Proceedings of the Third International Symposium on Air Quality Management at Urban, Regional and Global Scales. pp. 1117-1128, 26-30 September 2005, Istanbul – Turkey

EXTREMELY HIGH CONCENTRATION OF TSP AFFECTED BY ATMOSPHERIC BOUNDARY LAYER IN SEOUL METROPOLITAN AREA DURING DUSTSTORM PERIOD

H. Choi and C. H. Jang*

Kangnung National University, Department of Atmospheric Environmental Sciences, Kangnung, Kangwondo 210-702, Korea, du8392@hanmail.net
* Hanbat National University, Department of Civil & Urban Engineering, Daejeon 305-719, Korea, jangch@hanbat.ac.kr

ABSTRACT

Hourly concentrations of TSP, PM10, PM2.5 near the griund surface at Seoul city were examined from March 20 to March 25, 2001 (duststorm event) in order to investigate the effect of duststorm on the local aerosol concentration, The ratios of between fine and coarse particles such as TSP to PM10, TSP to PM2.5 and PM10-PM2.5 to PM2.5showed that a great amount of dust transported from the origin of duststorm generation were remarkable with a maximum ratio of 9.77 between TSP and PM2.5. Back trajectories of air masses at ever 6 hour showed the movement of dust partilcles in the lower atmosphere near 500m ~ 1500m (atmospheric boundary layer), which implied to transport from Baotou in the inner Mongolia to the direction of Seoul city and then the back trajectories passed near southern border of Mongolia and Baotou through Zengzhou on the middle (3000 m height) and lower levels (500 m height) and finally reached Seoul city. So, the TSP concentration at Seoul city was partially influenced upon the duststorm, under the prevailing westerly wind and the transported aerosol could influence upon high concentrations of pollutants of TSP, PM10 and PM2.5 of the city. The sudden high concentrations of TSP and PM10 were found for few hours, especially at 15 to 18, March 22. At 1200 LST, before the passage of cold front through Korean peninsula, the convective boundary layer (CBL) near Seoul was not shallow, but at 1500 LST, under the frontal passage, the CBL was remarkably shallower less than 300 m, due to the compression of boundary layer under the intrusion of cold air and resulted in the increase of the TSP concentration, even though mixed layer above maintained almost the same depth. At 1800 LST shortly after the front passage, that is, near sunset, the nocturnal cooling of the ground surface could cool down air parcels, enhanceing the shallower nocturnal surface inversion layer and casuing the maximum concentration of TSP of 1388 $\mu g/m^3$ near Seoul city.

Key Words : TSP, PM10, PM2.5, Dust storm, Convective Boundary Layer

1. INTRODUCTION

In the past ten years, dust storms called Asian Dust, Yellow Sand and KOSA have frequently and periodically occurred under strong wind blowing soil in the dried area of the northern China included five provinces of Xinjiang, Inner-Mongolia, Ningxi, Shanxi, Gansu and Gobi desert in Mongolia, and the storms have transported a great amount of dusts to eastern China, Korea, Japan, even north America. Duststorm can remove several hundred thousand tons of sand and dust from dried area such as western and northern dried area of China or desert area (Chon, 1994; Chung et al., 2001; Chung and Yoon, 1996; Jigjidsuren and Oyuntsetseg, 1998; Middleton, 1986; Natsagdorj, and Jugder, 1992a).

Particulate matters during Asian Dust event in 2001 and 2002 could be transported along with westerly wind of about 20 m/s wind speed (Kim and Kim, 2003; Kim, et al., 2003). Zhang and Zhong (1985) estimated that about the half of the total quantity of particulate matter are deposited near the source area (30%) and re-distributed on a local scale (20%) and the other half of them are expected to be subject to long-range transport. The transported amount of dust can serve as one of the major particulate matter sources all across the Asia and Pacific.

In order to investigate aerosol cycle, Aerosol Characterization Experiment in Asia (ACE-ASIA) was performed by many scientific groups in many locations of east Asia of Korea, China and Japan in 2001 (Carmichael et al., 1997; Chung et al., 2003). During the period of ACE-Asia, major measurement and researches in Korea had been done at the Gosan Supersite of Jeju island in the southern Korea. In other sites, except for Gosan, some of scientists personally carried out the measurement of aerosol and among the sites, aerosol data used in this study were acquired at Seoul city, Korea (Kim et al., 2002). Most of previous researches on ACE-Asia experiment have been focused on chemical analysis and synoptic scale meteorological influence for the duststorm with usually Gosan site data, without detail explanation on the effect of frontal passage or the depth of atmospheric boundary layer on the local pollutant concentration.

Thus, the objective of this study is to precisely investigate the evolution of atmospheric boundary layer influencing upon the horizontal transportation of the dust and its vertical distribution on the local pollutant concentration and to explain the effect of frontal passage, considering synoptic and meso-scale motions of atmosphere.

2. NUMERICAL METHOD AND AEROSOL DATA

2-1. Numerical model and input data

A three dimensional of non-hydrostatic meteorological called MM5, V3.5 with an isentropic coordinate vertically was used for investigating meteorological phenomena during dust storm period from March 18 through 25, 2001. For the numerical simulation using the model, three-dimensional NCEP date of a horizontal resolution of 2.5^0 x 2.5^0 including topography, vegetation, snow cover or water, meteorological element-wind temperature, moist content, heat budget, sea surface temperature in the surface layer and sounding data on meteorological elements from the surface to 100 mb upper level were used as initial data for the coarse domain.

