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Numerical Study on the Change of PM_{10} Profile by Asian dust

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The research was conducted to simulate and interpret the change of PM_{10} profile by Asian dust using the CALPUFF modeling system for the period April 6 through 18, 2001. The results, which are represented a daily variation of PM_{10} concentration before and after Asian dust, was located between a minimum concentration of 50 μg/㎥ and a maximum concentration of 100 μg/㎥. Most concentration peaks in the PM_{10} profile were shown within a level below 500 m and had a pattern that rapidly increased up the peak and decreased after the peak to 1000 m. Even though the shapes of the vertical profile during Asian dust days were similar to non-Asian dust days, no rapid change vertically was observed. In particular, the vertical profile on 1200 LST and 1800 LST was noticeably shifted to the higher concentrations, which means PM_{10} in the atmosphere was changed into a vertically and horizontally heterogeneous form under the Asian dust event. Finally, it is confirmed that the simulation result from CALPUFF might schematically sketched atmospheric PM_{10} profiles and their change by Asian dust throughout the comparison with profiles of aerosol extinction coefficients, which were acquired from Lidar measurement at KGAWO.

Key Words : PM_{10} profile, Asian dust, CALPUFF modeling system

1. Introduction

Particulate Matter (PM) in the Earth's atmosphere has been viewed as an important factor in interpreting air quality and climate change[6]. However, formal researches has been mainly limited to *in-situ* measurement of the physical and chemical characteristics and a numerical modeling on long-range transports[1,3,5,8,10~12].

The U.S. EPA (Environmental Protection Agency) has proposed the CALPUFF modeling system as a guideline model for regulatory applications involving long range transport. It can be applied for an estimation of non-steady-state effects, which consider situations such as spatial variability in meteorological fields, calm winds, fumigations, re-circulation or stagnation as well[2,4,9,14].

The objectives of this research are to simulate and interpret the vertical distribution of PM_{10} using the CALPUFF modeling system during Asian dust. The research started based on the assumption if the simulated PM_{10} concentration at the surface were similar to the observed result, the vertical sketch of PM_{10} concentration from the simulation would also show similar to the real pattern.

Aerosol extinction coefficients acquired through ground base Lidar measurement at Korea Global Atmosphere Watch Organization (KGAWO) were adopted for comparison with the simulated results. Since Lidar measurement at KGAWO were limited within several times in year 2001, the study had only selected two cases: the first corresponded to March 21 through 22 which was recorded as a Asian dust day and the second corresponded to April 4 which was recorded as a non-Asian dust. Therefore, the results of the simulation sketched a schematic vertical profile and its change rather than a correct quantity of PM_{10}.

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2. Methodology

2.1. CALPUFF Modeling System

The CALPUFF modeling system has been proposed as a guideline model for regulatory applications. This involves long-range transport and a case-by-case basis for near-field applications where non-steady-state effects occur. (1) and (2) introduce the basic equation for the contribution of a puff at a receptor, and Fig. 1 shows an overview of the program elements in the CALPUFF modeling system.

CALMET as a preprocessor for input meteorology and geographic data generates hourly wind and temperature fields on a three-dimensional gridded modeling domain. Mixing height, surface characteristics, and dispersion properties are also included in the file produced by CALMET[13].

Using the fields generated by CALMET, CALPUFF is a transport and dispersion model that advects "Puffs" of material emitted from modeled sources, simulating dispersion and transformation processes along the way. The primary output files from CALPUFF contain either hourly concentrations or hourly deposition fluxes evaluated at the selected receptor locations[14].

CALPOST is used to process these files, producing tabulations that summarize the results of the simulation, identifying the highest and second highest 3 hour average concentration at each receptor. For example, when performing visibility related modeling, CALPOST uses concentrations from CALPUFF to compute extinction coefficients and related measures of visibility and reports these for the selected averaging times and locations[14].

