Short Communication

Indoor particle counts during Asian dust events under everyday conditions at an apartment in Japan

Kumiko T Kanatani[1], Motonori Okumura[2], Susumu Tohno[2], Yuichi Adachi[3], Keiko Sato[4], Takeo Nakayama[1]

[1]Graduate School of Medicine, Kyoto University, Yoshida-Konoe-cho, Sakyo, Kyoto 606, Japan

[2]Graduate School of Energy Science, Kyoto University, Yoshida-Konoe-cho, Sakyo, Kyoto 606, Japan

[3]Department of Pediatrics, Faculty of Medicine, University of Toyama, Sugitani 2630, Toyama 930-0194

[4]Department of Medicine, Kyoto University, Yoshida-Konoe-cho, Sakyo, Kyoto 606, Japan

Correspondance should be addressed to Kumiko T Kanatani, kanatani.kumiko.2r@kyoto-u.ac.jp

Tel.: 81-80-6186-9375; FAX: +81-75-761-1065

Key words: indoor air, PM2.5, PM10, dust storm, Asian dust

Abstract

Objective. Asian dust storms originating from arid regions of Mongolia and China are a well-known springtime phenomenon throughout East Asia. Evidence is increasing for the adverse health effects caused by airborne desert dust inhalation. Given that people spend approximately 90% of their time indoors, indoor air quality is a significant concern. The present study aimed to examine the influence of outdoor particulate matter (PM) levels on indoor PM levels during Asian dust events under everyday conditions. *Methods.* We simultaneously monitored counts of particles larger than 0.3, 0.5, 1, 2, and 5 μm using two direct-reading instruments (Airborne Particle Counter KC-01D1, Rion), one placed in an apartment room and another on the veranda, under everyday conditions before and during an Asian dust event. We also examined how indoor particle counts were affected by opening a window, crawling, and air purifier use. *Results.* An Asian dust event on 24 April 2012 caused 50-fold and 20-fold increases in PM counts in outdoor and indoor air, respectively. A window open for 10 minutes resulted in a rapid increase of indoor PM counts up to 70% of outside levels that did not return to baseline levels after 3 hours. An air purifier rapidly reduced PM counts for all particle sizes measured. *Conclusions.* It is important to account for occupants' behaviors, such as window-opening and air purifier use, when estimating residential exposure to particulate matter.

1. Introduction

Asian dust events are well-known spring phenomena in East Asia that originate from the deserts of Mongolia and China. Asian cities experience yellow air on several days in the spring when the dust is blowing. The dust includes quartz, an amorphous and crystalline silica known to cause respiratory disease in people with occupational exposure or high levels of exposure from living close to deserts [1,2,3,4], and inflammation in the lungs of rats in experimental studies [5,6,7,8]. Furthermore, dust particles contain chemicals derived from air pollutants, such as sulfate (SO_4^{2-}) and nitrate (NO_3^{-}), as well as microbial agents, including bacteria, fungi, fungal spores, and viruses, that sometimes survive long-distance transportation [9,10,11]. The impact of airborne dust may be exacerbated by these potential allergens and pathogens.

Epidemiological studies have also provided increasing evidence of adverse health effects from airborne desert dust inhalation. Hospitalization risk increases significantly for asthmatic children [12], as do emergency ambulance dispatches [13] after Asian dust events in Japan. Non-accidental mortality and cardiovascular mortality also increase significantly after Asian dust events in Taiwan [14]. A Korean study, where the influence of desert dust was not necessarily specifically investigated, also shows that particulate matter number as well as mass concentration are significantly associated with respiratory and cardiovascular disease-related mortality among elderly [15].

Given that people spend approximately 90% of their time indoors [16], indoor air quality is a significant concern. In Japan, the season for Asian dust events coincides with one of the most comfortable periods of the year. Our preliminary investigation (not published) revealed that approximately half of pregnant women in Kyoto, Japan opened windows every day during April 2012 (1794 respondents/2107 queried).

We investigated how indoor particulate matter (PM) counts (larger than 0.3 μm, 0.5μm, 1μm, 2μm, and 5μm, respectively) are influenced by various factors, including window/door openness, activities (crawling), and air purifier use, under everyday conditions in an apartment in Japan on days with Asian dust events.

2. Methods

2.1. Monitoring situation. We monitored PM counts in a room on the 10th floor of an apartment building in a residential area of Kyoto. There is a 100 m distance from the apartment building to the nearest two-way road. The building is a reinforced concrete structure built in 2001, 11 years before this study.

The apartment is a 4LDK with 86 m^2 floor area, occupied by two adults and an 11-year-old girl. None of the occupants are at home during the daytime and all three are non-smokers. The floor is wooden and shoes are strictly prohibited in the rooms in accordance with Japanese culture. The monitored room of the apartment has a 22 m^2 floor area and is shown in Figure 1. The door in the monitored room was kept closed throughout the study period except when occupants went in or out, but there is a 0.8 cm-wide space at the bottom of the door even when it is closed. An air purifier was constantly used in the living-dining room during the observational period (2 m^3/min air-flow), and was moved to the monitored room for the experiment.

The study period is composed of observational period and experimental period. And observational period is composed of control period and Asian dust period; Figure 2. In experimental period, we performed experiments of opening windows (20cm, 10 minutes) and air-purifier use to see how these factors affect the PM counts indoors. We also performed experiment of crawling (160cm height researcher crawled on the floor for 10 minutes) to see if once falled dust on the floor affects the indoor air again through activities.

2.2. Monitoring equipment. The direct-reading instrument used to measure particle size and count was a Rion KC-01-D1 Airborne Particle Counter. The machine simultaneously counts particles larger than 0.3, 0.5, 1, 2, and 5 μm. We concurrently monitored the indoor PM counts 20 cm above the floor, and outdoor PM counts 120 cm above the veranda floor (Figure 1). Flow rate was 0.5L/min, and particle counts were measured every two minutes.

Room variables recorded during the study period included the following: window (open/closed), room door (open/closed), air conditioner (on/off), ventilation system (on/off), cooking in the apartment (yes/no), and the number of persons present during the testing.

