14.4 NUMERICAL SIMULATION OF AIR POLLUTION OVER KANTO AREA IN JAPAN USING THE MM5/CMAQ MODEL

- COMPARISON OF AIR POLLUTION CONCENTRATION BETWEEN TWO DIFFERENT CLIMATIC DAYS -

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1. INTRODUCTION

Urban air pollution is still an important recognized environmental problem. The primary pollutants, such as NOx, VOC, are the emissions from the industrial facilities, motor vehicles and heating systems. These emissions contribute to the formation of secondary pollutants like ozone and other oxidants through complex photochemistry in the atmosphere near ground level. The significant decrease of air pollution concentration is not observed in recent years though there are severe environmental standards. Due to the rapid increases in land covering and artificial heat release, the effects on the urban climate is very evident. It is found that meteorological factors, such as temperature, wind, precipitation, cloud, fog especially urban heat island (UHI), have close relationships with the air pollution concentrations.(Chao, 1990; Cuhadaroglu, et al, 1977; Escourrou, et al, 1990; Miyazaki, et al, 1991; Lacour, et al, 2006;). Conversely, atmospheric pollution also has important effects in modifying urban climate in various ways such as by increasing long-wave radiation from the sky in the canopy layer, and increasing absorption of short-wave radiation in the boundary layer. It is found that UHI can raise the rate of chemical reaction between nitrogen oxides (NOx) and Volatile Organic Compounds (VOCs), this lead to significantly increase surface ozone concentrations in city areas(Dewent, et al, 2003). In this paper, we would like to investigate influence of climatic change on the atmospheric pollution over Kanto area in Japan using two case studies; (1) simulation period with mild weather, and (2) the period that it's the hot and clear weather pattern associated with climatic change.

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2. MODLE DESCRIPTION

2.1 Meteorology model

The Fifth-Generation NCAR / Penn State Mesoscale Model (MM5) version 3.7, a limited-area, nonhydrostatic, terrain-following sigma-coordinate model(Dudhia, et al, 2005), is used in this research to provide spatial and temporal distribution of meteorological fields to the air quality model. It has some characteristic such as: (i) a multiple-nest capability, (ii) nonhydrostatic dynamics, which allows the model to be used at a few-kilometer scale, (iii) multitasking capability on shared- and distributed-memory machines, (iv) a four-dimensional data-assimilation capability (FDDA), and (v) more physics options.

2.2 Air Quality modeling

The Community Multi-scale Air Quality (CMAQ) modeling system version 4.6 developed by Environmental Protection Agency (USA), which was released in 2006, was used in this study. It is a multiple scale and multiple pollutant chemistry-transport model that includes all the critical science processes such as atmospheric transport, deposition, cloud mixing, emissions, gas- and aqueous-phase chemical transformation processes, and aerosol dynamics and chemistry. The CMAQ system can simulate concentrations of troposphere ozone, acid deposition, visibility, fine particulate and other air pollutants in the context of "one atmospheric" perspective involving complex atmospheric pollutant interactions on regional and urban scales.

3. ANALYSIS OUTLINE

3.1 Analysis domain

In this study, the MM5 simulation was performed with 3 nested domains (Fig 1). Detail configure of

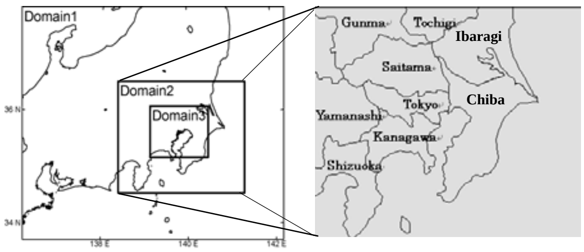


Fig.1 Analysis domain

Table 1 : Analysis size domains and grid resolution

	Computation domain (X[km] x Y[km])	Grid number	Horizontal resolution (km)
D1	450x540	51x61x23	9
D2	216x261	73x88x23	3
D3	99x120	100x121x23	1

model is summarized on Table 1. The 3 domains cover a region of Kanto with grid resolutions of 9 km, 3 km, and 1 km, respectively. The second domain size is 73x88 grid points and the third domain is 100x121 grid point. All of the domains have 23 vertical sigma levels from the surface to the 100-hPa level.

