SEASONAL VARIATION IN UPWIND AND DOWNWIND AREAS OF SEOUL, KOREA

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ABSTRACT

In order to investigate the exchange of atmospheric influence between Seoul proper and the neighboring area in the greater Seoul area, upwind and downwind areas of Seoul were determined by season. Four consecutive days were selected as the study period typical of each season on the basis of meteorological data in 1997. Mesoscale meteorology on the study period was reproduced by MM5 (PSU/NCAR Mesoscale Model) with horizontally nested grids. The meteorological field on the study area of 242 km x 226 km with grid spacing of 2 km was obtained by using the CALMET diagnostic meteorological model. Twenty-four hour upwind and downwind areas of Seoul were determined by calculating backward and forward trajectories, respectively, with u, v and w velocity vectors. The results showed that the upwind and downwind areas were extended to the northwest and the southeast, respectively, in spring and winter due to high wind speeds while they were restricted in the fringe of Seoul in summer and fall.

INTRODUCTION

The greater Seoul area (GSA), which has an area of 3,071 km^2, is crowded with 20 million people and 4.8 million cars. GSA covers only 3% of South Korea by the land, but its population and number of vehicles account for 46% and 40% of the total population and number of vehicles, respectively. Among them, half of people and cars reside within Seoul of 605 km^2, less than 20% of GSA.

Seoul proper and neighboring satellite cities are closely related by sharing the common airshed. Transboudary transport becomes more important with increasing secondary pollutants because of the time required atmospheric reactions, within GSA (across city boundaries) as well as in Northeast Asia (across national boundaries). In this work, the upwind and downwind areas of Seoul are determined by calculating backward and forward trajectories. The results will be useful for the development of air quality management plan by cities and provinces and for the design of monitoring network for ozone and other photochemical products.

METHODS

Four consecutive days typical of each season were selected by reviewing the meteorological data in 1997 in order to investigate seasonal variations as shown in Table 1. Precipitation days were excluded to avoid accompanied abrupt changes in meteorology. The year of 1997 had no particular meaning because it was tried to select typical days in each season. Nevertheless, comparison of the values in Table 1 with 30-year averages [1] revealed that wind speed was slightly lower except in spring, and temperature was generally higher. This difference was probably because precipitation days were not included in the study period and also probably due to changes in meteorology during the past 30 years.

Table 1. Meteorological conditions at the Seoul weather station during the study period in each season.

Season	Episode days (mm/dd)	Average wind speed (m/s)	Average temperature (^{o}C)	Precipitation (mm)
Spring	4/20-4/23	3.2	14.9	-
Summer	7/26-7/29	1.6	29.4	-
Fall	9/28-10/1	1.3	18.2	-
Winter	1/14-1/17	2.1	-1.8	0.0

Mesoscale wind field during the study period was reproduced with MM5 (PSU/NCAR Mesoscale Model) [2] with horizontally nested grids. The grid spacing was reduced from 108 km of Grid I to 36 km, 12 km, and 4 km of Grids II, III, and IV, respectively. The reanalysis data at 6 hour interval with grid spacing of 2.5^{o} x 2.5^{o} was used for initial and boundary values. Refined wind field with grid spacing of 2 km for the domain of 242 km x 226 km (Figure 1) was obtained using the CAMET diagnostic meteorological model [3]. The output from MM5 on Grid IV was used as an initial guess. Observed data from 35 surface weather stations (SWS) and 172-187 automatic weather stations (AWS) as well as 2-3 upper air stations over the southern part of the Korean Peninsula were used as observations. There were six layers up to 1,500 m with 10 m at the ground in the CALMET wind field while there were 23 layers to 100 hPa in the MM5 wind field.