Information regarding desert dust concentration was provided by Light Detection and Ranging (LIDAR) with a polarization analyzer in Osaka [17,18], which distinguish soil dust (non-spherical particles) from atmospheric pollutants (spherical particles) by measuring the extent of scattered reflected light [19,20]. We used the data of 135 m altitude. Suspended particulate matter (SPM; PM7) was measured at an air quality monitoring station in Kyoto located approximately 5 km from the apartment building.

3. Results

3.1. Forecast and station data during the study period (Apr. 22-25, 2012). The Chemical Weather Forecast System (CFORS) predicted the arrival of an Asian dust cloud in Kyoto at noon on Apr. 23 (Figure 3) [21,22], and LIDAR in Osaka measured high concentrations of soil dust during the same period (Figure 4) [17,18].

SPM measured by the Atmospheric Environmental Regional Observation System at a local site in Kyoto, 5 km from the apartment, increased from the afternoon of Apr. 23 until the morning of Apr. 26 (Figure 2).

Notably, CFORS predicted increased sulfate in the air during the same period (Figure 5) [21], and an increase in the spherical particulate matter was observed by LIDAR during this Asian dust event (Figure 4) [17], which was considered to be trans-boundary air pollution flying simultaneously with Asian dust.

3.2. Indoor and outdoor PM counts (/L) before and during dust storms. Figure 6 shows indoor and outdoor air PM counts (/L) before and during a dust storm with closed windows, without air-conditioner use in the monitored room, and without cooking throughout the study period. A room door was opened twice during each period and the apartment door was opened twice for short periods of time (several seconds) during each period. Before the dust storm, the PM (larger than 0.3 μm particles) counts were very low both indoors and outdoors (indoors: mean=5,186/L, range=921-12,670/L; outdoors: mean=4,779/L, range=1,154-23,637/L). During the dust storm, the indoor PM (particles larger than 0.3 μm) counts increased approximately 20 times while the outdoor PM counts increased approximately 50 times (indoors: mean=115,340/L, range=44,737-243,399/L; outdoors: mean=250,867/L, range=65,152-375,367/L) (Figure 6). Indoors, smaller PM levels seemed to be more influenced by outdoor PM levels than larger PM levels (Figure 6).

3.3. Factors that affect indoor PM counts. Figure 7 shows the time course of PM counts through experiments. Opening a window (20 cm) for 10 minutes resulted in a rapid increase in PM counts up to 70% of outdoor levels. Smaller PM sizes remained longer in room air, as high as 50% of outdoor levels for PM greater than 0.5 and 0.3 μm even after 3 hours. A researcher's crawling caused an increase in counts of PM larger than 1 μm. An air purifier (non-HEPA filter, 3 m^3/minute air-flow) reduced PM counts for all sizes in 30 minutes. With the air purifier on, window opening (20 cm) for 10 minutes still caused elevation of PM counts up to 50% of outdoor levels, but counts for all sizes rapidly returned to baseline levels after closing the window.

4. Discussion

This study measured indoor and outdoor particle counts during an Asian dust event under everyday conditions. An Asian dust event on Apr. 24, 2012 caused a 50-fold increase in PM counts outdoors and a 20-fold increase indoors in an apartment room in Japan. As far as we know, there is one report regarding PM changes in indoor air during Asian dust events at an office building in Taipei

[23]. This report showed that indoor PM2.5 and PM10 increased 3-fold during the dust storm while outdoor PM2.5 and PM10 increased 1.7-fold. The ventilation systems in this high-rise building utilize air from outside, and the authors concluded that this was likely the primary reason that air particle concentrations inside the building were significantly affected by outside air pollutants during dust storms. The ventilation system in our apartment was used once for 20 minutes, 2 hours before observation began. We speculate that in addition to this ventilation, the occupants opening doors, and their movements into and out of the rooms were the main routes of PMs entering the monitored room.

The PM increase observed in this study was larger than in the Taipei study. One explanation for this is that the baseline count was very low in our study (mean SPM during the control period was 1.7 $\mu g/m^3$, range=0-5 $\mu g/m^3$) compared to the control period in Taipei (PM2.5 and PM10 were 45 $\mu g/m^3$ and 70 $\mu g/m^3$, respectively). Secondly, in this study, air pollution other than desert dust was also observed during the Asian dust period; CFORS predicted sulfate aerosol arrival in our Asian dust period and LIDAR observed spherical as well as non-spherical particulate matter during this time period. Accordingly, the observed PM count increase is considered to be a mixture of desert-dust and other air pollution. Lastly, this study and the Taipei study may have also differed in the original scales of the Asian dust storms observed.

An open window (20 cm) for 10 minutes resulted in a rapid increase of indoor PM counts up to 70% of outside levels, which was maintained for three hours after closing the window. An air purifier rapidly reduced the PM counts for all particle sizes larger than 0.3 μm.

Previous reports have often noted that air change rates in occupied houses are highest when weather conditions are mild, and several investigators have speculated that this is due to increased window-opening behavior under mild conditions. Iwashita and Akasaka measured ventilation rates using gas tracers and questionnaire surveys assessing indoor environment and residents' behavior, and concluded that 87% of the total air change rate was due to occupant behavior [24]. US researchers quantitatively confirmed that having a single window open can increase air change rates [25].

This study's PM observations indoors and outdoors during an Asian dust event are consistent with the previous reports above, and suggest the importance of accounting for occupant behaviors such as window-opening and air purifier use when estimating residential exposure to particulate matter.

In conclusion, Asian Dust arrival caused a 50-fold increase in PM counts outdoors and a 20-fold increase indoors under everyday conditions on Apr. 24, 2012, in Kyoto, Japan.

A window open for 10 minutes resulted in a rapid increase of indoor PM counts up to 70% of outside levels that was maintained for three hours. An air purifier rapidly reduced PM counts for all particle sizes larger than 0.3 μm.

The results suggest it is important to account for occupant behaviors, such as window-opening and air purifier use, when estimating residential exposure to particulate matter.

Conflict of Interests

The authors declare no conflict of interest.

Acknowledgments

We thank Dr. Nobuo Sugimoto for providing LIDAR data, the Kyoto City Environmental Protection Guidance Division for SPM data, Dr. Itsushi Uno for CFORS images, and Mr. Tadashi Hioki for fruitful discussion. This research was supported by the Environment Research and Technology Development Fund (C-1152) of the Ministry of the Environment, Japan.