3.2 Model configuration

In this study, the physic options in the MM5 simulation are following: Grell cumulus parameterization scheme(Grell, et al, 1994); MRF planetary boundary layer scheme(Hong, et al, 1996); explicit simple ice microphysics(Hsie, et al, 1984); cloud-radiation scheme(Dudhia, 1989) and FDDA. The cumulus parameterization scheme is not used for the 3 and 1-km domains. The CMAQ was configured with the following options: (1) CB-IV speciation with aerosol and aqueous chemistry; (2) the Piecewise Parabolic Method for both horizontal and vertical advection; (3) eddy vertical diffusion; (4) photolysis; (5) no Plume-in-Grid; (6) the EBI chemistry solver configured for CB-IV; (7) use of the 3rd-generation aerosol model; (8) use of the 2nd-generation aerosol deposition model; (9) use of RADM cloud model; (10) 16 vertical layers. More detailed description of the scientific mechanisms and implementations of CMAQ can be found in Byun and Ching(Byun and Ching, 1999).

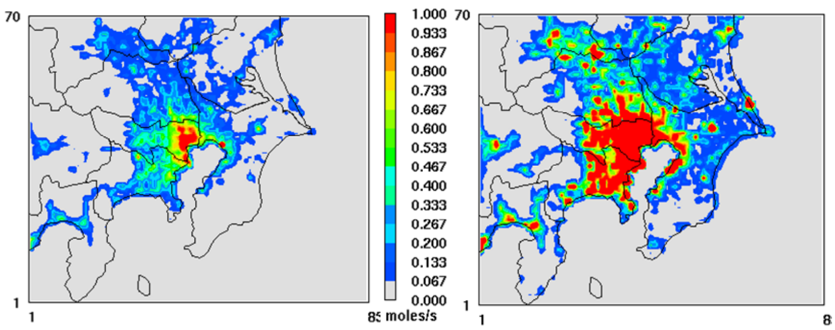
3.3 Study period and simulation conditions

In this study, the MM5 simulation is done 96 hours with two periods: (1) with the mild weather, starting from 09 JST July 19 to 09 JST July 23, 2005; and (2) with the hot weather pattern associated with UHI event over Tokyo area, starting from 09 JST August 03 to 09 JST August 07, 2005. A meteorological condition with weak surface wind and high temperature in August case is favorable for photochemical production of ozone. Global meteorological data (FNL) from NCAR with horizontal resolution of 1^0x1^0 was used to provide initial and boundary conditions for MM5 model and FDDA process. Hourly emission data used here are the horizontal 3km x 3km emission estimated by Hayami et al.(Hayami, et al, 2004) (Fig 2). After MM5 simulation finishing, the same simulation periods have been run for CMAQ model in domain 1. The initial condition for domain 1 was derived from the simulation results of the East-Asia region by Hayami (Hayami, et al, 2004). The boundary condition was derived from the observation report of Japan Clean Air Program (JCAP, 1999). Finally, output of CMAQ model in domain 1 used to produce initial and boundary condition for CMAQ model in domain 2 with two periods from 00 JST on 20 to 00 JST on 23 July and from 00 JST on 04 to 00 JST on 07 August.

4 RESULTS AND DISCUSION

4.1 Validation of MM5 simulation

In order to validate the simulation of MM5 model, we compared the 2m temperature and 10m wind velocity with measured data at some stations in Kanto area; Ebina(Kanagawa),Kumagaya(Saitama),Kofu(Yamanashi), Nerima(Tokyo), Hachiouji(Tokyo), and Fuchu (Tokyo), which are shown in Fig.3. The comparison results of the temperatures are shown in Fig.5 and Fig.6, MM5 simulate well its diurnal variation in all prediction periods (0-72h) at all stations. On the other hand, the minimum temperature intends to overestimate on the hot day (August). For wind



NOx NMVOC

Fig. 2 Hour emission data for CMAQ at 14 JST August 6 (mole/s/grid)

Fig.3 Monitor stations used for MM5 validation

Fig.4 Monitor stations used for CMAQ validation

velocity, in Fig.7 and Fig.8 we can see the MM5 model simulations agree well with measured data in term of diurnal variation, but the MM5 does not simulate small variation of observed wind velocity. This may relate to parameterization of boundary layer in model.