Then through the interpolation process of those information, modified input data were set for next triple nesting processes with grid numbers of 125 x 105 with horizontal 27 km interval and vertical grid number of 23 in the coarse domain and in the second domain, grid number of 82 x 82 with 9 km interval and in the third domain, grid number 61 x 61 with 3 km interval. 2.5^0 degree interval terrain date was used for the largest domain and then the 0.9km interval data was used for fine mesh domain. MRF method was adopted as boundary layer process in the planetary boundary layer, simple ice method for the prediction was also considered. After the nesting process from a large domain to a small domain, author made a straight cutting line from the west toward east, that is, on the dust transportation root from the dust storm generation area, China toward Seoul district, Korea, in order to investigate vertical structure of meteorological distribution of wind, temperature, relative humidity, total cloud mixing ratio for moisture contents of the atmosphere and vertical velocity. In the first large domain, a straight cutting line lay in the line of Mogolia-near Beijing-Seoul-Kyoto-Pacific Ocean like; (10, 90), (130, 40), in the 2nd domain (60, 70) (100, 55) including Seoul city for cutting both upper trough line of cold low at 500 mb level and cold front of low-pressure near surface and in the 3rd domain including Seoul city, (10, 41) (55, 41), respectively

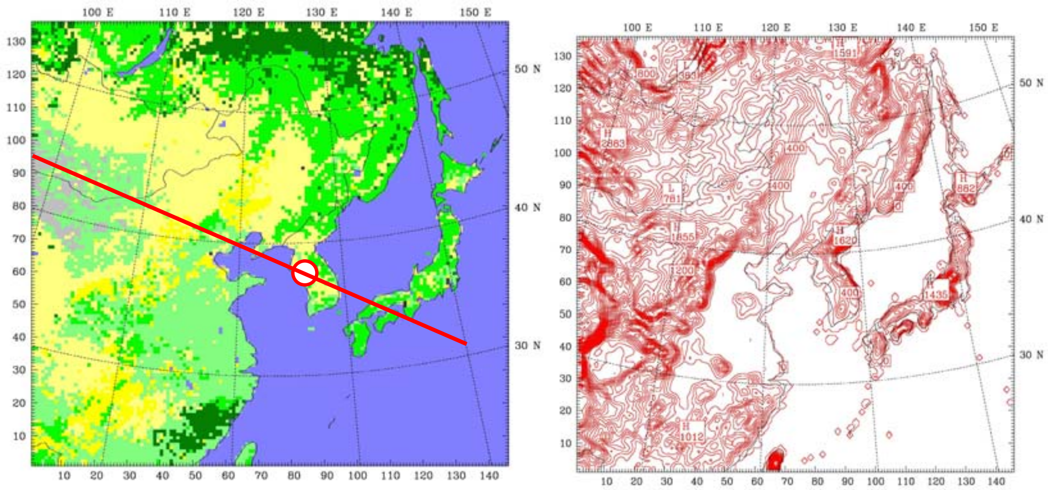


Figure 1. Land-use data and topography for a coarse domain of a horizontal grid size 27 km for MM5 model. Circle denotes Seoul city district, Korea.

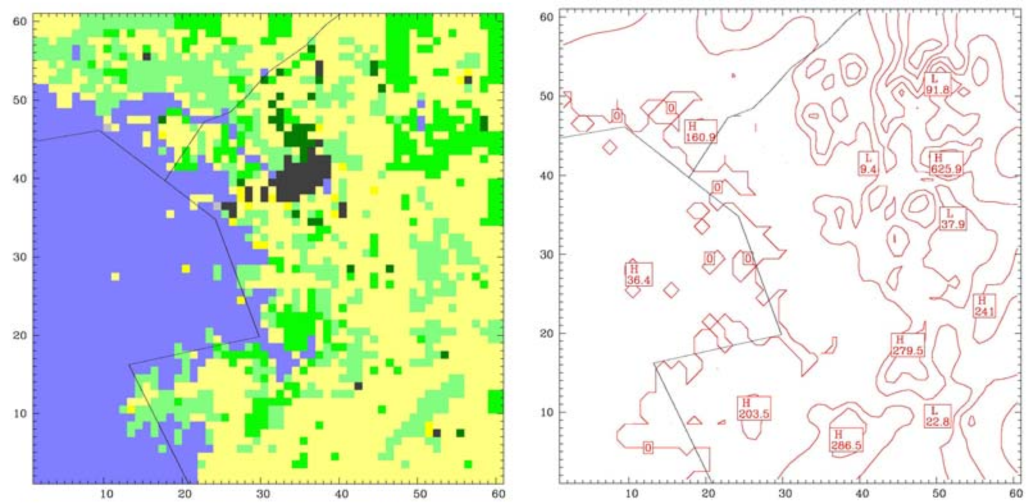


Figure 2. Land-use data and topography for a fine-mesh domain of a horizontal grid size 3 kmfor MM5 model including Seoul city. Major black part of the figure denotes Seoul metropolitan area.

2.2 TSP, PM10 and PM2.5 data in Seoul

In general, when the hourly TSP concentration is over 200 μg/m^3, one may refer to the effect of the duststorm to the local pollutant state in Korea. Before March 19, the concentration of TSP at Seoul was less than 200 μg/m^3 and from March 20, the TSP concentration started to increase over than 200 μg/m^3 and visibility became very bad less than 1 km. Thus, Korean Meteorological Administration announced that the effect of duststorm prevailed in the Seoul district.

During ACE-ASIA period from March through May, 2001, Prof. Kim (Kim et al., 2003), Sejong University with a measurement point (37^{0}32'N, 127^{0}04'E) performed the measurement of aerosol for his research from March through May, 2001 (Kim et al., 2002, 2003). The site of collection of particulate matter (PM) samples on the top of the 5th floor, Natural Science Building of the university in the eastern part of Seoul city consists of a moderately developed urban area, surrounded by a large-scale public park in the east, residential area in the north and west and commercial area in the south. After the measurement of the aerosol, some of hourly-data of aerosol from March 19 through 25, 2001 were permitted for author to use this study. Thus, much detail explanation on how to treat the measured data is given by Professor Kim's previous papers (Kim et al., 2003).