References

1. Griffin, D.W. Atmospheric movement of microorganisms in clouds of desert dust and implications for human health. Clin Microbiol Rev., 2007,20, 459–77.

2. Valiante, D.J., Schill D.P., Rosenman K.D., Socie E. Highway repair: a new silicosis threat. Am J Public Health, 2004,94,876–80.

3. Eagan, T.M., Gulsvik, A., Eide, G.E., Bakke, P.S. Occupational airborne exposure and the incidence of respiratory symptoms and asthma. Am J Respir Crit Care Med., 2002, 166,933–38.

4. Kassimi, F.A., Majed, S.A., Hajjaj, M.S. Silicosis in a Himalayan village population: role of environmental dust. Thorax 1991,46, 861–2.

5. Ichinose, T., Yoshida, S., Sadakane, K., Takano, H., Yanagisawa, R., Inoue, K. et al. Effects of Asian sand dust, Arizona sand dust, amorphous silica and aluminum oxide on allergic inflammation in the murine lung. Inhal Toxicol. 2008,20, 685–94.

6. He, M., Ichinose, T., Yoshida, S., Yamamoto S., Inoue, K., Takano H., et al. Asian sand dust enhances murine lung inflammation caused by Klebsiella pneumoniae, Tox App Pharm. 2012,258, 237–47.

7. Murphy, S.A., Be´rube´a, K.A., Pooleya, F.D., Richards, R.J. The response of lung epithelium to well characterised fine particles. Life Sci., 1988,62,1789–99.

8. Mancino, D., Vuotto, M.L., Minucci, M. Effects of a crystalline silica on antibody production to T-dependent and T-independent antigens in Balb/c mice. Int Arch Allergy Appl Immunol., 1984,73,10–3.

9. Chen, P.S., Tsai, F.T., Lin, C.K., Yang, C.Y., Chan, C.C., Young, C.Y., et al. Ambient influenza and avian influenza virus during dust storm days and background days. Environ. Health Perspect. 2010, 118, 1211–16.

10. Kobayashi, F., Kodanikuchi, K., Kakikawa, M., Maki, T., Yamada, M., Tobo, Y., et al. Direct samplings, separated culture, and identifications of kosa bioaerosols over Noto Peninsula, Suzu City (Japanese) Earozoru Kenkyu, 2010,25,23–8.

11. Maki, T., Susuki, S., Kobayashi, F., Kakikawa, M., Tobo, Y., Yamada, M., et al. Phylogenetic analysis of atmospheric halotolerant bacterial communities at high altitude in an Asian dust (KOSA) arrival region, Suzu City. Sci. Total Environ., 2010,408, 4556–62.

12. Kanatani, K.T., Ito I., Al-Delaimy, W.K., Adachi, Y., Mathews, W.C., Ramsdell, J.W., et al. Desert dust exposure is associated with increased risk of asthma hospitalization in children. Am J Respir Crit Care Med. 2010,182,1475-81.

13. Ueda, K., Shimizu, A., Nitta, H., Inoue, K. Long-range transported Asian Dust and emergency ambulance dispatches. Inhal Toxicol. 2012,12, 858-67.

14. Chan, C.C., Ng, H.C. A case-crossover analysis of Asian dust storms and mortality in the downwind areas using 14-year data in Taipei. Sci Total Environ. 2011, 410-411,47-52.

15. Cho, YS., Lee, JT., Jung CH., Kim, YS. Relationship between particulate mattr measured by optical particle counter and mortality in Seoul, Korea, during 2001. J Environ Health. 2008;71(2):37-43.

16. Lunden, M.M., Thatcher, T.L., Hering, S.V., Brown, N.J. Use of time- and chemically resolved particulate data to characterize the infiltration of outdoor PM2.5 into a residence in the San Joaquin Valley. Eiviron. Sci. Technolo., 2003,37,4724-32.

17. http://soramame.taiki.go.jp/dss/kosa/en/index.html

18. Sugimoto N, Lee CH. Characteristics of dust aerosols inferred from lidar depolarization measurements at two wavelengths. Appl. Opt., 2006;45:7468–74.

19 Shimizu, A., N. Sugimoto, I. Matsui, K. Arao, I. Uno, T. Murayama, N. Kagawa, K. Aoki, A. Uchiyama, and A. Yamazaki, Continuous observations of Asian dust and other aerosols by polarization lidar in China and Japan during ACE-Asia, J. Geophys. Res., 109, D19S17, doi:10.1029/2002JD003253, 2004.

20 Sugimoto, N., I. Uno, M. Nishikawa, A. Shimizu, I. Matsui, X. Dong, Y. Chen, H. Quan, Record Heavy Asian Dust in Beijing in 2002: Observations and Model Analysis of Recent Events, Geophys. Res. Lett. 30, 12, 1640, doi:10.1029/2002GL016349, 2003.

21. http://www-cfors.nies.go.jp/~cfors/

22. Uno, I., G. R. Carmichael, D. G. Streets, Y. Tang, J. J. Yienger, S. Satake, et al. Regional chemical weather forecasting system CFORS: Model descriptions and analysis of surface observations at Japanese island stations during the ACE-Asia experiment. Journal of Geophysical Research, 2003, 108(D23), 8668.

23. Kuo, H.-W., Shen H.-Y. Indoor and outdoor PM 2.5 and PM 10 concentrations in the air during a dust storm. Build and Environ. 2010, 45,610–4

24. Iwashita, G., Akasaka, H. The Effects of Human Behavior on Natural Ventilation Rate and Indoor Air Environment in Summer—A Field Study in Southern Japan. Energy Bldgs. 1997, 25, 195-205

25. Cynthia Howard-Reed, Lance A. Wallace & Wayne R. Ott. The Effect of Opening Windows on Air Change Rates in Two Homes. J Air Waste Manage Assoc. 2002, 52, 147-59

Figure Legends

Fig. 1. Floor plan of the monitored apartment. Two particle counters (orange circles) were placed 20 cm above the floor in the monitored room and 120cm from the veranda floor. An air purifier was placed in the living-dining room during the observational period and moved to the monitored room for the experiment.

