Meteorological Condition and atmospheric Boundary Layer Influenced upon Temporal Concentrations of PM1, PM2.5 at a Coastal City, Korea for Yellow Sand Event from Gobi Desert

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Abstract

Effects of meteorological conditions and atmospheric boundary layer influenced upon the formation of a sudden high hourly concentrations of PM_{10}, $PM_{2.5}$ and PM_1 during the Yellow Sand Event period were investigated by measuring mass concentrations from particle size of 300 nm ~ 20 µm using a GRIMM aerosol sampler at the eastern coast city, Gangneung of Korea from March 26 to April 4, 2004. In order to make an analysis of the transportation of dust particles from Gobi Desert to Korean peninsula, GOES-9 DCD satellite images and NOAA backward trajectories were used. Furthermore, Weather Research & Forecasting Model (WRF)-2.2 was used for generating atmospheric boundary layer and evaluating meteorological elements. During the Yellow Sand Event period, abrupt high PM_{10}, $PM_{2.5}$ and PM_1 concentrations were detected at 09:00 LST (the beginning time of office hour), especially with 180.78ug/m3 of PM10, when a high traffic density on the road took place. During the daytime, convective boundary Layer (CBL) due to daytime heating of ground surface by solar radiation is developed in the basin up to about 800 m height and thermal internal boundary layer (TIBL) under a similar driving mechanism of the CBL is also developed with much shallow depth along the coastal slope to the top of the mountain up to 300 m height. Thus, dusts transported from Gobi Desert passing by China to the Korean eastern coast (local city) and dust and gaseous emitted from the road of the city should be lifted to the top of CBL, resulting in very low PM concentrations near the surface, but very high hear the top of the CBL. Shortly after sunset, nocturnal cooling of the ground surface causes cooling of air masses near ground surface and produces nocturnal surface inversion layer (NSIL), which is much more shrunken nighttime surface inversion layer of about 200m height than the daytime convective boundary layer. Much shrunken atmospheric boundary layer can induce the increase of pollutant concentration, even though same amount of dusts transported from China and emitted from the local ground surface before sunset and after sunset is produced. Thus, around 20:00LST (two hours after the ending time of office hour), a maximum PM concentration was caused by both dusts transported from Gobi Desert and emitted from the road under a high traffic density at the local city and simultaneously, much shrunken nocturnal surface inversion layer.

Keywords: Pm10, PM2.5, PM1, Yellow Sand Event, Convective boundary layer, Thermal internal boundary, Nocturnal surface inversion layer, WRF-2.2, GOES-9 DCD satellite, NOAA Hysplit model of backward trajectory

Introduction

In the past ten years, dust storms, called another name of Sand Storm or Yellow Sand, KOSA is one of severe meteorological phenomena, have frequently and periodically occurred under strong wind blowing soil in the dried area of the northern China and Gobi desert in Mongolia and have transported dusts to eastern China, Korea and Japan. The transported dusts are not only significantly harmful to our health, causing diseases of eye and asthma and allergies, but also ecological environment, suppressing plant growth under blocking pores of the plant and disturbance of photosynthetic activity. Kim et al.[1] explained that particulate matter (PM) during Asian dust events in 2001 and 2002 could have be transported toward Seoul, Korea, by a strong westerly wind of about 20 m/s.

Asian dust mainly originated from elevated ground at 1500 m or above sea level in Taklamakan, Gobi and Ordos deserts and Loess plateau and have seasonal cycles as generally observed in the dry season, spring. The threshold value of wind velocity for the dust mobilization of dust storm is 4.6 m/s in Sahara region[2] and 6.5 m/s for Austrian dust storm at 10 m above the ground, while that in the Loess Plateau and Gobi desert is in a range of 10 m/s ~12 m/s from field observation and wind tunnel experiments[3]. Tegen and Fung[4] and Zhang and Zhong[4] investigated that regions of dust storm occur more than 30 days per year coincide with those regions with relative humidity of air less than 40%, which is the representation of the surface water content of the soil layer. Zhang and Zhong[5] and Zhang and Arimoto[6] 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.