4.2 Validation of ozone concentration

In this study, the results from the CMAQ model were compared with measured data from 10 air quality monitoring stations located within the Tokyo city; Shinjuku, Setagaya, Nerima, Hachiouji, Fuchu, Machida, Tamashi, Nishi-Tokyo, and Shinagawa, which are shown in Fig.4. Fig.9 and Fig.10 show the ozone time series comparison between the CMAQ simulation and observations at some monitoring stations for the case of July and the case of August. Generally, simulated O3 concentration tendency showed good agreement with observations in July. The peak ozone concentration is well simulated. For the case of August, on, the peak ozone concentration is, however, underestimated. One reason may relate to calculating of the vertical diffusion coefficient in the MM5 model.

Moreover, there are other various possible factors which could also cause these discrepancies such as meteorological condition predicted by MM5, initial and boundary conditions for O3, NOx and VOC, and emission data, chemical and meteorological parameters in MM5/CMAQ model. This will be investigated in the next work.

4.3 Ozone concentration

Fig.11 shows the spatial distribution of the 2m temperature and 10m wind from MM5 simulation in domain at 14 JST. In the case of July, the temperature is low and the northeasterly wind is strong, most of Kanto area was dominated by easterly and northeasterly winds. For the case of August, the weather pattern associated with UHI event, we can see the region of temperature higher than 34 ^{o}C cover Tokyo metropolitan at 14 JST on August 6 and the horizontal wind speed is a little weak. This meteorological situation supports the development of a sea breezes circulation, therefore the atmospheric pollution in the northern cities of Kanto area will be strongly influenced by UHI event. This difference in meteorological condition between two above mentioned periods can influence on atmospheric pollution over Kanto area. The Fig.12 is the spatial distribution of hourly O3 concentration predicted by CMAQ model at 14 JST on July 22 and at 14 JST on August 6. The result showed that atmospheric pollution concentration under hot and clear weather condition is higher than that under mild condition (July 22) and the area with high O3 concentration in August is also larger. In the case of July, because of the northeasterly wind, O3 concentration is diffused to the southwestern part of Kanto. It was found the area higher 80 ppbV in Shizuoka. In the August, however, it was found that a high O3 concentration area covers almost the northwestern part of Kanto due to transition of the south and southeastern flow predicted by MM5. Because of this wind direction, some cities in the northern such as Saitama, Gunma, and Tochigi have O3 concentration very high (more than 90 ppbV). Comparison of averaged O3 concentration simulation of some areas (average ozone concentrations of these areas) between the case of July and the case of August is illustrated on Fig.13. From this picture we can see O3 concentration remarkably increases on the hot day (August 6) comparison with that on the mild day (July 22) during afternoon time (11:00 JST – 17:00 JST). The difference of O3 concentration can reach 10 ppbV.

