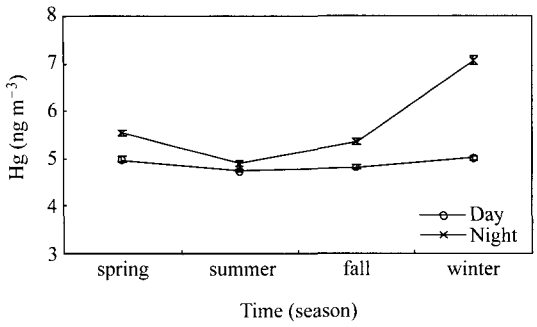

Fig. 5. Comparison of temporal distribution patterns of Hg are compared across different seasons after being sorted into two data groups for day and night periods.

fact that seasonalities exist in source processes of Hg and that they can differ largely between urbanized and relatively clean environments.

The factors affecting Hg distributions have been investigated using a number of statistical approaches in our previous studies (e.g., Kim and Kim, 2002). In this study, to simply describe the fundamental facets of the mechanisms involved in the seasonal variation of Hg, we analyzed our data sets after dividing them into monthly intervals (Table 3). The results of this comparison indicate that the maximum value occurs in the month of November with the mean value of 6.62 ng m^{-3}, while the minimum occurs in September with 3.72 ng m^{-3}. Comparison of the monthly mean values for the whole data sets indicates that entire months can be grouped into either 'high' or 'low' months. It is found that the higher concentrations at our study site generally occur from late fall (November) to early spring (April). As a result, Hg concentration levels in the remaining months (May through October) are much lower. If we divide the entire data sets using this simple criterion of high and low months, their mean values are found to differ considerably such as: 6.16 ± 0.45 (high months) vs 4.36 ± 0.53 ng m^{-3} (low months).

As seen in Fig. 6(b) and 6(c), these data were further compared in two different manners. The monthly distribution patterns of Hg were examined one step further by such additional criteria as

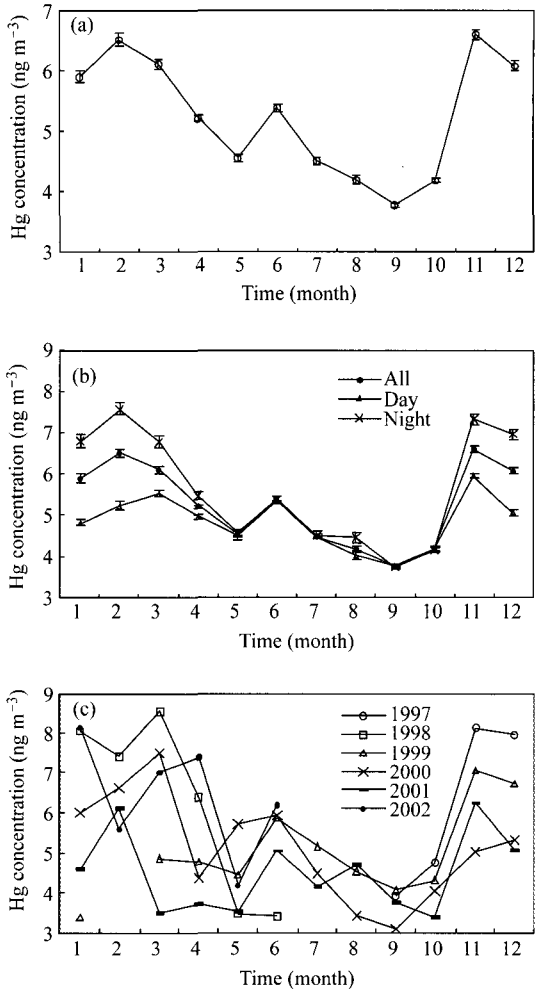

Fig. 6. Monthly distribution pattern of Hg in the study area. Comparison is made: (a) all data sets; (b) diurnally divided data groups; and (c) annually divided data groups.

diurnal and annual basis. When these monthly data sets were checked in terms of diurnal basis, another interesting aspect of temporal variability is apparent. It is found that notable signals of diurnal variations are found only during high months, while there are virtually no such signals in low month data sets. This comparison thus suggests that the changes in Hg levels over an annual scale can be explained better by our simple grouping scheme of high vs. low months rather than the typical classification of

four different seasons.