Monitoring researches by many scientists have been undertaken on the visibility, the chemical component and remote sensing by aircraft and satellite like NOAA, GMS and TOMS aerosol index and so on. The dust is to make a great contribution to low visibility and air quality in spring in northern Asian countries and even U.S.A.[7-8]. Choi, et al[9] presented the transportation and merging of particulate matters, considering meso and synoptic scale meteorological wind field and sea and mountain effects near the Seoul metropolitan area, using three-numerical modeling.

The purpose of this study is to investigate the effects of meteorological conditions and atmospheric boundary layer influenced upon the formation of a sudden high concentration of PM_{10}, $PM_{2.5}$ and PM_1 concentrations during the Yellow Sand Event period.

Measurement of Aerosol and topography

Instrument: Concentrations of particle sizes 100 ng/m^3 to 20 µg/m^3 have been measured by GRIMM aerosol samplers over the eastern coastal region of Korea from March 26 ~ April 4, 2004, during the period of spring dust storm in China. One aerosol-sampling instrument was installed at an elevation of 896m on Mt. Taegulyang in the western, upwind side of the mountains and the other at Gangwon Regional Meteorological Administration in the coastal city of Gangnrung, which is adjacent to the East Sea. The GRIMM Model 1107 is a portable particle analyzer and is specifically designed for PM_{10}, $PM_{2.5}$, and PM_1 environmental ambient air analysis using laser-light scattering technology. This technology enables the Model 1107 to make very precise "cut points" for all three PM size classifications. This patented system allows the user to collect all three PM fractions simultaneously without changing sampling heads or weighing filters.

The Model 1107 is the only PM monitor to offer dual technology consisting of both optical and gravimetrical analysis. This monitoring system measures particulates via laser-light scattering. Air containing multiple particle sizes passes through a flat laser beam produced by a precisely focused laser and several collimator lenses. The scattered light is then detected by a 15 channel, pulse-height analyzer for size classification. The counts from each size classification are then converted to mass by a well established equation. The data are then presented as PM_{10}, $PM_{2.5}$, and PM_1.

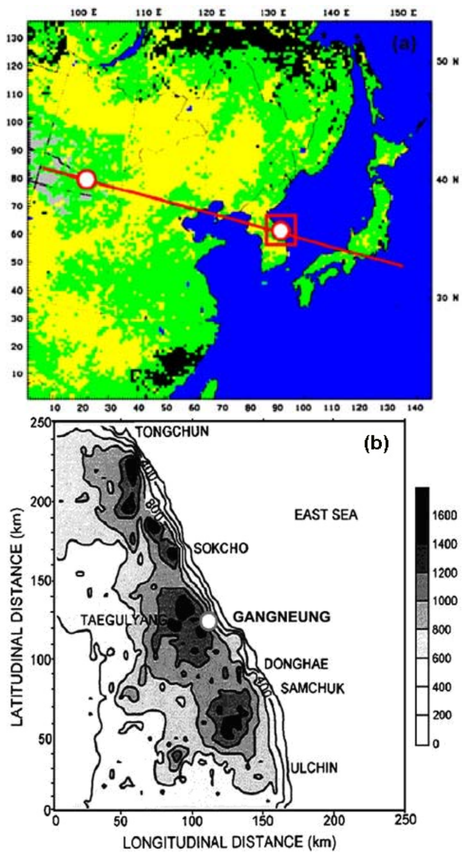

Fig. 1: Topographical features in (a) the vicinity of Korean peninsula for numerical simulation using WRF-2.2 model and (b) the mountainous coastal region surrounding Gangneung city (20 m above mean sea level) and Mt. Taegulyang (860 m) in a fine-mesh domain (horizontal resolution of 3km). In (a), circles denote Gobi Desert and Gangneung city.

Topography in study area: The study area, Gangneung city ($37^0$45N, $128^0$54E) was located in a mountainous coastal region of the eastern Korean peninsula. The city consists of high mountainous in the west, basin in the middle and sea in the east (a smallest box as a fine-mesh domain in Fig. 1). GRIMM aerosol samplers were set up, one on Mt. Taegulyang (896 m above mean sea level) and another at Gangwon Regional Meteorological Administration in Gangneung city (20 m above mean sea level) adjacent to the East Sea. Terrain data with a horizontal resolution of 1° were used for the largest domain, and 1 km horizontal resolution data were used for the fine-mesh domain and 1 km horizontal resolution data were used for the fine-mesh domain. horizontal Beijing, Seoul, and Kyoto to the Pacific Ocean was selected for analysis. This path was the major transport route from the area in China where the dust storm originated.