The basic equation for the contribution of a puff at a receptor is given by

$$C = \frac{Q}{2\pi\sigma_x\sigma_y}\, g\, \exp\left[-d_a^2/(2\sigma_x^2)\right]\exp\left[-d_c^2/(2\sigma_y^2)\right] \quad (1)$$

$$g = \frac{2}{(2\pi)^{1/2}\sigma_z}\sum_{n=-\infty}^{\infty}\exp\left[-(H_e+2nh)^2/(2\sigma_z^2)\right] \quad (2)$$

where

C is the ground level concentration (g/m^3),

Q is the pollutant mass (g) in the puff,

σ_x is the standard deviation (m) of the Gaussian distribution in the along-wind direction,

σ_y is the standard deviation (m) of the Gaussian distribution in the cross-wind direction,

σ_z is the standard deviation (m) of the Gaussian distribution in the vertical direction,

d_a is the distance (m) from the puff center to the receptor in the along-wind direction,

d_c is the distance (m) from the puff center to the receptor in the cross-wind direction,

g is vertical term (m) of the Gaussian equation,

H is the effective height (m) above the ground of the puff center, and

h is the mixed-layer-height (m), respectively.

2.2. Data

One upper-air weather station database by Korea Meteorological Administration (KMA), five weather stations databases, 25 Automatic Weather Stations (AWS) databases, one marine observation station (BUOY) database, and two airport weather station databases were used as input for CALMET (Fig. 2(a)). Both the United States Geological Survey (USGS)'s 30 arc second (900 m) Digital Elevation Model (DEM) database and 30 arc second (900m) Global Land Cover Characterization (GLCC version 1) were adopted for the geophysical data analysis (Fig. 2(b)). In addition, Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) mesoscale model (MM5V3) was used as a diagnostic meteorological model.

An initial PM_{10} emission over Busan was calculated based on the PM_{10} emission database calculated in 1998[15], and 500 $\mu g/m^3$ was given for dust amounts coming through each boundary to have 10 vertical layers, respectively. The Asian dust warning system of Korea Meteorological Administration (KMA) defines these concentration mounts of Asian dust as at 'a level of advisory'.

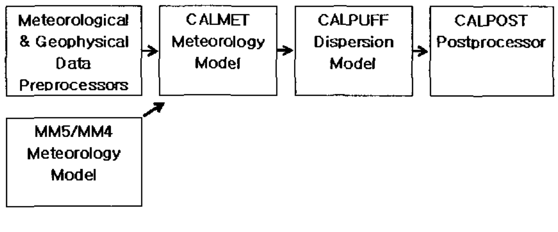
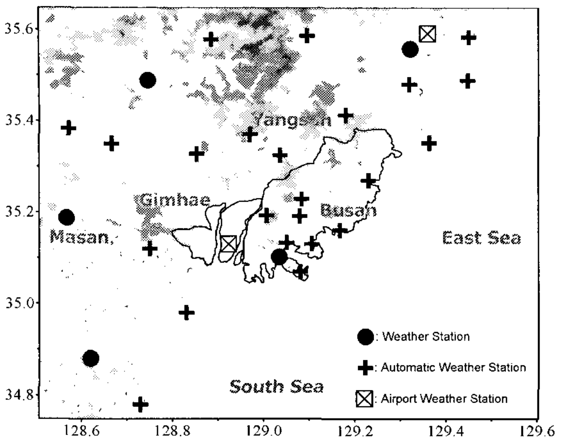
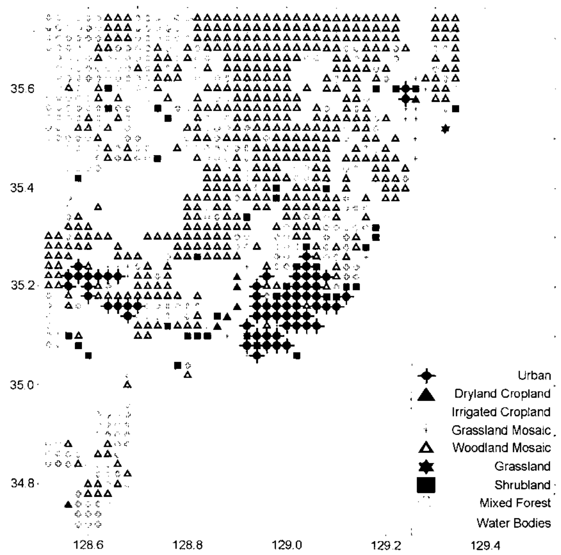