3. RESULT AND DISCUSSION

3.1 Local concentration of aerosol in Seoul: duststorm period

In the past 10 years, previous Asian Dust events were detected for few days or less per year, but the Asian Dust event days in 2001 were found with unexpectedly high frequency with 27 days from January to May. The measurements on duststorm and non-duststorm days were made on only weekday period, such as 11 days from March 19 to 31. Hourly concentrations of TSP, PM10, PM2.5 near the ground surface gave us an important information on how much different concentrations of coarse and fine particles between duststorm period and non-duststorm period. According to the report of Korean Meteorological Administration, duststorm event was detected from March 20 through March 25 in the Seoul district of Korea (Figure 3 and 4).

In general, the concentrations of TSP and PM2.5 during duststorm period were twice as high as the concentrations non-dustorm period. Maximum concentrations of TSP and PM2.5 were also found with values of 1388 μg/m^3 and 142 μg/m^3 at 1600 LST (LST= 9hours + UTC), March 22, 2001 with a ratio of 9.77 and at 1800 LST, with a ratio of 10.04. For this period, the measurement of PM10 was not successful due to some mechanical problems of the instrument, until 12o'clock on March 23. Then the measurement of PM10 continued to be to 0000 LST on April 1. The ratios of TSP to PM10, TSP to PM2.5 and PM10 - PM2.5 to PM2.5 were about 2, 6 and 2.

During the period of duststorm event, relative humidity was low around 50% with a minimum of 41%, but those vales measured by Korean meteorological Administration. The ratios of TSP to PM10, TSP to PM2.5 and PM10-PM2.5 to PM2.5 were examined in order to investigate the effect of duststorm on the local aerosol concentration, which accompanied a great amount of dust from the origin of duststorm generation. The ratios between fine and coarse particles were remarkable.

In general, the for non-duststorm period, since small size particles are observed in Korea, the Ministry of Environment, of Korean Government measure PM10 concentration instead of TSP in the recent years.

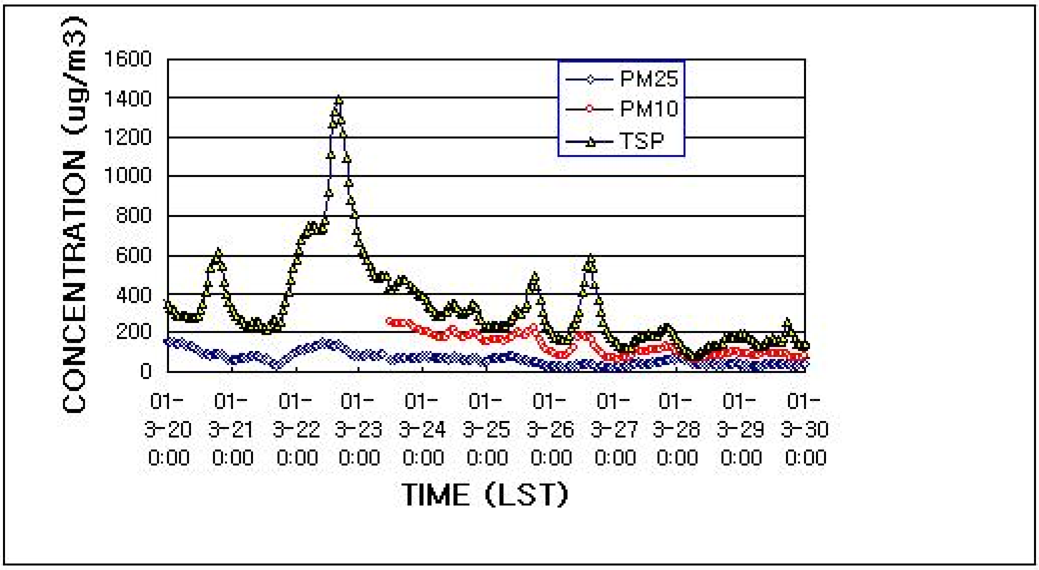


Figure 3. Hourly based concentration of PM2.5, PM10 and TSP from March 20 through 30, 2001, including duststorm and non-duststorm periods.

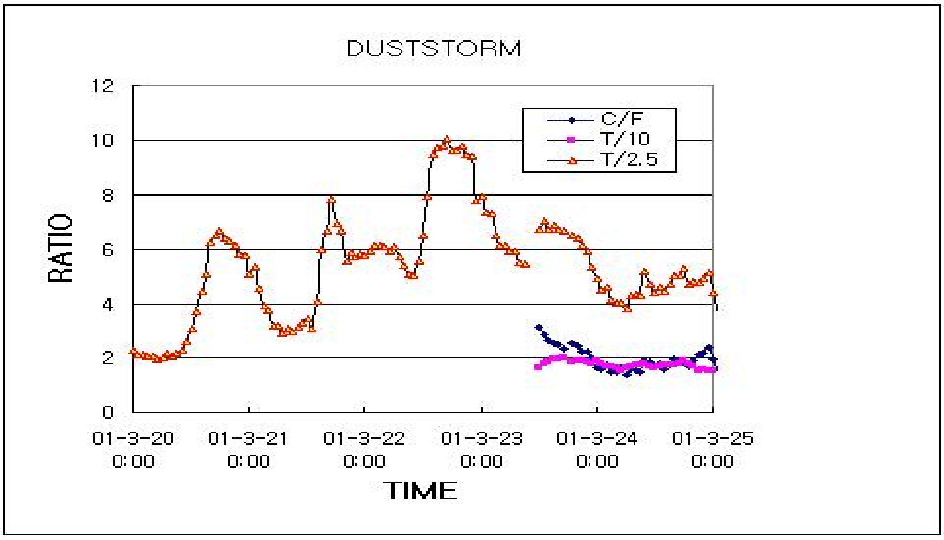


Figure 4. Ratio of TSP to PM10, PM2.5 and PM10-PM2.5 to PM2.5 during duststorm period from March 20 through March 25, 2001 at Seoul city, Korea.