As a simple means to test the long-term variation patterns of Hg in our study, we computed annual mean values of Hg for the 7 year study period. The results, shown in Table 4, suggest that there were moderate but constant reductions in concentration levels from 1997 (6.60 ng m^{-3}) to 2001 (4.61 ng m^{-3}). It then began to increase significantly in 2002, recording the highest annual mean value of 6.87 ng m^{-3}. The representativeness of the 2002 data however suffers in that its measurements only cover the sum of six months from January to June. Examination of monthly mean values indicates that the values obtained in those months were notably higher than the ones measured in previous years; however, it may not necessarily imply that such pattern is realistic. Consequently, the enhanced mean value in 2002 does not mean that the general pattern began to reverse in 2002. To assess the long-term trend of Hg distribution in our study site more meaningfully, we may have to extend our efforts in a more consistent manner in future years.

4. CONCLUSION

The Hg concentrations were determined from the Yang Jae district of Seoul for the total duration of a 7-year period, between 1997 and 2002. The results of our investigation demonstrated that the temporal distribution patterns of Hg are quite consistent in various respects such as both diurnally and seasonally. A comparison of diurnal distribution patterns indicated strong consistency with the dominance of its concentrations in the nighttime relative to daytime. This short-term pattern over 24 hr scale is expected to result from the combined effects of such factors as nighttime source processes (e.g., household heating) and meteorological conditions (e.g., formation of inversion layer). Examination of seasonal trends showed that the highest mean value tended to occur consistently during winter, while the lowest occurred during summer. The causes of such seasonal trends may also be sought from the effects of both meteorological and source processes that proceed over more extended period across seasons. However, if one considers that the relative dominance of wintertime is no more apparent in a relatively clean environment (as seen from other studies made in Europe or America), relative seasonal patterns of Hg in urban areas (like our study site) can be affected more sensitively by anthropogenic processes than by any other factors.

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REFERENCES

Ames, M., G. Gullu, and I. Olmez (1998,) Atmospheric mercury in the vapor phase, and in fine and coarse particulate matter at Perch river, New York. Atmos. Environment 32, 865-872.

Artaxo, P., R.C. de Campos, E.T. Fernandes, J.V. Martins, Z. Xiao, O. Lindqvist, M.T. Fernandez-Jimenez, and W. Maenhaut (2000) Large scale mercury and trace element measurements in the Amazon basin, Atmospheric Environment 34, 4085-4096.

Blanchard, I. (1980) Russia's Age of Silver. Routledge, London.

Kim, K.-H. and M.-Y. Kim (1999) The exchange of gaseous mercury across soil-air interface in a residential area of Seoul, Korea Atmospheric Environment 33, 3153-3165.

Kim, K.-H. and M.-Y. Kim (2000) The effects of anthropogenic sources on temporal distribution characteristics of total gaseous mercury in Korea. Atmospheric Environment. 34, 3337-3347.

Kim, K.-H. and M.-Y. Kim (2001) The temporal distribution characteristics of total gaseous mercury at an urban monitoring site in Seoul during 1999 to 2000. Atmospheric Environment. 35(25), 4253-4263.

Kim, K.-H. and M.-Y. Kim (2002) A decadal shift in total gaseous mercury concentration levels in Seoul, Korea: changes between the late 1980s and the late 1990s. Atmospheric Environment. 36, 663-675.

Kim, K.-H., M.Y. Kim, J. Kim, and G. Lee (2002) The concentrations and fluxes of total gaseous mercury in a western coastal area of Korea during the spring period, 2001. Atmospheric Environment. 36(21), 63-77.

Kim, K.-H., M.Y. Kim, J. Kim, and G. Lee (2003) Effects of changes in environmental conditions on atmospheric mercury exchange: Comparative analysis from a rice paddy field during the two spring periods of 2001 and 2002. J. Geophys. Res., 108(D19), 4607, doi: 10.1029/2003JD003375

Lee, D.S., G.J. Dollard, and S. Pepler (1998) Gas-phase mercury in the atmosphere of the United Kingdom. Atmos. Environment. 32, 855-864.

Nadim, F., C. Perkins, S. Liu, R.J. Carley, G.E. Hoag (2001) Long-term investigation of atmospheric mercury contamination in Connecticut. Chemosphere, 45, 1033-1043.

Pirrone, N., I. Allegrini, G.J. Keeler, J.O. Nriagu, R. Rossman, and J.A. Robbins (1996) Historical atmospheric mercury emissions and depositions in North America compared to mercury accumulations in sedimentary records. Atmospheric Environment 32(5), 929-940.

Slemr, F. and H.E. Scheel (1998) Trends in atmospheric mercury concentrations at the summit of the Wank mountain, southern Germany. Atmospheric environment 32(5), 845-853.