Fig. 1. Overview of the program elements in the CALPUFF modeling system.



(a)



(b)

Fig. 2. (a) Meteorological stations used in CALPUFF modeling system and (b) land use and land cover (LULC) information for the modeling domain from USGS.

Numerical simulation had been run for three cases corresponding to before, during, and after Asian dust. The results were compared with a temporal and local variation of PM_{10} concentration generated by Ministry of Environment at Kwangbokdong around the center of Busan.

In the early stage, the results between observed and simulated PM_{10} concentration showed noticeable differences for all simulation periods. For example, simulated PM_{10} showed the concentration around 10 μg/m³. Therefore, an emission fitting was applied, which regulated a similarity in order to obtain Fig. 3. In Fig. 3, even though several peaks in the Asian dust event were not simulated well by the model, a trend and an average concentration of PM_{10} from the simulation showed a reasonable pattern with *in-situ* measurement results.

Aerosol extinction coefficient corresponds to a vertical dense of PM as the sum of both absorption and scattering coefficients by atmospheric PM[7]. Finally, PM_{10} profiles from the simulation were compared with the profiles of aerosol extinction coefficients (km^{-1}) generated by Lidar measurement at KGAWO. In year 2001, Lidar measurement were limited within several times since Lidar instrument were installed in early March of year 2001 and needed times for calibrations. Therefore, under such the limitation, the study had selected two cases: the first corresponded to March 21 through 22 which was recorded as a Asian dust day and the second corresponded to April 4 which was recorded as a non-Asian dust.

2.3. Domain and Period

The modeling domain was defined as the latitude of 34.75-35.65°N and the longitude of 128.51-129.61°E (Fig. 2). This included Ulsan metropolitan, Masan, Changwon, and Milyang in view of an interaction with small cites close to Busan. Additionally, a domain center of 100 km × 100 km was located over Busan. As the total number of cells was 2500, the resolution of fine gridded cells in the defined domain was 2 km × 2 km. Fig. 2(a) shows not only the

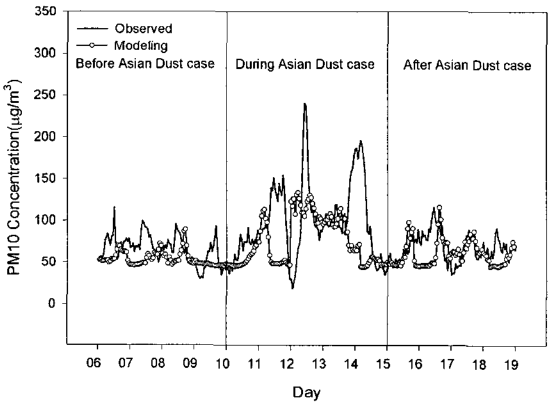


Fig. 3. Time series of PM_{10} concentration observed at 15 m above the ground over Kwangbokdong (line) and CALPUFF PM_{10} simulation results (circle and line) during 6-18 April 2001.

modeling domain but also the location of the meteorological stations generating the data requested by CALMET. Fig. 2(b) indicates land use and land cover category from USGS used in MM5 and CALMET.