Fig. 2. Local SPM measurements during the control and Asian Dust periods.

Fig. 3. Asian dust distribution prediction by the Chemical Weather Forecast System [17]. The Asian dust clouds were predicted to arrive in Kyoto at noon on Apr. 23, 2012.

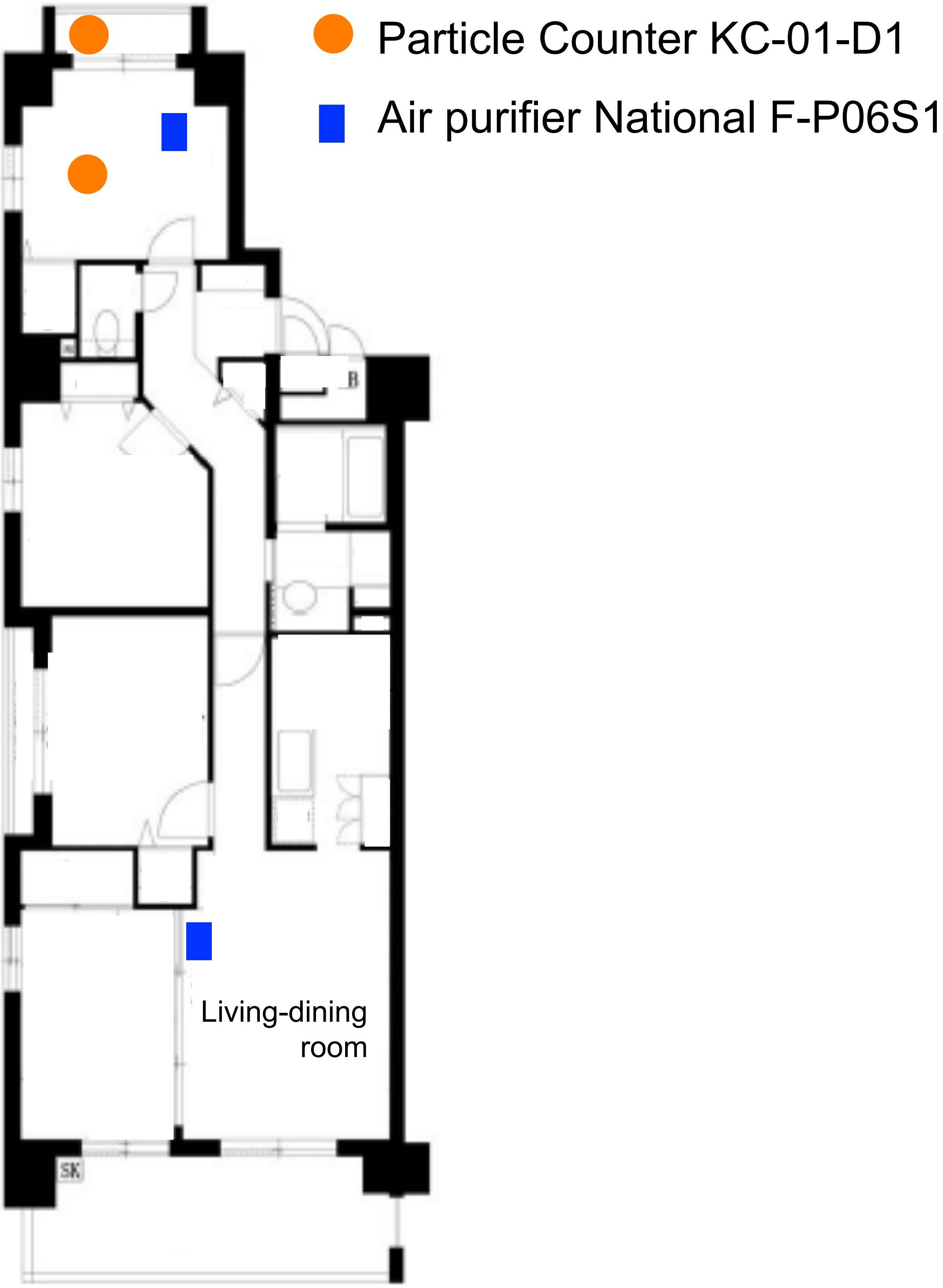
Fig. 4. Estimation of non-spherical and spherical particle concentrations by Light Detection and Ranging (LIDAR) [21].

Fig. 5. Sulfate distribution prediction by the Chemical Weather Forecast System [17].

Fig. 6. Comparison of particle counts/L inside and outside during control (left) and Asian dust (right) periods.