Numerical Method and Input Data

For evaluating wind field and generate atmospheric boundary layer, a three-dimensional Weather Research & Forecasting Model (WRF)-2.2 version was adopted for 48 hours numerical simulation from 0000 UTC (Local

Standard Time (LST) = 9h + UTC; 0900 LST), October 22 through 0000 UTC, October 24, 2006. During the numerical simulation using the model, wind, temperature, potential temperature, relative humidity, relative vorticity, potential vorticity, streamline, in northeastern Asia (first domain), Korean peninsula (second domain) and near Gangneung city in the eastern coastal region of Korea (third domain). One way, triple nesting technique was adopted using a horizontal grid spacing of 27 km, 9km and 3 km covering a 91 x 91 grid square in each domain. NCEP/NCAR reanalysis FNL (1.0^0 x 1.0^0) data was used as meteorological input data to the model and was vertically interpolated onto 36 levels with sequentially larger intervals increasing with height from the surface to the upper boundary level of 100 hPa.

In the atmospheric boundary layer, the WSM 6 scheme was used for heat and moist budgets and microphysical processes and for the planetary boundary layer, the YSU PBL scheme was adopted. The Kain-Fritsch (new Eta) for cumulus parameterization, the five thermal diffusion model for land surface, and the RRTM long wave radiation scheme and dudhia short wave radiation schemes were also used. Hourly archived wind, air temperature, relative humidity, potential vorticity, cloud and geopotential tendency by Gangwon Regional Meteorological Administration in Gangneung city were used for the verification of numerical results of the meteorological elements.

Results and Discussion

Aerosol concentration: Before the influence of dust from China, that is, before the Yellow Sand Event to the coastal site until March 29, PM_{10}, $PM_{2.5}$ and PM_1 concentrations near the ground of the city were very low and their maximum values of each PM concentrations were 72.33 $\mu g/m^3$, 41.00 $\mu g/m^3$, 35.33 $\mu g/m^3$, and their minima were 12.53 $\mu g/m^3$, 6.75 $\mu g/m^3$, 5.82 $\mu g/m^3$ (Figs. 2 and 3). GOES-9 DCD satellite pictures and backward trajectories of dust particles by NOAA Hysplit model using FNL meteorological data showed very detail information on temporal transportation routes and flowing height and spreading area of dust particles (Figs. 4a, 4b, 5a and 5b). Similarly, from surface weather map, one can assume that dust storm was generated behind of tail of cold front, where strong surface wind prevailed (Fig. 4a) and dust particles followed behind the passage of cold front (Figs. 4a and 4b). When maximum PM concentration was detected at Gangneung city, cold front had already passed by the city, 3 hours earlier.

For depicting backward trajectories of dust particles, the heights of dust particle trajectory were set up at 3000 m, 2000 m and 500 m, respectively. Before maximum PM concentration was detected at Gangneung city, dust particles flow above 1 km from China, but below 500 m, particles came from southern Yellow Sea and Kyushu Island (clean air masses). However, when maximum PM concentration was detected at the city, all of dust particles came from Gobi Desert and Nei-mongo in the northern China toward the study area. GOES-9 DCD satellite pictures gave us more detail information on spreading area and transportation route of dust particles, but they did not inform the flowing height of the particles.

During the Yellow Sand Event period from on March 30 ~ April 2, when the large amount of dust from China passed over Korean peninsula and reached the vicinity of Gangneung city in the eastern coast, under a westerly wind influence, PM_{10}, $PM_{2.5}$ and PM_1 concentrations reached 238.87 $\mu g/m^3$, 46.50 $\mu g/m^3$ and 30.25 $\mu g/m^3$ On the other hand, their minima were 41.68 $\mu g/m^3$, 7.17 $\mu g/m^3$ and 2.77 $\mu g/m^3$, indicating their maxima being at least five times larger than their minima. On the other hand, $PM_{2.5}$ and PM_1 concentrations were not much changed regardless before or during the period of dust. In Fig. 3, coarse particulate matters larger than 2.5 um of particle size made major contribution to the increase of PM10 concentration during dust storm period from March 30 ~ April 2, 2003. A high PM concentration at 09:00 LST at Gangneung city, in the eastern coast of Korea was affected by emission of gases and dust from vehicle on the road at the beginning of office hour under huge transportation of dusts from Gobi Desert in Mongolia. Maximum concentration of PM at 20:00 LST occurred under the shrunken nocturnal surface inversion layer as shown in Fig. 7b.