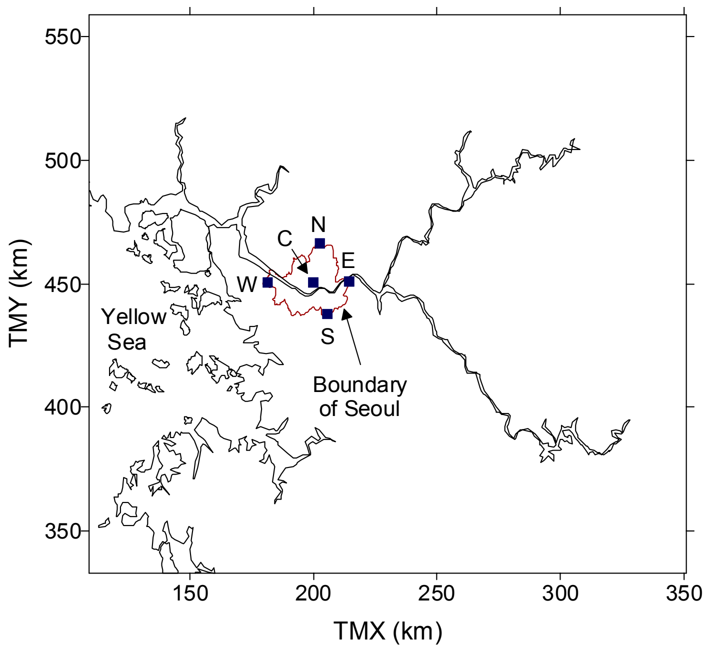

Figure 1. Origins of the trajectories for determining upwind and downwind areas of Seoul. C, N, E, S, and W denote the center, north, east, south, and west of Seoul, respectively.

While isentropic calculation is common in the regional scale trajectory analysis, trajectories were calculated every second with u, v, w velocity vectors. A trajectory was started at 10 m height, two times a day, 0900 and 2100 LST, from five locations, C, E, W, N, and S, within and around Seoul as shown in Figure 1. The upwind area was determined by identifying the location of backward trajectory for 24 hours for three days. For example, in spring, backward trajectories were started on April 21, 22, and 23, and their locations on April 20, 21, and 22 were identified. The downwind area was similarly determined by identifying the location of forward trajectory for 24 hours. In spring, trajectories were started on April 20, 21, and 22.

RESULTS

Figure 2 shows selected wind fields at the ground in each season obtained with CALMET. By using the wind data from AWS where local influences were strong [4], the terrain effects were distinct on the mountainous area in the east in contrast to high wind speeds over the sea especially at night in summer (7/27 21:00). In addition, since the wind speeds from AWS were generally lower than those from SWS that were for observing the regional scale variations, wind speeds in Figure 2 were also lower than those with MM5 alone.