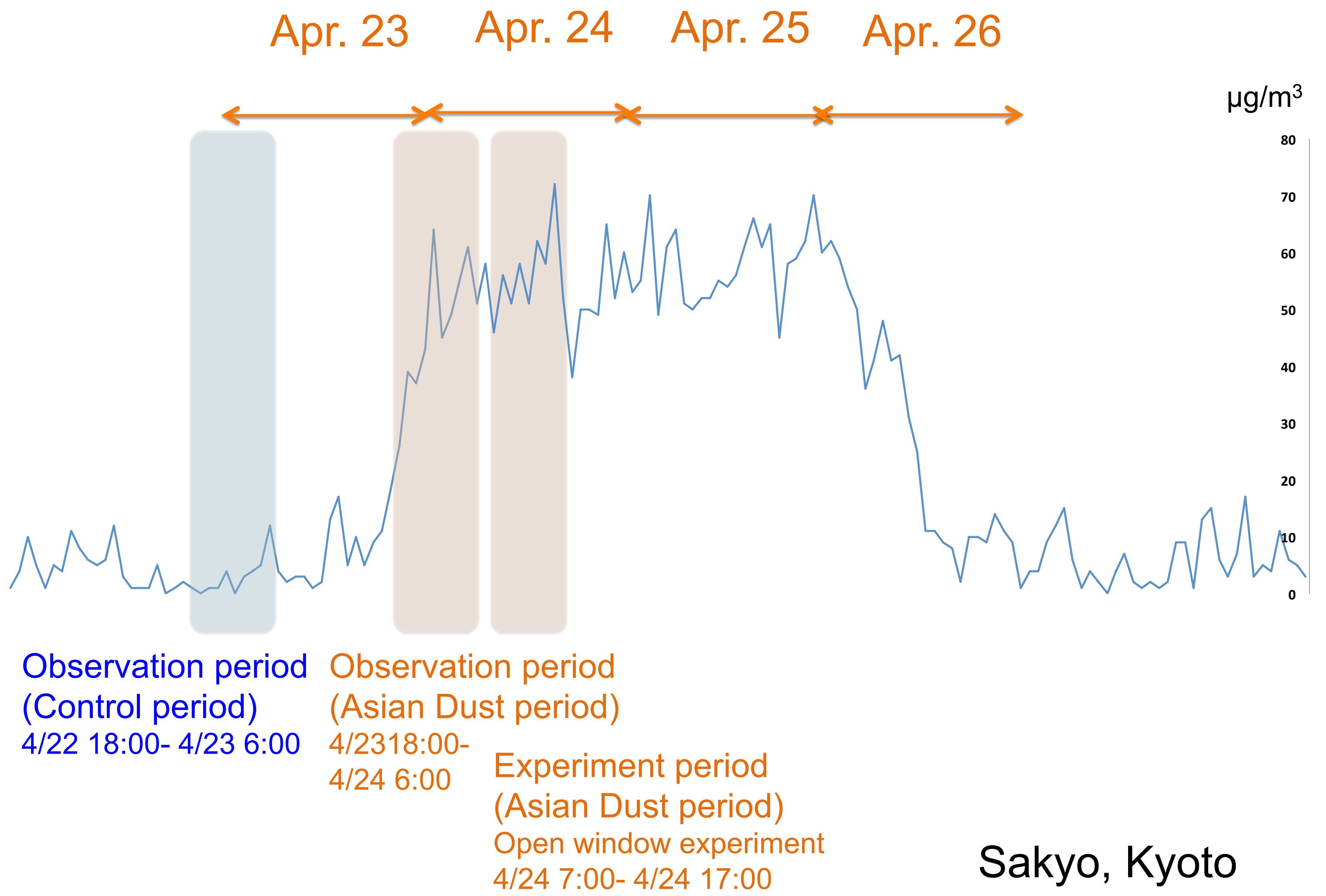
Fig. 7. PM counts/L in outdoor (upper) and indoor (lower) air under various conditions.

Figure1



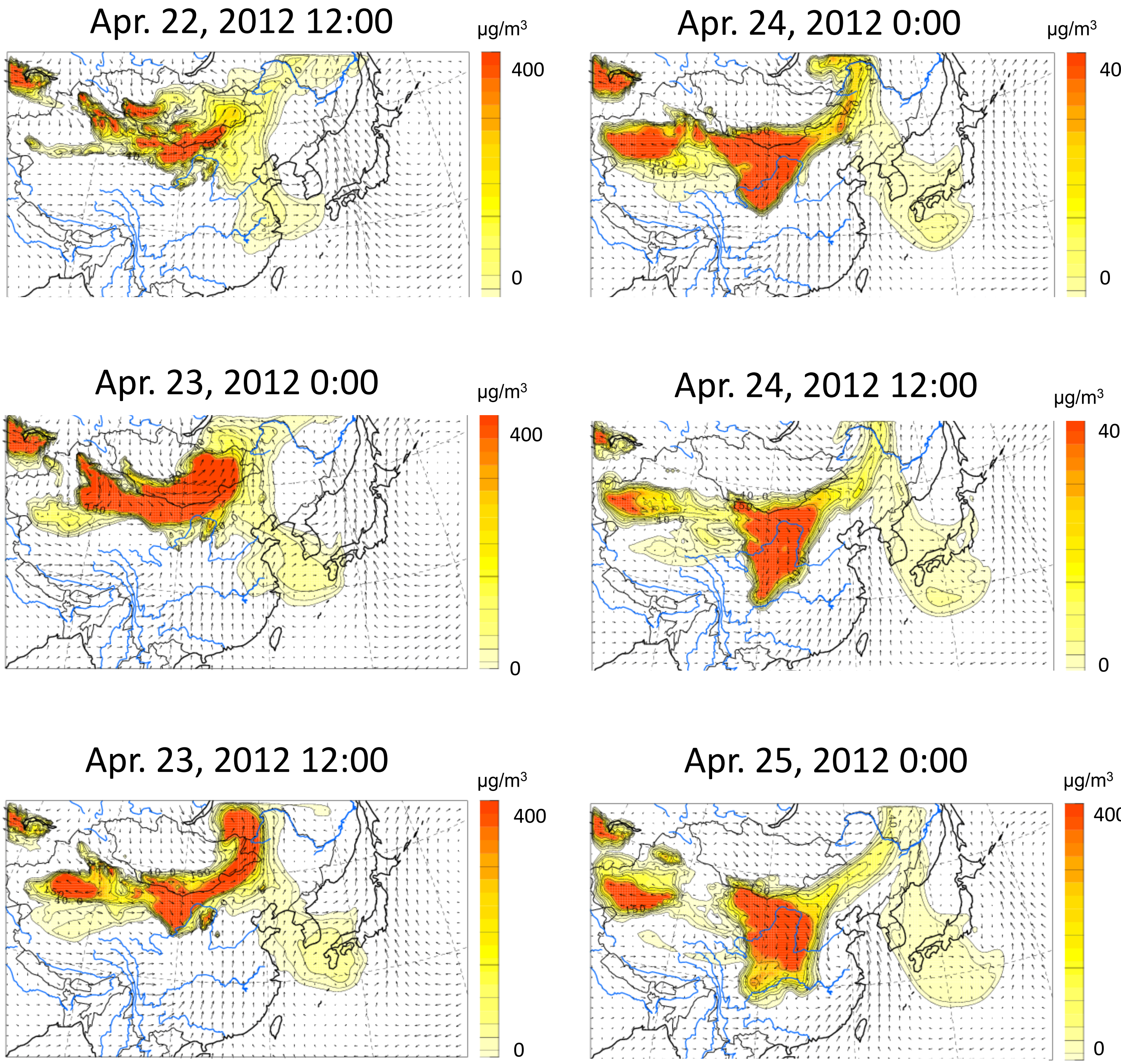
Particle Counter KC-01-D1
Air purifier National F-P06S1
Living-dining room
B
SK