The simulation periods were defined as April 6 through 18 of 2001, which was called as 'Super Dust Storm'. This period was subdivided into 3 cases: Before Asian dust Case (BAC) from April 6 to 9, During Asian dust Case (DAC) from April 10 to 14, and After Asian dust Case (AAC) from April 15 to 18 as shown in Fig. 3.

3. Results

During the non-Asian dust period, 1200 LST of BAC and 1800 LST of AAC illustrated higher concentrations than other times and most of the peaks in vertical profiles of PM_{10} were shown within 500 m below. The pattern had an increasing trend from the surface to the peak and showed a decrease after the peak up to 1000 m, which is usually estimated as the height of the Planetary Boundary Layer (PBL) (Fig. 4(a), (c)). In particular, there was no noticeable change in the vertical profiles of PM_{10} concentration above 1000 m. Therefore, it is enough to say that most of PM_{10} was concentrated near the surface during non-Asian dust period.

In contrast, for Asian dust events, the shape of concentration curve near the surface had a similar pattern to non-Asian dust cases except for 0600 LST. However, the vertical rapid change of PM_{10} concentration became weaker above 500 m and no rapid decrease above 1000 m was observed. It is also noticeable that curves above 1000 m indicated different concentrations with time. That it, the amounts of PM_{10} transported by Asian dust were enough to disturb a normal profile.

Fig. 5 illustrates a locality in the vertical profiles of PM_{10}. The central area corresponded around Busan, the western area corresponded to the region around Gimhae and Masan, the eastern area corresponded to East Sea of Korea, the southern area corresponded to South Sea of Korea, and the northern area corresponded to Yangsan (see Fig. 2(a)). In the eastern area, the profile not only was rarely changed with height but also was lower than the other area. This was caused by lower emissions. In contrast, the western area and the central area showed the highest concentration. This was considered to be caused by the higher emission rate and a complex terrain concerned with air ventilation.

The PM_{10} profiles shifted from left to right throughout all areas on DAC, which indicated a higher concentration. The difference of average PM_{10} concentration at a high level above 1000 m was