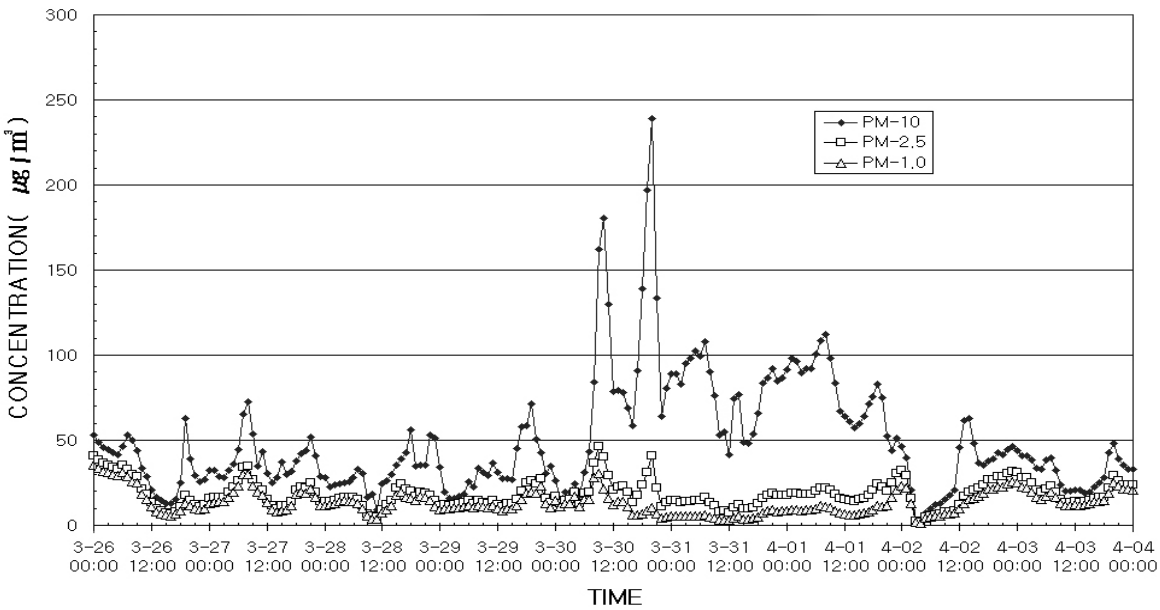

Fig. 2:Hourly-based concentrations (µg/m^3) of PM10, PM2.5, and PM1 collected at an aerosol-sampling point of Gangwon Regional Meteorological Administration in Gangneung, Korea, during March 26 ~ April 4, 2004. Particulate matter concentrations at 1500 LST were low due to a deep convective boundary layer. A high PM_{10} $_c$oncentration at 09:00 LST, March 30 was affected by combination of gaseous and dust emitted from vehicles on the road at the beginning of office hour as usual and dust transported from Gobi Desert in Mongoria. The maximum PM concentration at 22:00 LST occurred under the shrunken nocturnal surface inversion layer at night as shown in Fig. 7b.