Figure2



Apr. 23
Apr. 24
Apr. 25
Apr. 26
μg/m3
80
70
60
50
40
30
20
10
0
Observation period
(Control period)
4/22 18:00- 4/23 6:00
Observation period
(Asian Dust period)
4/2318:00-
4/24 6:00
Experiment period
(Asian Dust period)
Open window experiment
4/24 7:00- 4/24 17:00
Sakyo, Kyoto

Figure3



Apr. 22, 2012 12:00
μg/m3
400
0
Apr. 24, 2012 0:00
μg/m3
400
0
Apr. 23, 2012 0:00
μg/m3
400
0
Apr. 24, 2012 12:00
μg/m3
400
0
Apr. 23, 2012 12:00
μg/m3
400
0
Apr. 25, 2012 0:00
μg/m3
400
0

Figure4

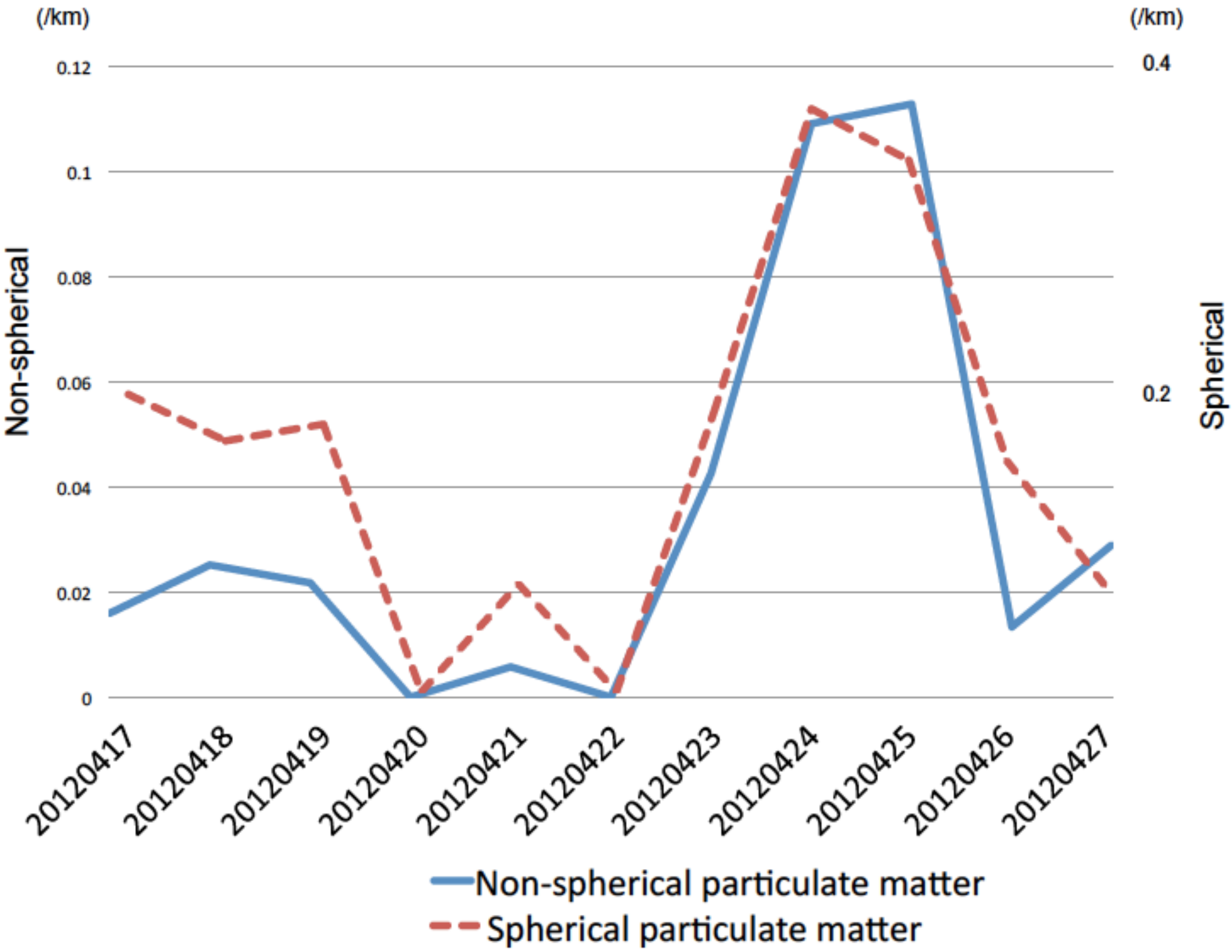

(/km)
(/km)
0.12
0.1
0.08
0.06
0.04
0.02
0
0.4
0.2
Non-spherical
Spherical
20120417
20120418
20120419
20120420
20120421
20120422
20120423
20120424
20120425
20120426
20120427
Non-spherical particulate matter
Spherical particulate matter