3.2 Local concentration of aerosol in Seoul: non-duststorm period

During the non-duststorm period, the ratios of TSP to PM10, TSP to PM2.5 and PM10-PM2.5 to PM2.5 were found with values of about 2, 4 and 0.5, but on March

26, the ratios reached 16.37, 3.4 and 3.81 (Figure 5). On March 26, the aerosol concentration was still under the influence of duststorm, even though visibility was remarkably much improved than the previous days and Korean Meteorological Administration reported that the effect of the duststorm disappeared at Seoul city. Thus, we classified March 26 was to be duststorm day. Through the comparison of TSP, PM10 and PM2.5 between non-duststorm period and duststorm period, coarse particles made a great contribution to the increase of total suspended particulate concentration for the period of duststorm period.at Seoul city, and the ratio of coarse particle to fine particle such as (PM10 - PM2.5)/PM2.5 during the duststorm period was approximately twice as much as that during the non-duststorm period. It means that although a great amount of dust during duststorm period were transported into the Seoul district three times as much as that during non-duststorm period, the amount of coarse particle only twice increased.

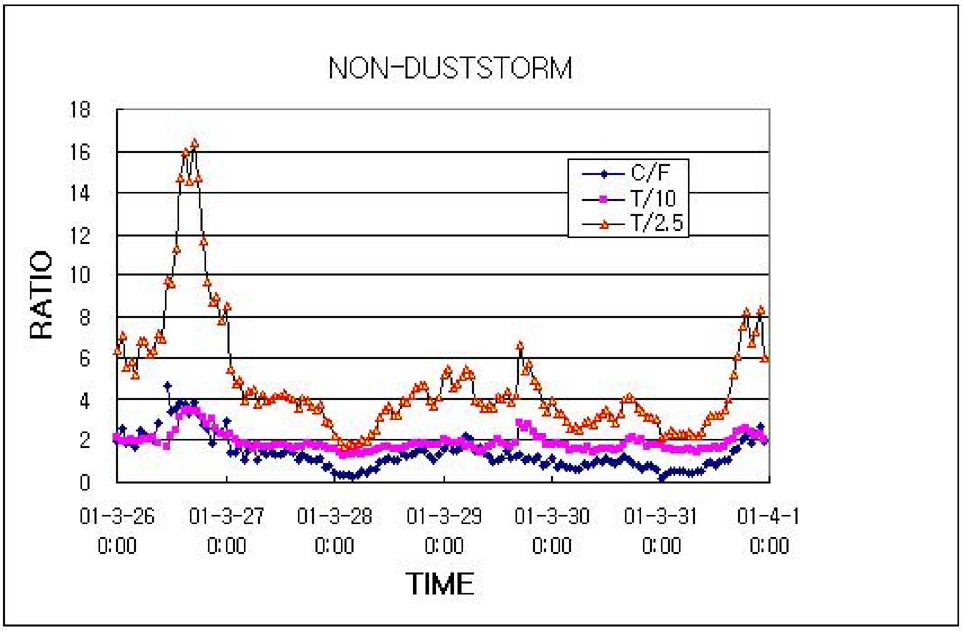
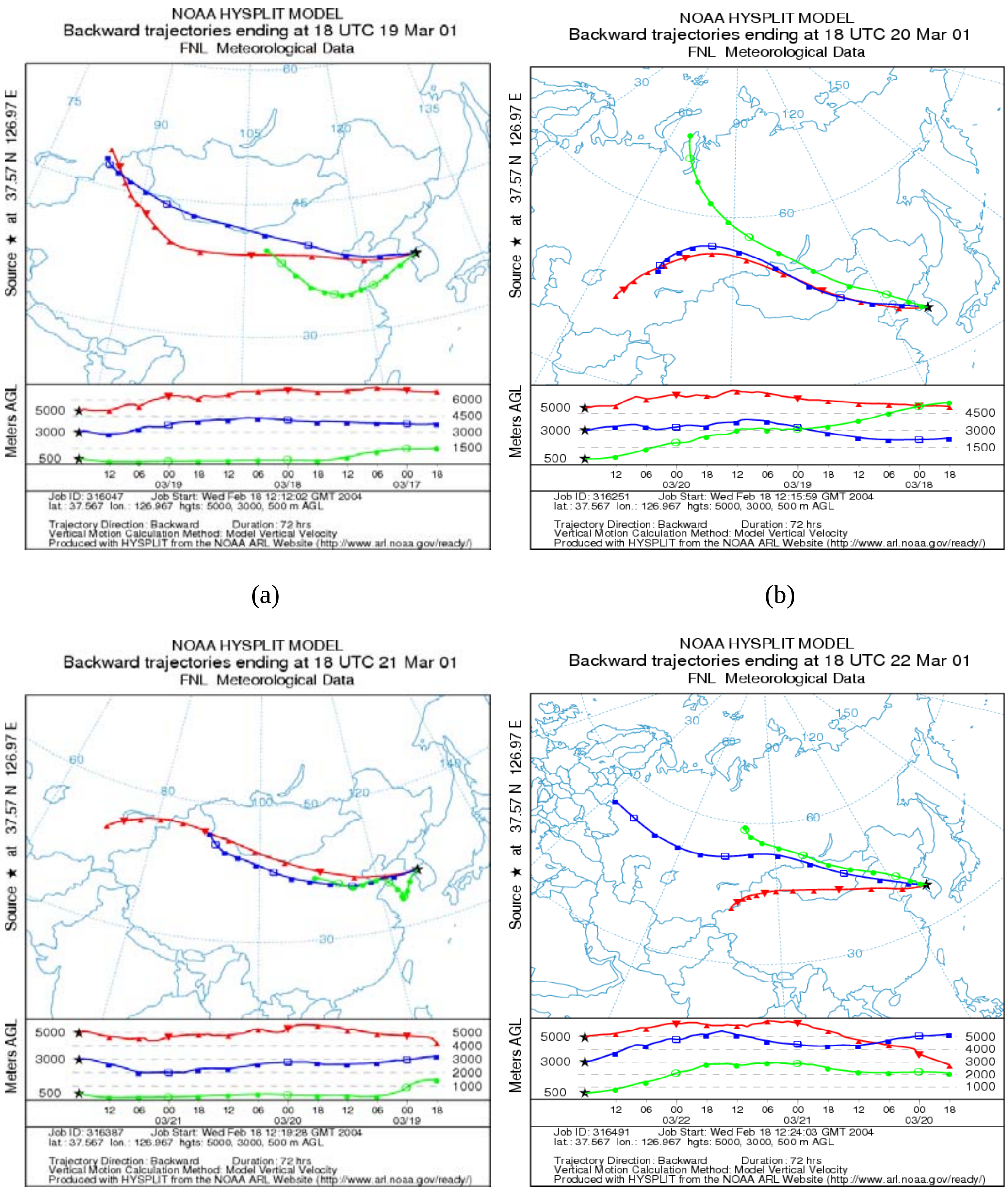