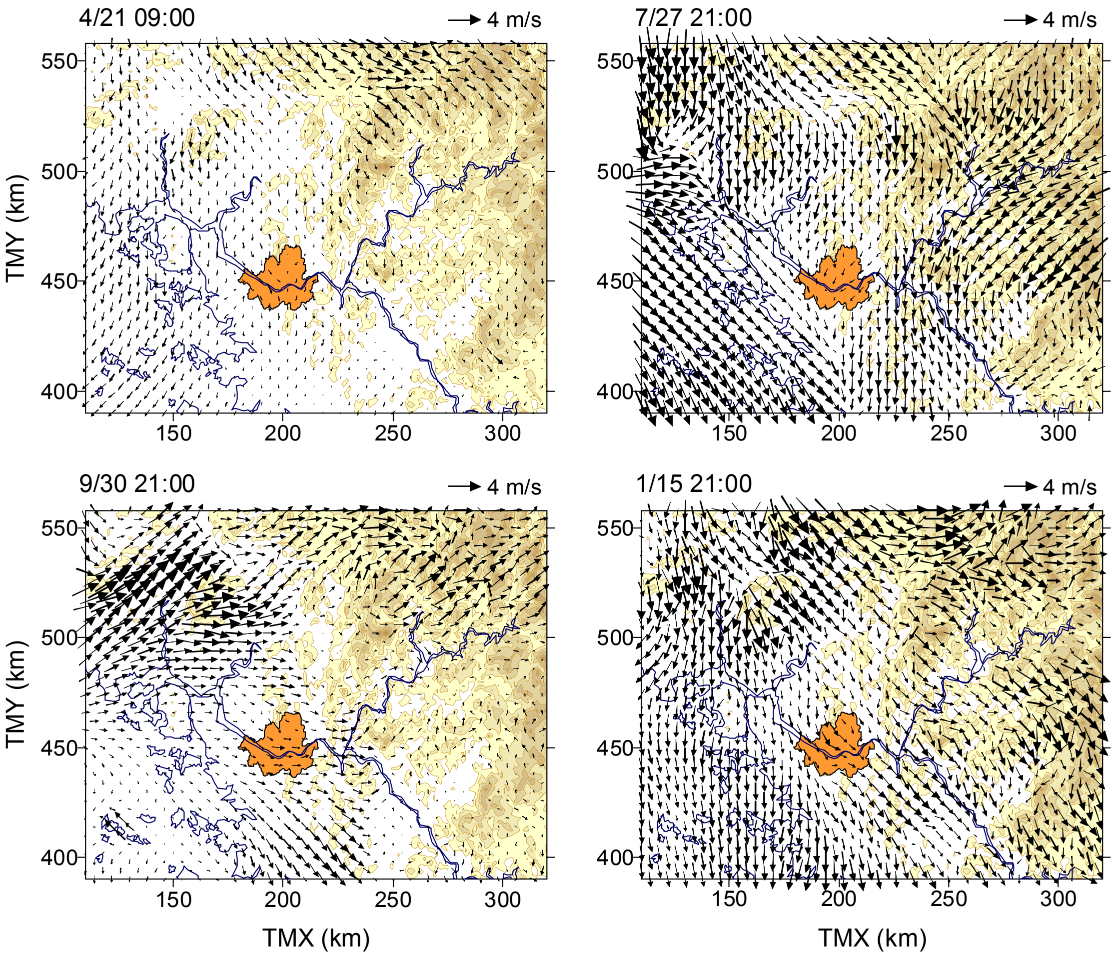

Figure 2. Selected wind fields at the ground in each season, obtained with CALMET. Because of high density of grid points, velocity vectors are shown at every four grid points. Shaded area in the middle denotes the area of Seoul. Filled contours on the background represent topography at 200 m intervals.

Figure 3 shows backward trajectories starting from the center of Seoul. Since trajectory was calculated two times a day for thee days, total six trajectories were shown. Scattering of trajectories in spring and winter indicates fast movement of air mass along with high wind speed. High density of trajectories in small area in fall represents slow movement of air mass due to low wind speed. In winter most of trajectories come from the northwest because of strong synoptic wind while in summer diverse directions of trajectories imply various changes in wind direction.