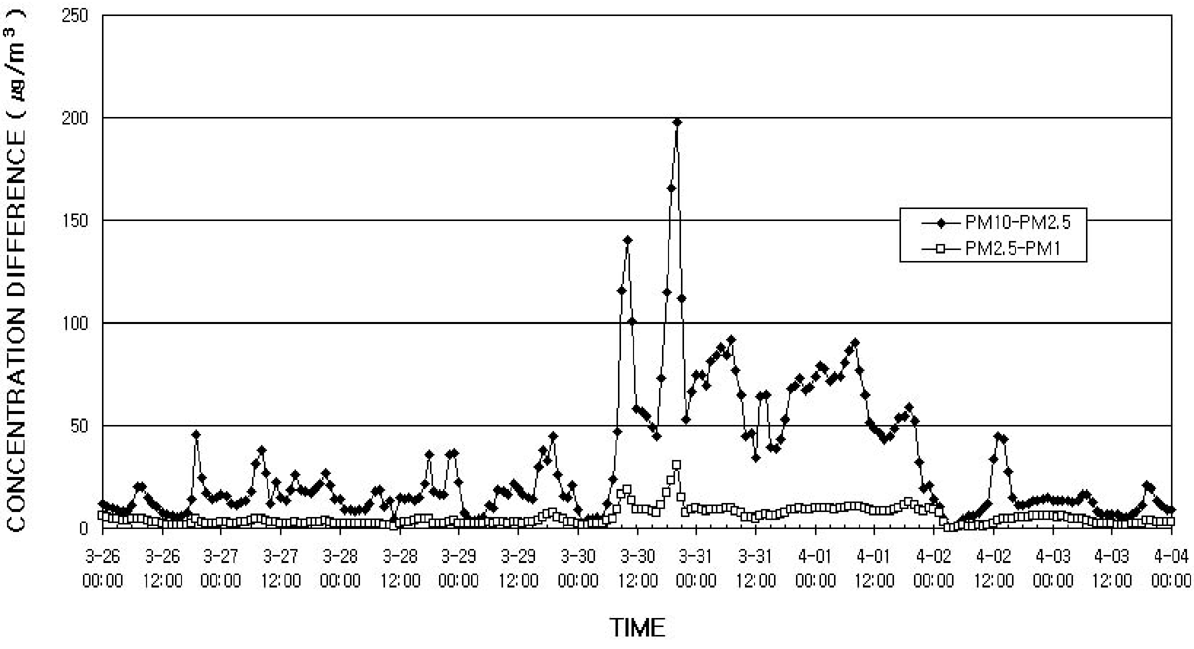

Fig. 3:Coarse particulate matters larger than 2.5 um of particle size makes major contribution to the increase of PM10 concentration during the Yellow Sand Event period from March 30 ~ April 2, 2003. During A high PM concentration at 09:00 LST at Gangneung city, in the eastern coast of Korea was affected by emission of gases and dust from vehicle on the road at the beginning of office hour under large transportation of dusts from Gobi Desert in Mongolia. Maximum concentration of PM at 20:00 LST occurred under the shrunken nocturnal surface inversion layer at night as shown in Fig. 7b.