Figure5

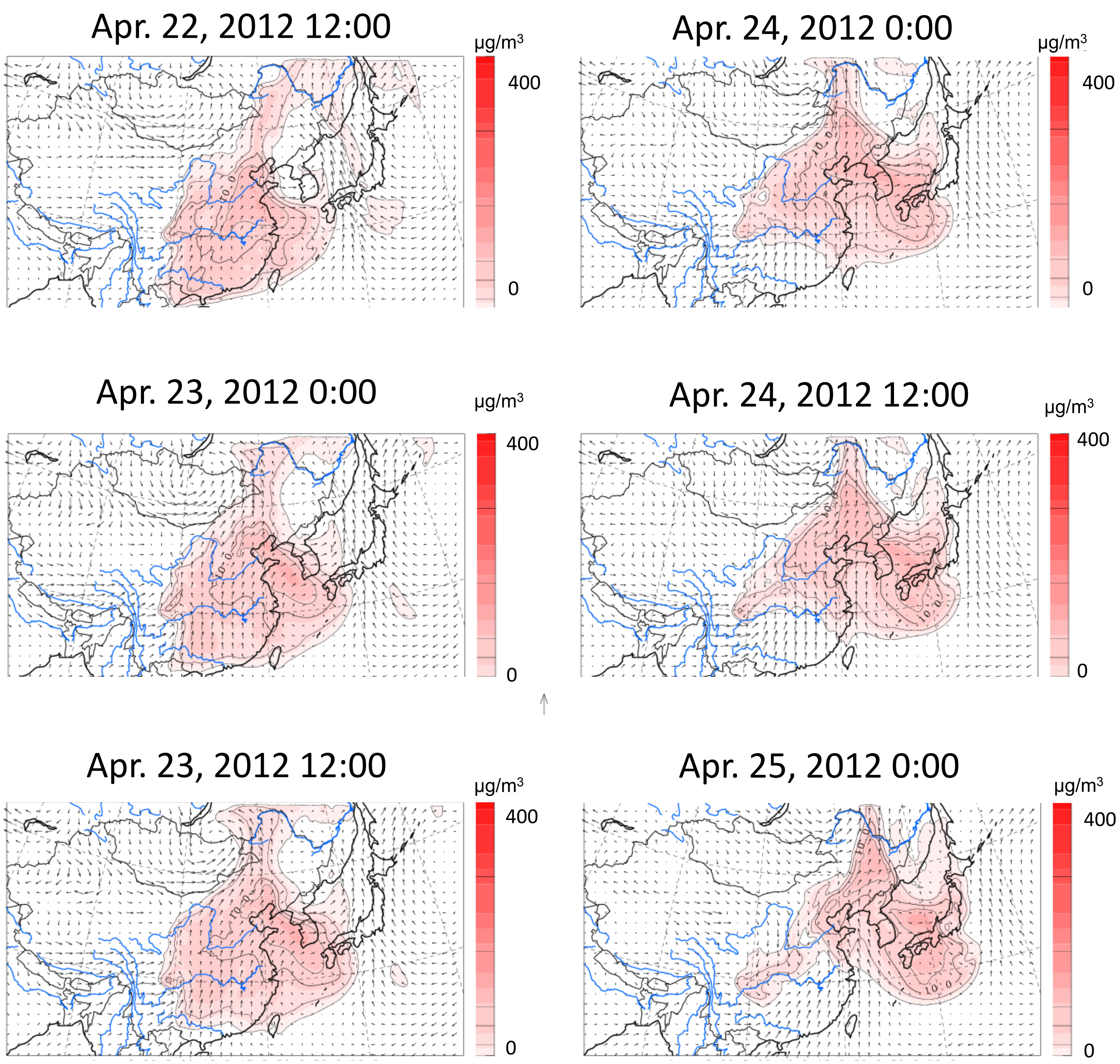

Apr. 22, 2012 12:00
Apr. 24, 2012 0:00
Apr. 23, 2012 0:00
Apr. 24, 2012 12:00
Apr. 23, 2012 12:00
Apr. 25, 2012 0:00
µg/m3
400
0