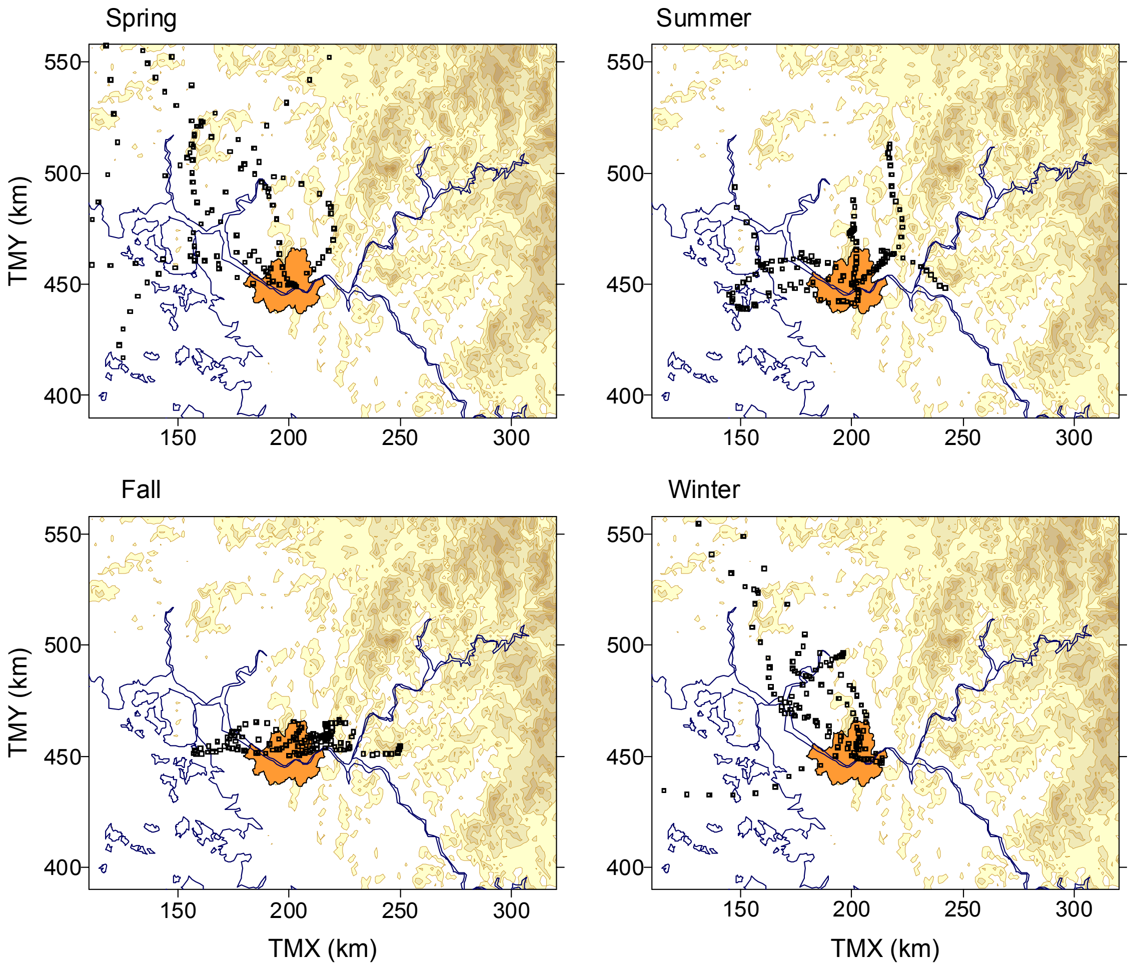

Figure 3. Backward trajectories for 24 hours starting from the center of Seoul. The location of trajectory is shown at one hour intervals.

Overall features of the forward trajectory were similar to those of the backward trajectory. However, since the trajectory was generally heading southeast to the mountainous area, it was more influenced by topography.

The traveling distance was generally less than 100-120 km. As was mentioned, the trajectory was started at 10 m height. Variation in height was not large in most cases, within 1-2 m probably because of short transport time. Sometimes backward trajectories approached below the starting level, indicating a possible uptake of emissions at the ground. On the other hand, in summer, forward trajectories resided within Seoul and in the nearby area and moved upward being separated from the direct influence from the ground.

The upwind and downwind areas determined in the present work are given in Figure 4. Please note that the upwind and downwind areas were determined by the final location of backward and forward trajectories, respectively. Because the trajectory was started at five locations as shown in Figure 1, total sixty locations (five locations x three days x two times x backward/forward) should appear in Figure 4. However, in spring, only eleven locations are shown in the upwind area. It means that other 19 locations are located outside of the domain due to strong winds, and this is why the area is opened.