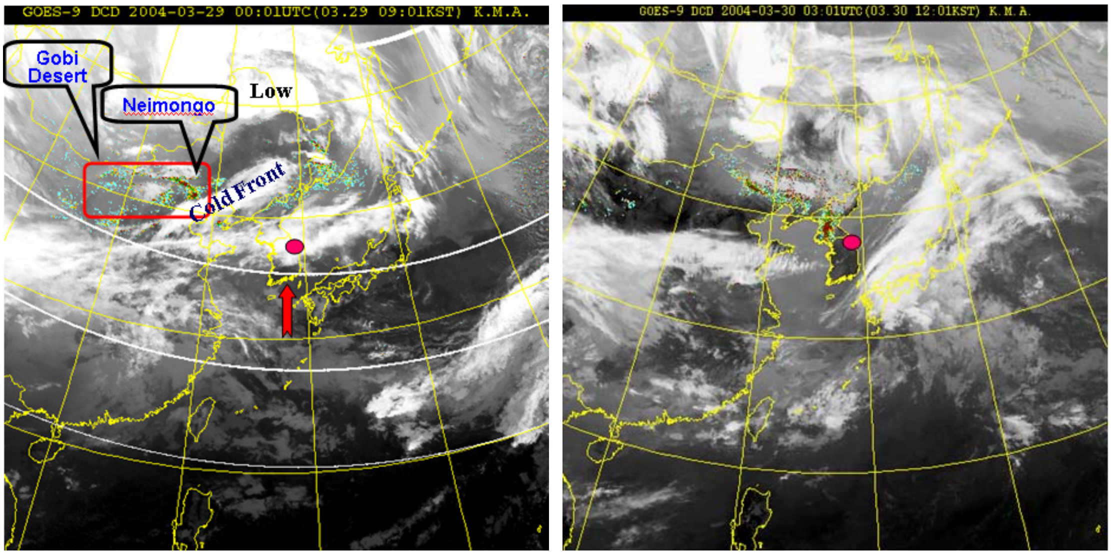

Fig. 4:GOES-9 DCD satellite pictures at (a) 09:00 LST, March 29, 2004 and (b) 12:00 LST, March 30, 2004 (eight hours before the maximum PM concentration at Gangneung city). A rectangle denotes dust generation area (Gobi Desert). Dust particles were transported from Gobi Desert (origin) toward the northeastern China (Manchuria) and northern Korea, finally reaching Gangneung city (circle) of the Korean eastern coast. Scattered colorful area indicates dispersion areas of dust particles and thick white band denotes clouds on cold front. Arrow and circle denote Korea and Gangneung city, respectively.

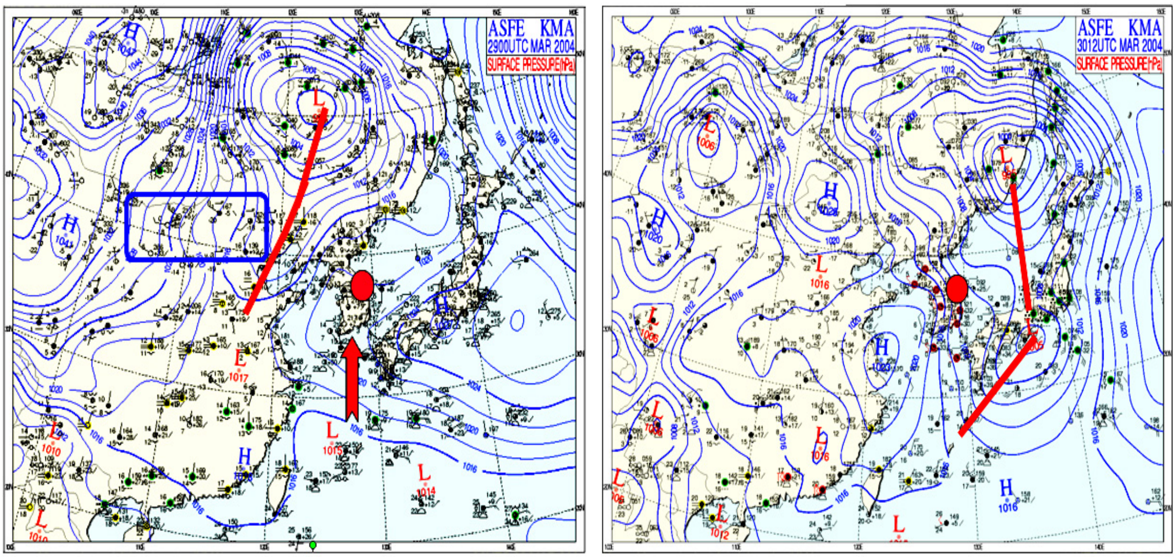

Fig. 5:Surface weather map at (a) 09:00 LST, March 29, 2004 and (b) 21:00 LST, March 30, 2004 (occurrence time of maximum PM at Gangneung city). A rectangle, thick long line and circle in (a) denote dust origin (near Gobi Desert), cold front and Gangneung city, respectively. Dust storm (the Yellow Sand Event) was generated behind of tail of cold front, where strong surface wind prevailed and then floating dust particles moved toward east.

During the dust storm event period, abrupt high PM_{10}, $PM_{2.5}$ and PM_1 concentrations were detected at 09:00 LST (the beginning time of office hour), especially with 180.78 ug/m^3 of PM_{10}, when a high traffic density on the road took place. During the daytime, convective Boundary Layer (CBL) due to thermal heating of ground surface by solar radiation is developed in the basin up to about 800 m height and thermal internal boundary layer (TIBL) under a similar driving mechanism of the CBL is also developed with much shallower depth along the coastal slope to the top of the mountain up to 300 m height (Fig. 7a). Thus, dusts transported from Gobi Desert passing by China to the Korean eastern coast (local city) and both dust and gaseous emitted from the road of the city should be lifted to the top of CBL due to thermal heating of air, resulting in very low PM concentrations near the ground surface of the coastal city, but very high hear the top of the CBL.