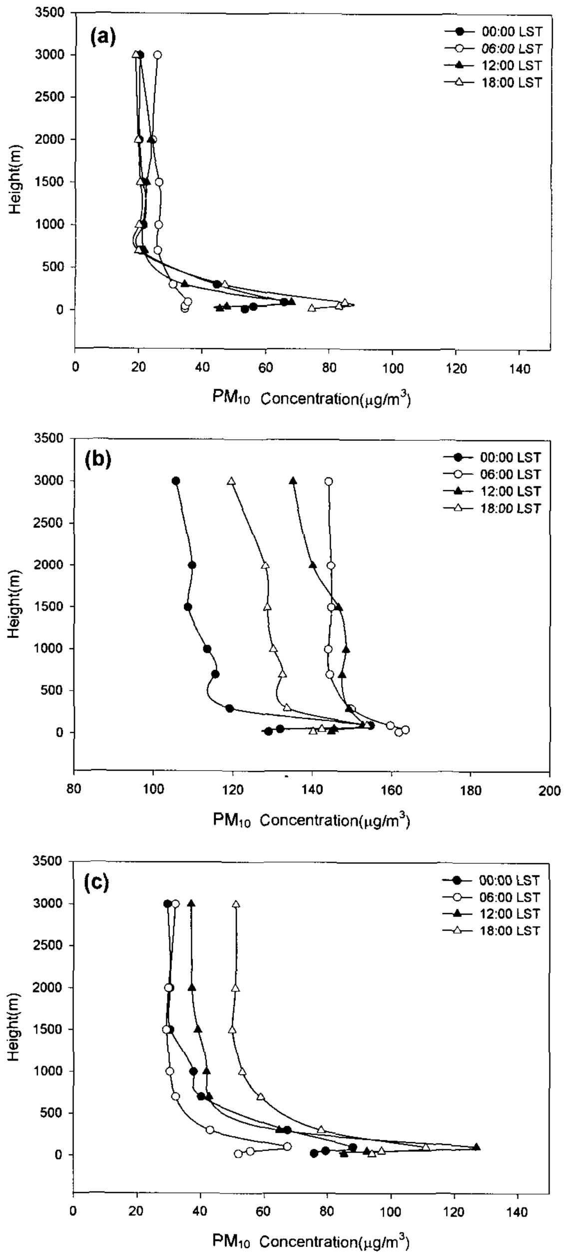


Fig. 4. Vertical distribution with the time of PM_{10} concentration simulated by CALPUFF: (a) the BAC, (b) the DAC, and (c) the AAC, respectively.

noticeable and various concentration patterns unlike the patterns of both BAC and AAC were recognized. In particular, the increased rate of lower level concentration was higher in western and central areas than others, and the vertical profile of the eastern area showed a similar pattern to the other DAC (Fig. 5 (b)). This means that Asian dust had a vertical and horizontal heterogeneous form.

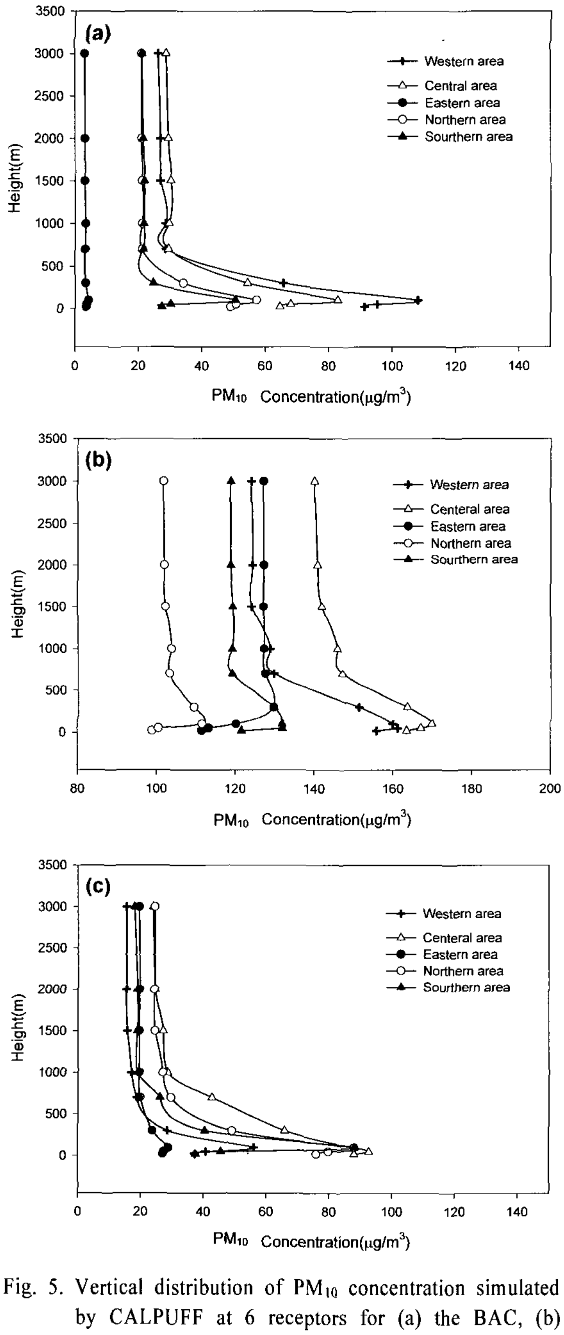


Fig. 5. Vertical distribution of PM_{10} concentration simulated by CALPUFF at 6 receptors for (a) the BAC, (b) DAC, and (c) the AAC, respectively; western area (Masan and Gimhae), central area (around 4 grids of Kwangbokdong), eastern area (East Sea), northern area (Yangsan), southern area (South Sea).