Figure 5. Ratio of TSP to PM10, PM2.5 and PM10-PM2.5 to PM2.5 from March 26 through March 31, 2001. March 26 was treated in non-dustststsorm period, as KMA declared non-duststorm day.

3.3 Origin of air masses during duststorm and non-duststorm periods

In order to investigate the effect of the dust transported from China on the concentrations of TSP and PM10 at Seoul city, back trajectories of air masses at ever 6 hour were given for duststorm period from March 20 to 25, 2001, including its beginning stage. Backward trajectory of air masses are seen separately in figures. Three levels through the surface to 10km height such as 500m ~ 1500m (showing roughly atmospheric boundary layer), 3km ~ 4500m (middle atmosphere) and 5000m ~ 6000m (high atmosphere including the effect of stratosphere) were considered.
In the inside maps of backward trajectory, trajectories in the upper part indicate the movements of air masses on each levels and ones in the below part indicate the

movements of air masses from upper level toward lower level or not. Air trajectories beginning stage of DS on from March 19 before the detection of DS effects at Seoul city gave us that air masses in the upper and middle atmospheres of 5 km and 3km heights passed through in the middle or north-eastern part of Mongolia.

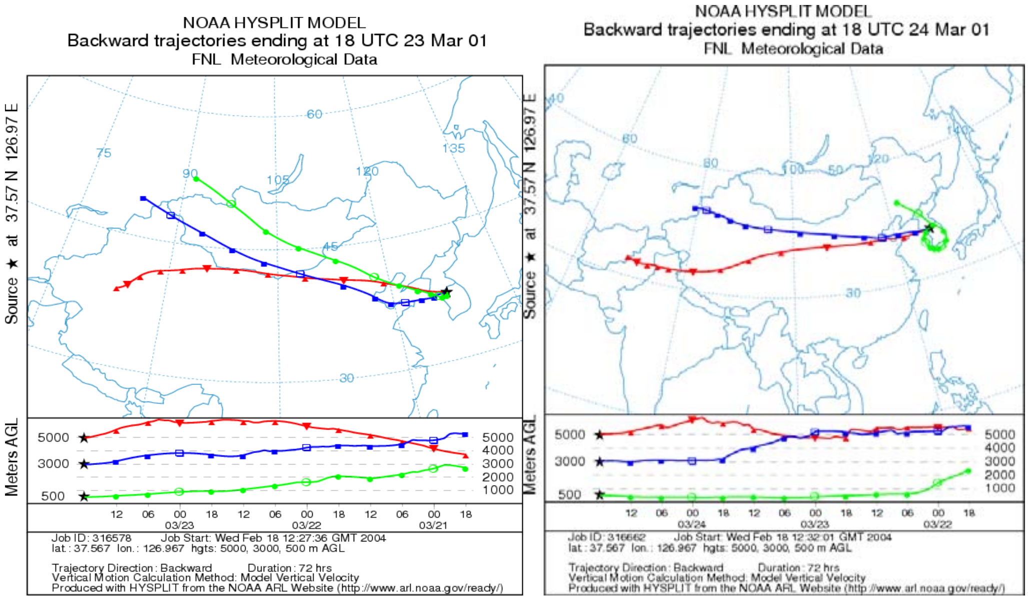


(a) (b)

(c) (d)

Figure 6. Back trajectory at every 6 hour on 3 levels-5000m (high level; red), 3000m (middle level; blue) and 500m (low level; green) over the ground at Seoul on March 19, 20, 21 and 22, 2001.