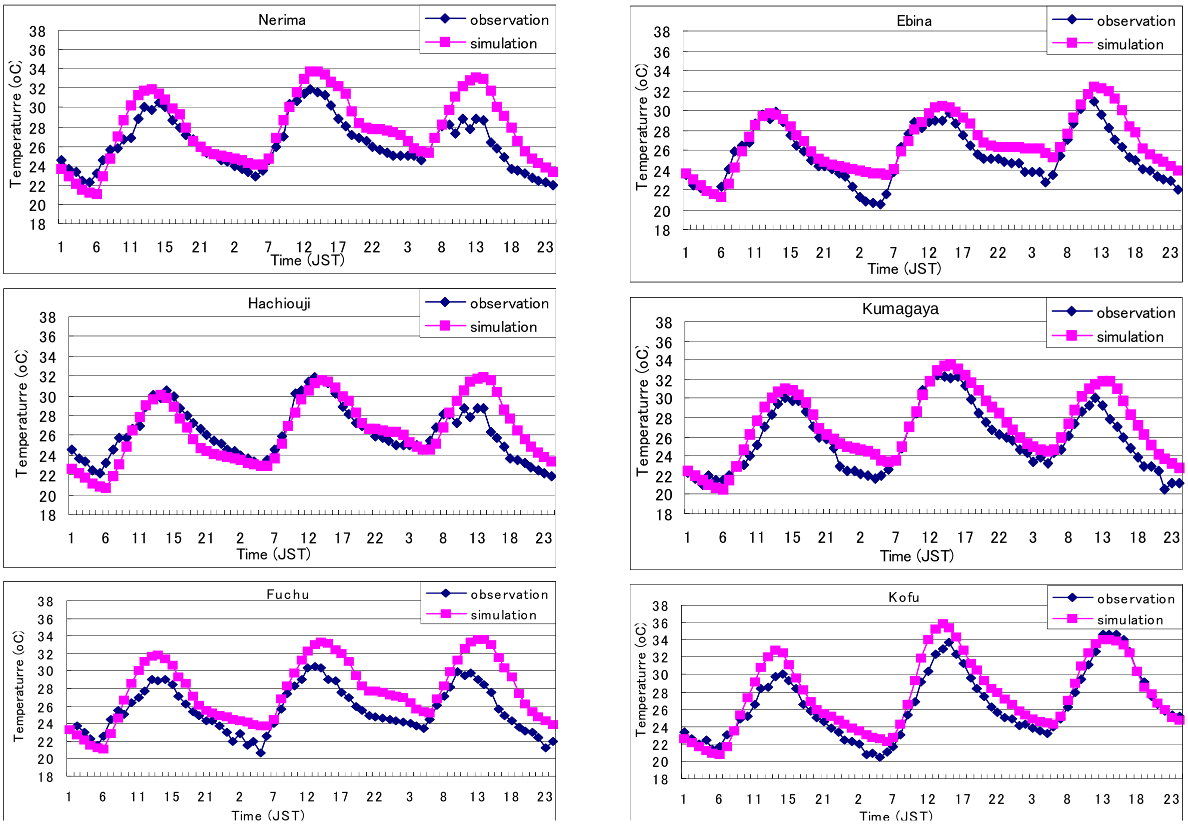


Fig. 5 Temperature (2 m height) variation of observation and simulation during 20-23 July 2005 at some stations