Fig. 6 shows the time series of the vertical aerosol extinction coefficiens measured at KGAWO on April 4, 2001 recorded as a non-Asian dust day. Fig. 7 is the same result except for in March 21 through 22, 2001 recorded as a Asian dust day. Under non-Asian dust, the peaks are below 500 m and rapidly decreases. Similarly, there was no noticeable change in the PM_{10} profile above PBL (1.5 km~) except for the second peak, which is shown as 2.5~3.0 km. It thought to be caused by cloud cover such a stratus or stratoculumus throughout the day. On the other hands, Lidar measurement during an Asian dust event showed similar vertical profiles of PM_{10} compared with

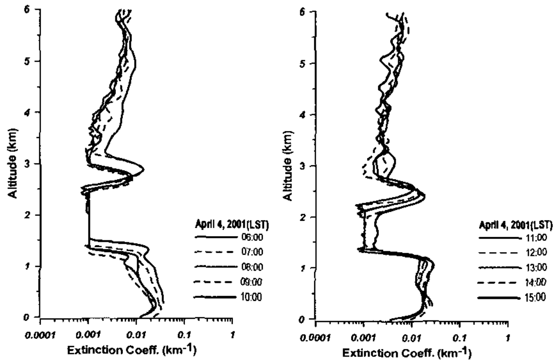


Fig. 6. Time series of vertical aerosol extinction coefficients measured by Lidar at KGAWO on April 4, 2001, recorded as non-Asian dust day.

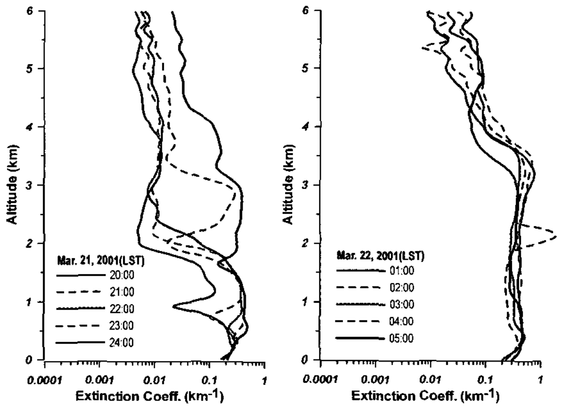


Fig. 7. Time series of vertical aerosol extinction coefficients measured by Lidar at KGAWO on March 21-22, 2001, recorded as Asian dust day.

those in DAC. Even though small peaks below 500 m were observed, no noticeable change above peaks or disturbed patterns in the PM_{10} profile were observed. It shows that the profile was shifted from left to right through all areas, which indicates highly dense PM_{10} in the atmosphere.

4. Conclusions

This research has focused on simulating and interpreting the change of the PM_{10} profile over Busan by Asian dust. The results are as follows:

• Daily variation of PM_{10} concentration before and after Asian dust showed a time dependant pattern located between from the minimum concentration of 50 μg/m³ and the maximum concentration of 100 μg/m³. However, these patterns were disturbed during Asian dust periods and showed irregular change.

• On vertical distribution of PM_{10}, most of the concentration peaks in the PM_{10} profile were shown within the level below 500 m. From the surface, the PM_{10} concentration rapidly increased to the peak at 500 m and rapidly decreased after the peak to be 1000 m around PBL. Then, no noticeable change in the profile was observed above 1000 m.

• During Asian dust, the shape of the vertical profile was similar to other cases of non-Asian dust days except for 0600 LST. However, there was no rapid change vertically and the vertical profile on 1200 LST and 1800 LST was noticeably shifted from left to right, which means PM_{10} had a vertically and horizontally heterogeneous form.

• Even though aerosol extinction coefficient acquired from Lidar measurement at KGAWO does not correspond to simulation periods in view of a quality of vertical profile of PM_{10} concentration, it is enough to say that the simulation result from CALPUFF might schematically sketch atmospheric PM_{10} profile before and after Asian dust periods.

Acknowledgments

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