Figure6

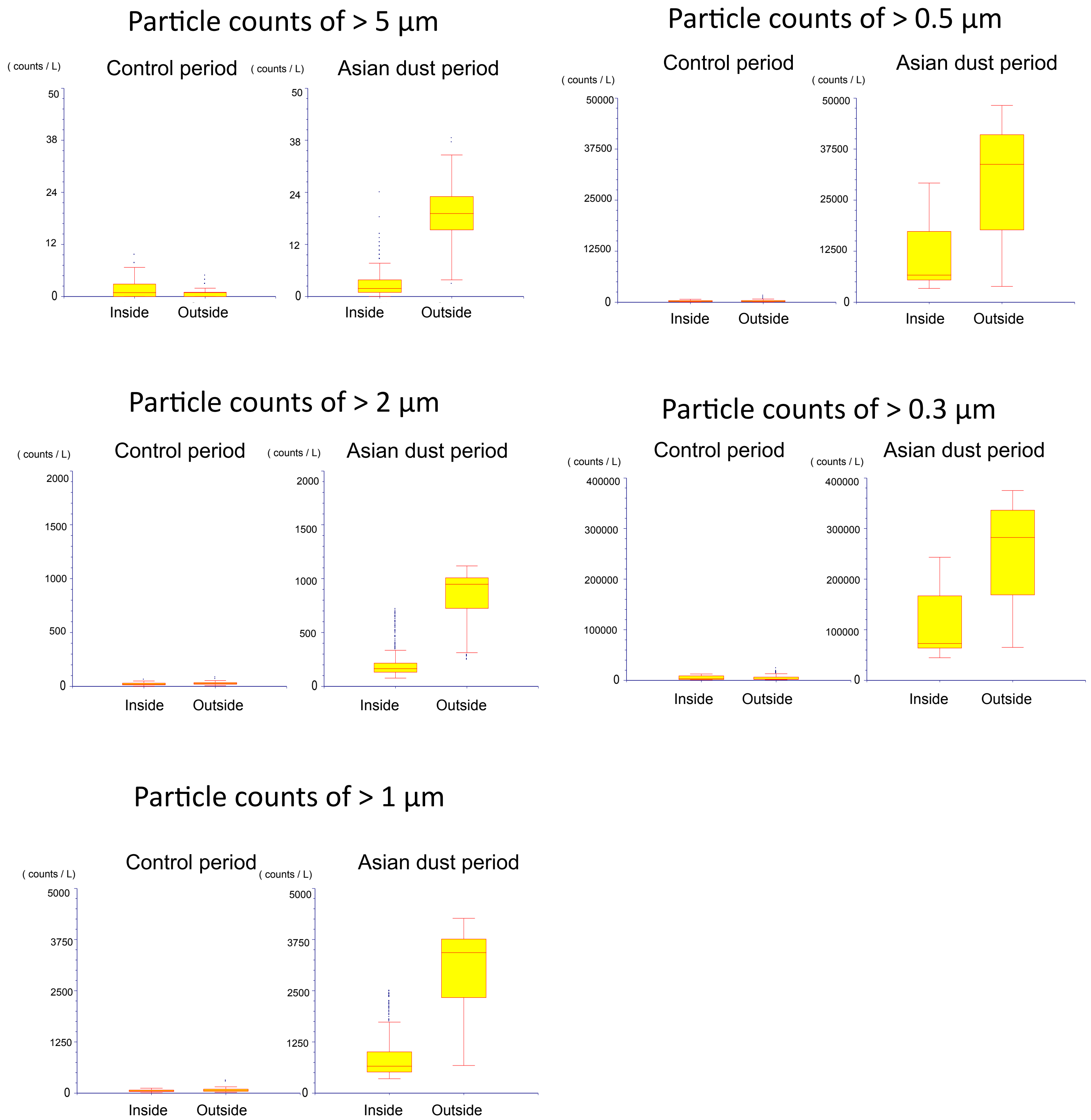
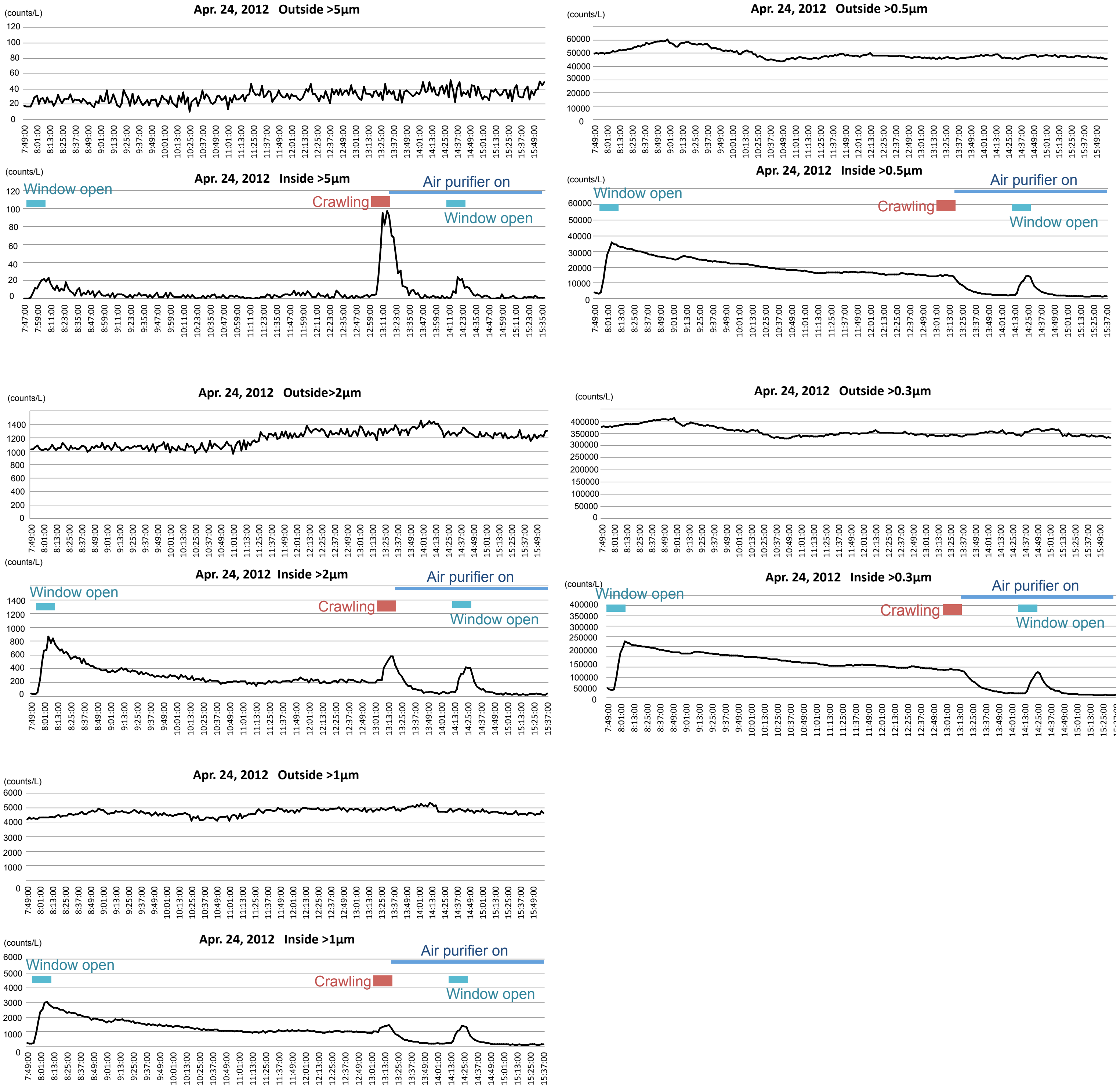

Particle counts of > 5 µm
Control period
Asian dust period
(counts / L)
50
38
24
12
0
Inside
Outside
Particle counts of > 0.5 µm
Control period
Asian dust period
(counts / L)
50000
37500
25000
12500
0
Inside
Outside
Particle counts of > 2 µm
Control period
Asian dust period
(counts / L)
2000
1500
1000
500
0
Inside
Outside
Particle counts of > 0.3 µm
Control period
Asian dust period
(counts / L)
400000
300000
200000
100000
0
Inside
Outside
Particle counts of > 1 µm
Control period
Asian dust period
(counts / L)
5000
3750
2500
1250
0
Inside
Outside

Figure7


Apr. 24, 2012 Outside >5µm
(counts/L)
Apr. 24, 2012 Outside >0.5µm
(counts/L)
Apr. 24, 2012 Inside >5µm
Window open
Crawling
Air purifier on
Window open
Apr. 24, 2012 Inside >0.5µm
Window open
Crawling
Air purifier on
Window open
Apr. 24, 2012 Outside>2µm
(counts/L)
Apr. 24, 2012 Outside >0.3µm
(counts/L)
Apr. 24, 2012 Inside >2µm
Window open
Crawling
Air purifier on
Window open
Apr. 24, 2012 Inside >0.3µm
Window open
Crawling
Air purifier on
Window open
Apr. 24, 2012 Outside >1µm
(counts/L)
Apr. 24, 2012 Inside >1µm
Window open
Crawling
Air purifier on
Window open