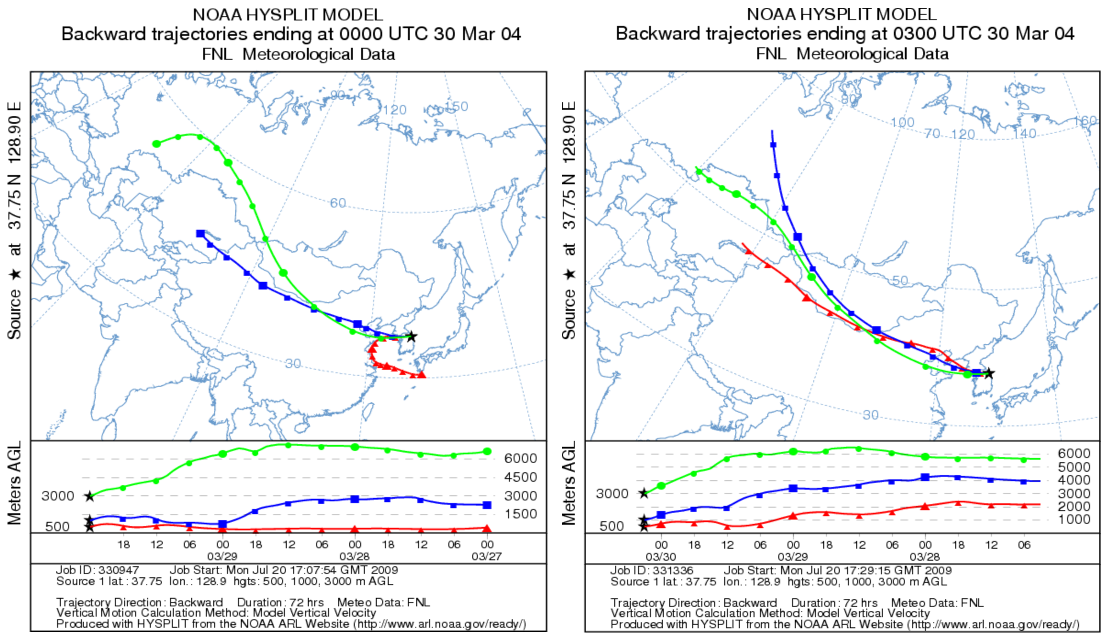

Fig. 6: Backward trajectories by NOAA Hysplit model ending at (a) 09:00 LST (0000 UTC), March 30, 2004 and (b) 21:00 LST, March 30 (occurrence time of maximum PM concentration). The heights of dust particle trajectory were 3000 m, 2000 m and 500 m, respectively. Before maximum concentration of PM was detected at Gangneung city, dust particles flow above 1 km from China, but below 500 m, particles came from southern Yellow Sea and Kyushu Island (clean air masses), but when maximum concentration of PM was detected at the city, all of dust particles came from Gobi Desert and Nei-mongo in the northern China toward the study area.