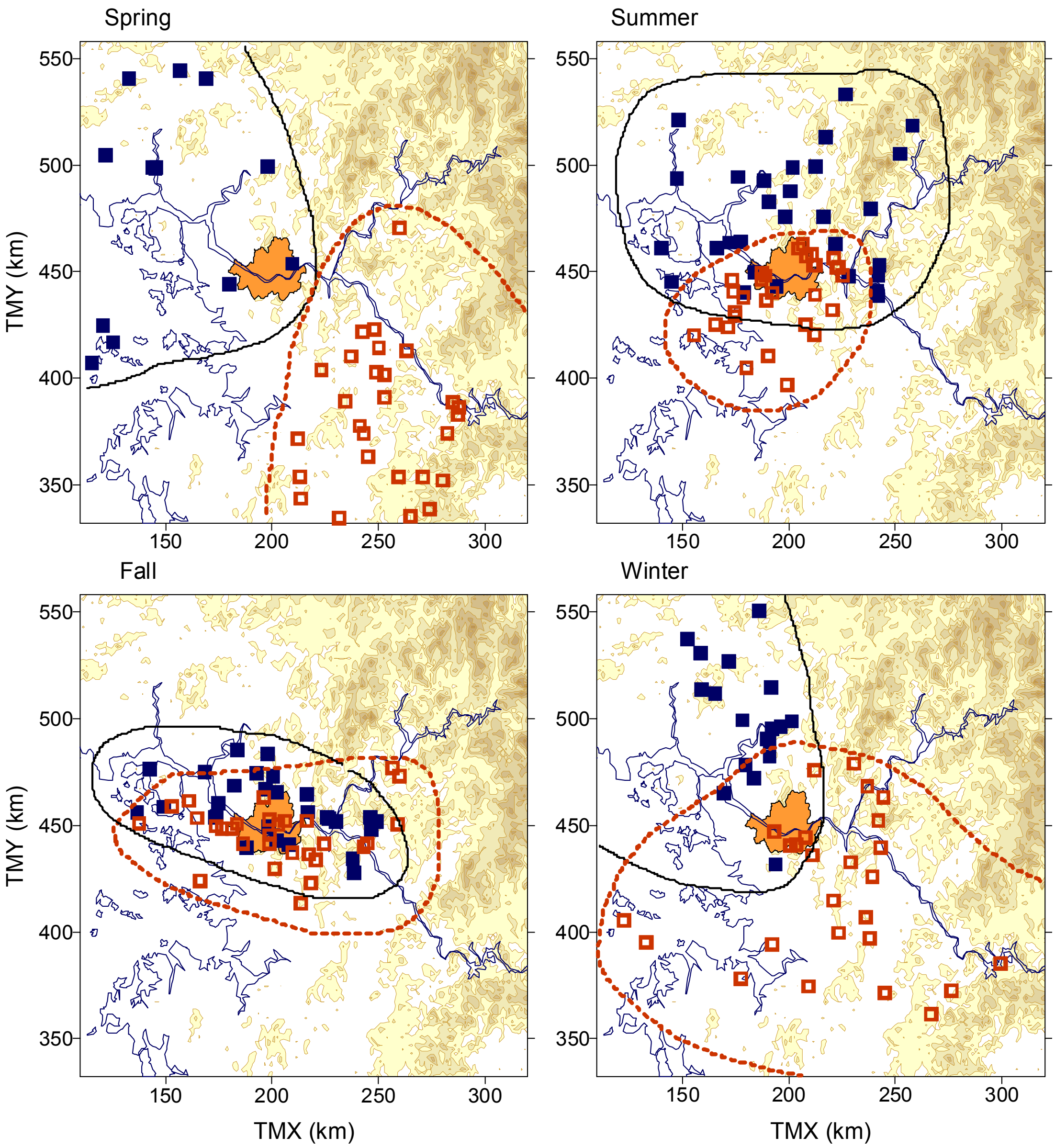

Figure 4. Upwind and downwind areas of Seoul. Solid and open symbols denote the locations of backward and forward trajectories before and after 24 hours, resepctively. Thin solid line and dotted line surrounding the symbols denote the decided upwind and downwind areas, respectively.

In spring and winter, the areas align from northwest to southeast associated with prevailing northwesterly winds. As mentioned, their shapes are longish parabolic due to relatively high wind speeds. In summer and fall, the areas are located from north to south; their shapes are closed and elliptic due to low wind speeds. Basically, the shape and location of upwind and downwind areas are symmetric in spite of some differences in the location and shape. Only the downwind areas to the east and northeast are limited due to the complex terrain and wind variation over it.

DISCUSSION AND CONCLUSIONS

The upwind and downwind areas of Seoul were determined with a refined wind field in order to understand the exchange of atmospheric influence between Seoul and the neighboring cities near the ground.

In summer and fall, local emissions were more important than the transport across the city boundaries. This was particularly true in fall in which average wind speed was the lowest. Nevertheless, in summer, concentrated downwind influence from Seoul was resulted on the small area to the south including Seoul. Furthermore, in summer, forward trajectories moved up, and thus would retain a high level of ozone without mixing with fresh NO if photochemical reactions were active.

In winter and spring, air mass easily came in from the northwest over the sea, but was restricted in the downwind area due to complex terrain. Therefore, if air mass contained pollutants, its effect could be maximized whether they were from the Asian Continent or incorporated from the coastal area in the west. The latter would be more significant since trajectories sometimes approached along lower levels in the upwind area and thus easily took emissions from the ground.

ACKNOWLEDGMENTS

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