It means that air parcels reflecting the environmental aspects in the Siberia and steppes in Mongolia may be assumed to be clean and these air masses are transported into Seoul district. Air masses in the lower atmosphere near 500m ~ 1500m (atmospheric boundary layer) are also transported from Baotou in the Nei Mongo (in the border of northern China) toward Seoul city, showing different pattern to the upper and lower levels. After back trajectories in the middle and lower levels passed near southern border of Mongolia and Baotou through Zengzhou and Xuzhou and finally reached Seoul city, the TSP concentration at Seoul city was partially influenced upon the duststorm.



(a) (b)

Figure 7. As shown in Figure 6, except for at Seoul on March 23 and 24, 2001.

Through March 20 to 25 in the main stage of DS event in Korean side, air masses in the 3km and 5km height levels, which blew off from Ximiao, Ningxia and Lang Shan near Nei Mongo below the southern part of Mongolia passed through the northern part of China, reaching the Seoul district. The dust blew off from the ground surface in the source region horizontally under the strong surface wind was uplifted into the atmosphere above at least 3km height over the ground surface and should be transported through Beijing area into Seoul district under the prevailing westerly wind. The transported aerosol could influence upon high concentrations of pollutants of TSP, PM10 and PM2.5 of the city. From back trajectories of air masses, we can partially understand the path of air parcel and from which level the air parcel moved down to the ground surface, vice versa. Since back trajectory does not directly reflect all directions of moving parcels and only their major direction, it is also indirect and qualitative method for the transport of dust to the interested area.

In this research, the sudden high concentrations of TSP and PM10 were found for few hours, especially at 15 to 18, March 22, 2001. One of important goal is to find out why such a sharp concentration of the TSP took a place, even though transported amount of dust was assumed to be in the same for several hours. From the back trajectory, it is difficult to explain the reason why sudden high concentration of TSP occurred at 1800 LT, March 22. The driving mechanism is given in detail in the next section.

From March 26 through, differently from no detection of duststorm effect at Seoul, back trajectory still showed that air masses in the upper atmosphere near 5000 m and 3000 m passed through the southern Monoglia and Nei Mongo, and one in the lower atmosphere had a similar path, even their paths were slightly deviated. Sometimes their trajectories lay on the eastern Mongolia, but these kinds of trajectories maintained until March 26 and TSP concentration at Seoul was still high, but visibility was not bad, except for good visibility until March 31.

3.4 Atmospheric boundary layer effect

In the general, during the day, thermal convection on the ground surface of plain area like Seoul city (basin) occurs due to solar heating process to the ground surface, and then heated air parcel from the soil has bouncy force and is uplifted to the convective boundary layer. The emitted pollutant from the source of the ground is also accompanied to the top of the CBL and it should be merged, resulting in a low concentration of pollutant near the ground surface. Oppositely, nighttime cooling of the ground surface produces nocturnal surface inversion layer (NSIL). Shallow surface inversion layer slowly moves down toward the ground surface and air parcels inside the NSIL moves also down to the surface, resulting in calm wind or very weak wind, call a stabilization of air. The uplifted pollutant during the day also moves down and the emitted pollutant for nighttime hours can not move upward by the constraint of the NISL. The pollutant should be merged near the surface, showing the increase of the pollutant concentration at night.
In the coastal region in the left side of Seoul city , during the day, easterly sea breeze due to higher air temperature on the left side of Figure 2 than air temperature over inland basin, Seoul city surrounded by mountains and sea in its west outlet is associated with valley wind due to higher air temperature than that over the mountain surface on the right side, resulting in sea-valley wind from sea toward top of the mountain, which drives onshore wind. The emitted pollutant or particulate matters from the ground surface and transported pollutant from the sea side should all together go toward the top of the convective boundary layer of the city and sequentially go toward the top of the mountain, resulting the high concentration of the TSP in the mountain top, while the TSP concentration is low near the ground surface of the city. Since Seoul city is surrounded by mountains and sea in the west outlet, it has a characterists of coastal and urban topographical effects, its TSP concentration is generally low (Choi, 2004).
However, at night, land breeze occurred from inland toward sea due to cooler air temperature over the land surface than the sea surface. Simultaneously, cooler air temperature over the mountain than that over the inland basin at the same altitude produces mountain wind to blow from the mountain top toward the basin. Then mountain wind associated with land breeze produces land-mountain breeze in the city and results in offshore wind toward the sea in the left of Seoul city.
In addition, we have to consider the effects of atmospheric boundary layer. For instance, between 0900 LST and 1200 LST, March 22, there was a passage of cold front through Korean peninsula. Before the passage of cold front, the convective boundary layer (here white color area in the vertical distribution of potential vorticity) near Seoul was not shallow, but during the passage of the front, convective

boundary layer was remarkably shallow, resulting in the compression of boundary layer and the increase of the TSP concentration (Figure 8). Normally, small size particle easily floats up to the convective boundary layer, because its settling velocity is too small, but in the case of duststorm, a great amount of the coarse dusts of large size were observed in the study area (Figure 3 and 4). Thus, the dusts also move down to the ground surface, even inside the convective boundary layer.