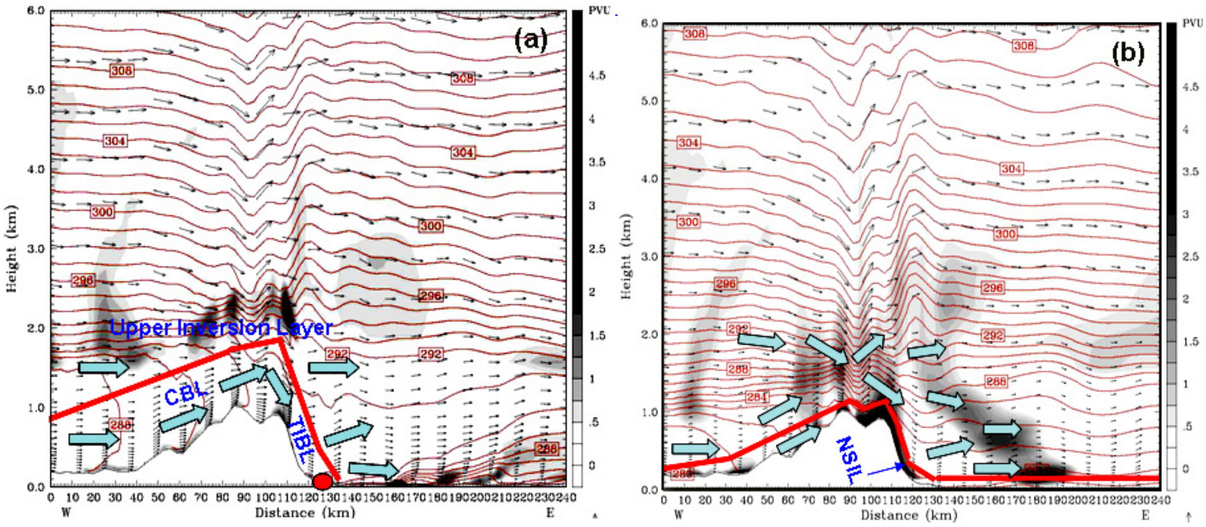

Fig. 7: Vertical profiles of potential temperature (k) and wind speed (m/s) evaluated by WRF-2.2 model on March 30, 2004, at (a) 0900 LST and (b) 2100 LST. Circle on the bottom denotes Gangneung city. Atmospheric boundary layer at (a) 15:00 LST, March 30, 2004 and (b) 20:00 LST, March 30 (occurrence time of maximum PM) at Gangneung city in Korea. Thick line, CBL, TIBL and circle in (a) and NSIL in (b) denote the top of convective boundary layer, thermal internal boundary layer, Gangneung city and nocturnal surface inversion layer. CBL and TIBL were developed with wide thickness, resulting in low PM concentration at the coastal city, while NSIL was much shallower than CBL or TIBL, resulting in maximum PM concentration under large amounts of dust particles transported from Gobi Desert by westerly wind.

Shortly after sunset, nocturnal cooling of the ground surface causes cooling of air masses near ground surface and produces nocturnal surface inversion layer (NSIL), which is much more shrunken nighttime surface inversion layer of about 200m height than the daytime convective boundary layer (Fig. 7b). Much shrunken atmospheric boundary layer can induce the increase of pollutant concentration, even though same amount of dusts transported from China and emitted from the local ground surface before sunset and after sunset is produced.

Around 20:00LST (two hours after the ending time of office hour), a maximum PM concentration was caused by both dusts transported from Gobi Desert and emitted from the road under a high traffic density at the local city and simultaneously, much shrunken nocturnal surface inversion layer. Thus, CBL and TIBL were developed with wide thickness, resulting in low PM concentration at the coastal city, while NSIL was much shallower than TIBL and CBL, resulting in maximum PM concentration under large amounts of dust particles from Gobi Desert by westerly wind.

Conclusion

During the Yellow sand Event period from March 30 ~ April 2, 2004, a large amount of dust passed over the coastal city of Gangneung, Korea, due to the influence of strong westerly wind. During the dust storm event period, sudden high PM_{10}, $PM_{2.5}$ and PM_1 concentrations were detected at 09:00 LST (the beginning time of office hour), when a high traffic density on the road took place. For daytime hours, convective Boundary Layer is developed in the inland basin up to about 800 m height and thermal internal boundary layer form the coast along the mountain slope is also developed up to 300 m height. Dusts from Gobi Desert passing by the northern China (Nei-Mongo) to a Korean eastern coast city were combined with both dust and gaseous emitted from vehicles on the road in the coastal city. Due to the strong thermal heat of ground surface, air parcels including pollutants such as dusts and gaseous should be lifted to the top of CBL, resulting in very low PM concentrations near the surface, but very high PM concentrations at the top of the CBL.

At night, nocturnal cooling of the ground surface induced the falling of particles floated during the day and produced nocturnal surface inversion layer. Much shallower nocturnal surface inversion layer than the daytime convective boundary layer can cause the increase of pollutant concentration, even though same amount of dusts transported from China to the local city. Around 20:00LST (two hours after the ending time of office hour), the combination of dusts from Gobi Desert and dust particles emitted from vehicles and road could produce a maximum PM concentration under much shrunken nocturnal surface inversion layer. Thus, CBL and TIBL were developed with wide thickness, resulting in low PM concentration at the coastal city, while NSIL was much shallower than CBL, resulting in maximum PM concentration under large amounts of dust particles from Gobi Desert by westerly wind.

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