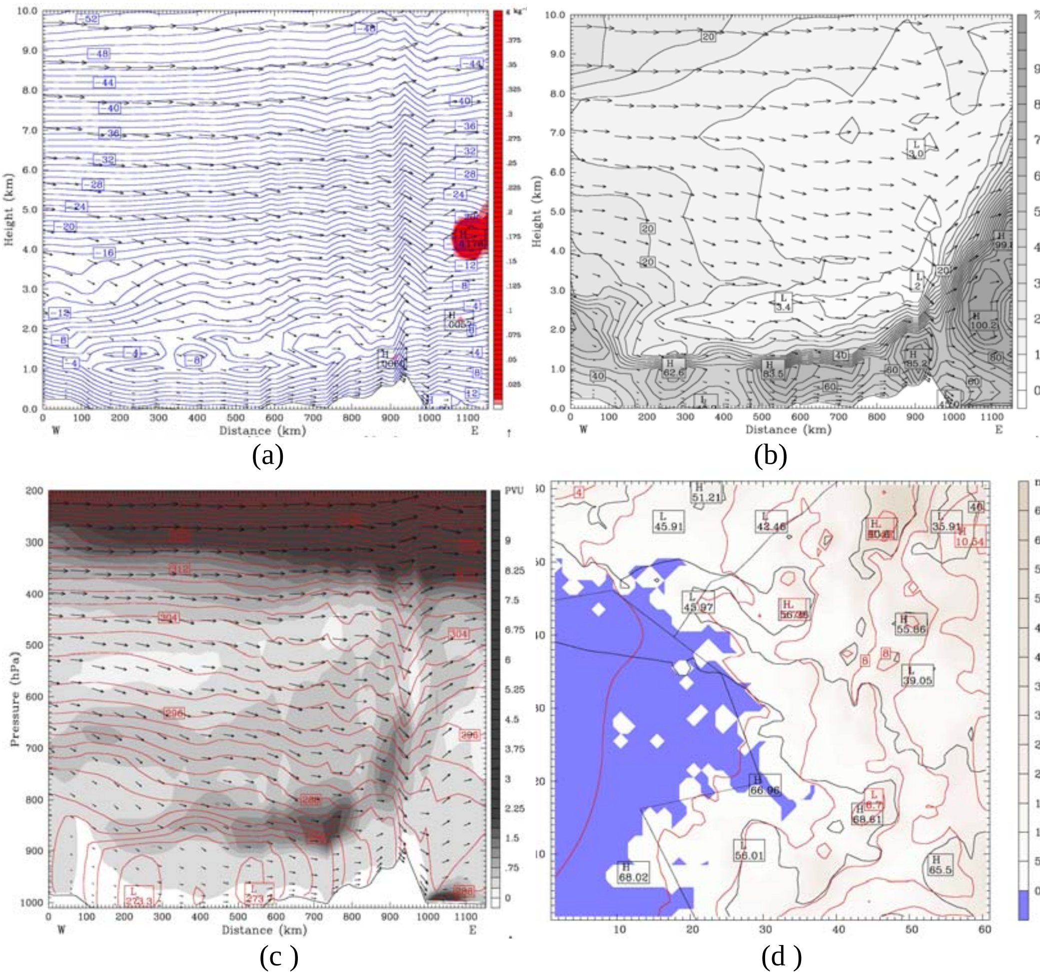


Figure 8. (a) Vertical distribution of air temperature (^{0}C)-cloud mixing ratio (g/kg)-wind vector (m/s) on the root of duststorm from China to Seoul city, (b) relative humidity (RH; %)-wind vector (m/s), (c) Ertel potential vorticity (PVU-a function of diabatic and frictional terms. bottom white-unstable layer, gray-mixed layer, dark black-stable layer) and (d) horizontal air temperature (^{0}C)-RH in Seoul city at 1200 LST, March 22. In Figure (c), unstable layer (white color near the surface of 50 ~ 1000 on x-axis; Seoul city (700 ~ 750)) is shallow.

On the figures of vertical distribution of air temperature at 1200 LST and 1500 LST, March 22, 2001, air temperature was different front of Seoul city and rear, especially relative humidity was much lower in the left hand side than right hand side, due to the temperature contrast. The intrusion of cold air could more cool down the ground surface, resulting in the shallower nocturnal surface inversion layer near Seoul city and the maximum concentration of TSP (Figure 9). Under the frontal passage, the depth of CBL less than 300 m, even though mixed layer above maintained almost the same depth. Thus, the shrunken CBL may make a great contribution to the increase of the TSP concentration.

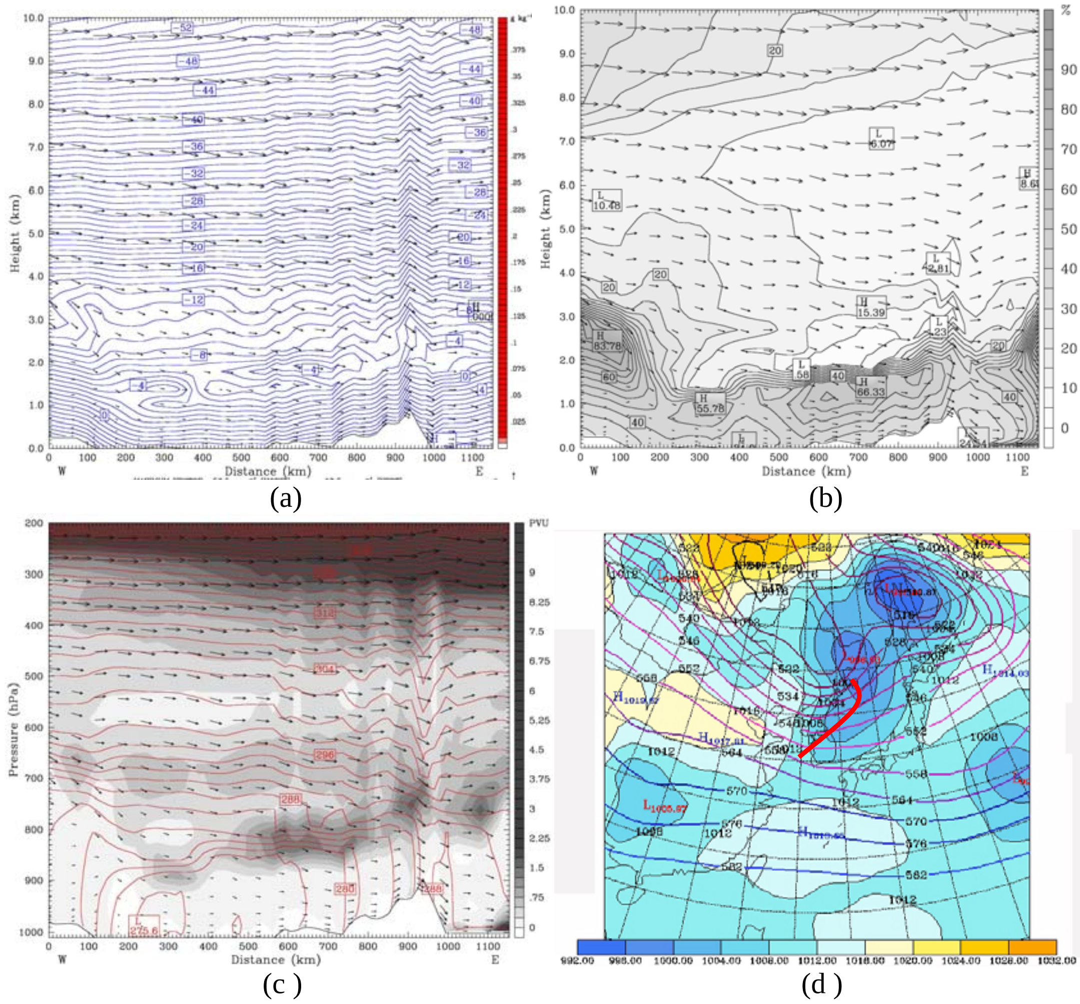


Figure 9. As shown in Figure 8, except for 1500 LST, March 22 and (d) geopotential height at 500 mb level and mean sea surface pressure (red line-surface cold front). In (c), unstable layer (white color near the ground surface of 400 ~ 750 on x-axis; Seoul city (700 ~ 750)) is much shallower than that at 1200 LST (before frontal passage). In (d), Seoul is located in above part of cold front tail.

At this time, the transported amount of dust from the duststorm area was almost the same at Seoul, including the whole Korean peninsula by the numerical simulation by Uno et al. (2001), but the TSP concentration by the measurement of high volume sampler was much higher after the frontal passage than before it (Figure 9).

4. CONCLUSION

Shortly after the cold frontal passage over Seoul city, even there was in the reduction state of the long-range transported amount of the dust from the southern part of

Mongolia toward Seoul city, Korea, the extremely high concentration of TSP in Seoul city occurred at 1600 LST. When and after the cold front passes the Seoul area, the atmospheric boundary layer, especially convective boundary layer was much shrunken than before its passage, with the depth of CBL less than 300 m, even though mixed layer above maintained almost the same depth. Thus, the shrunken CBL may make a great contribution to the increase of the TSP concentration. Simultaneously, the positive association of large scale meteorological motion with boundary layer forcing can make a great contribution to the high concentration of TSP in the local area, even in the large area.

5. ACKNOWLEDGEMENTS

Authors much thanks the College of Environmental Sciences, Peking University, China for using computer system and anaysis and Prof. K. H. Kim, Sejong University, Korea for using aerosol data of March in 2001 for Asian Dust event.

REFERENCES

Carmichael, G. R., Hong, M. S., Ueda, H., Chen, L. L., Murano, K., Park, J. K., Lee,H., Kim, Y., Kang, C., Shim, S., 1997. Aerosol composition at Cheju Island, Korea. J. Geophy. Res., 102(5), 6047-6061.

Choi, H., Zhang, Y. H. Takahashi, S., 2004. Recycling of suspended particulates by the interaction of sea-land breeze circulation and complex coastal terrain. Meteor. & Atmos. Phys., 87, 109-120.

Chon, H., 1994. Historical records of yellow sand observations in China. Res. Environ. Sci., 7-6, 1-11.

Chung, Y. S., Yoon, M. B., 1996. On the occurrence of yellow sand and atmospheric loadings. Atmos. Environ., 30, 2387-2397.

Chung, Y. .S., Kim, H. S., Jugder, D., Natsagdorj, L., Chen, S. J., 2003. On sand and duststorms and associated significant dustfall observed in Chongju-Chongwon, Korea. Water, Air, and Soil Pollut: Focuss 3: 5-19.

Jigjidsuren, S., Oyuntsetseg, S., 1998. Pastureland utilization problems and ecosystem. Ecological sustainable development. Ulaanbaatar, No.2, 206-212.

Kim, H. K., Kim, M. Y., 2003. The effects of Asian dust on particulate matter fractionation in Seoul, Korea during spring 2001. Atmos. Environ., 51, 707-721.

Middleton, N. J., 1986. A geography of dust storms in southwest Asia. J. Climate., 6, 183-196.

Natsagdorj, L., Jugder, D., 1992a. Statistics method for prediction of dust storms over the Gobi and steppe area in Mongolia in spring. Scientific report, Ulaanbaaatar, pp83.

Zhang, Y., Zhong, Y., 1985. The simulation and diagnosis for a strong wind associated with northeast low. Acta Meteor. Sinica, 43, 97-105.

Uno, I., Carmichael, G. R., Streets, D. G., Tang, Y., Yienger, J. J., Satake, S., Wang, Z., Woo, J. H., Guttikunda, G., Uematsu, M., Matsumoto, K., Tanimoto, H., Yoshioka, K., Iida, T., 2003. Regional chemical weather forecasting using CFORS: Analysis of surface observations at Japanese island stations during the ACE-Asia experiment. J. Geophy. Res., in press.