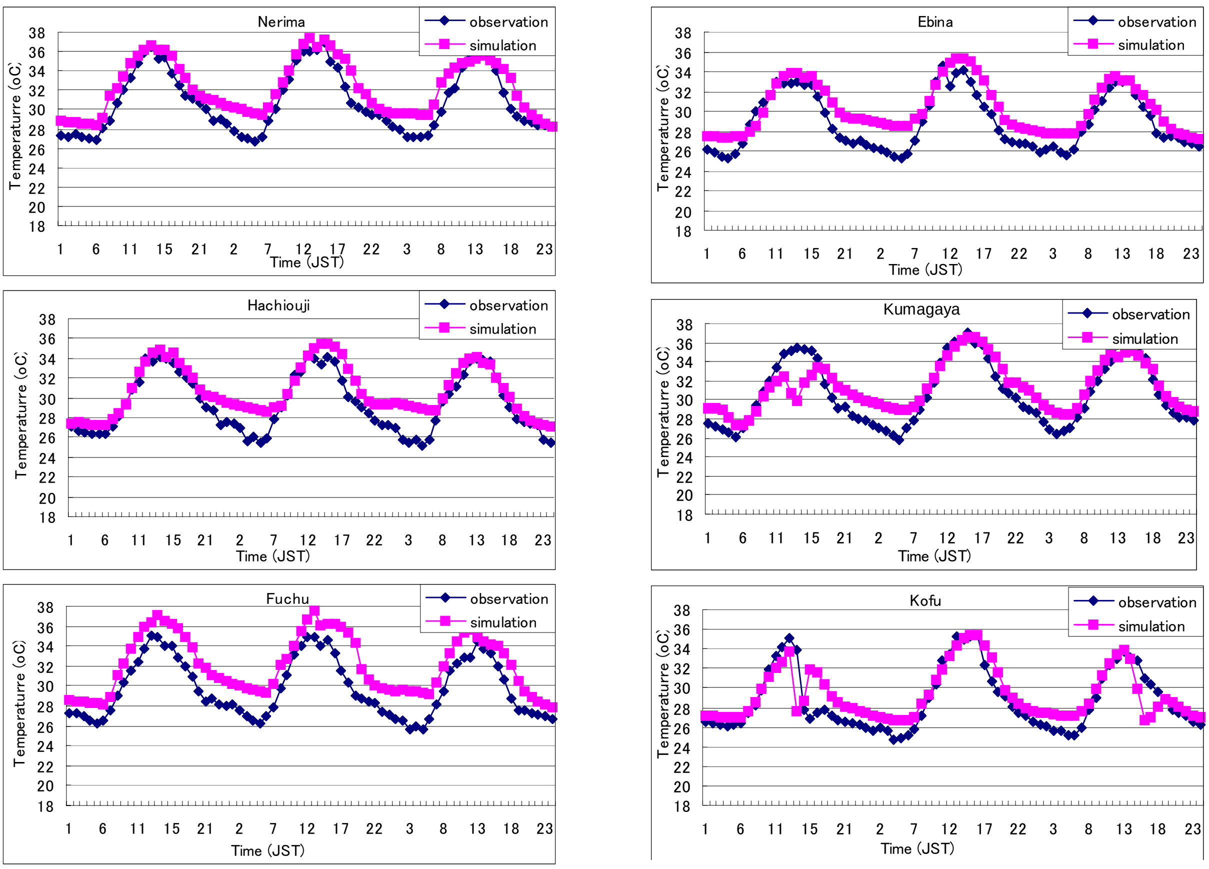


Fig. 6 Temperature (2 m height) variation of observation and simulation during 4-7 August 2005 at some stations

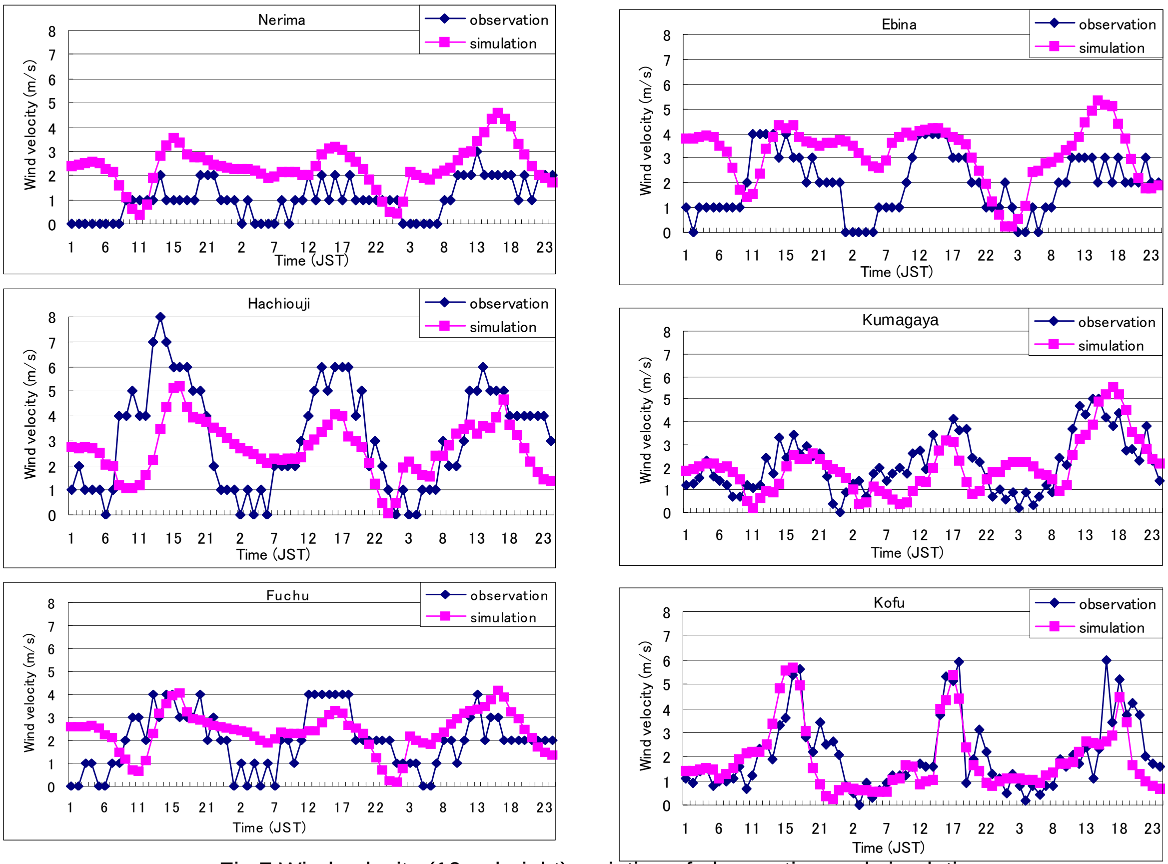


Fig.7 Wind velocity (10 m height) variation of observation and simulation
during 20-23 July 2005 at some stations

Fig.8 Wind velocity (10 m height) variation of observation and simulation
during 4-7 August 2005, at some stations

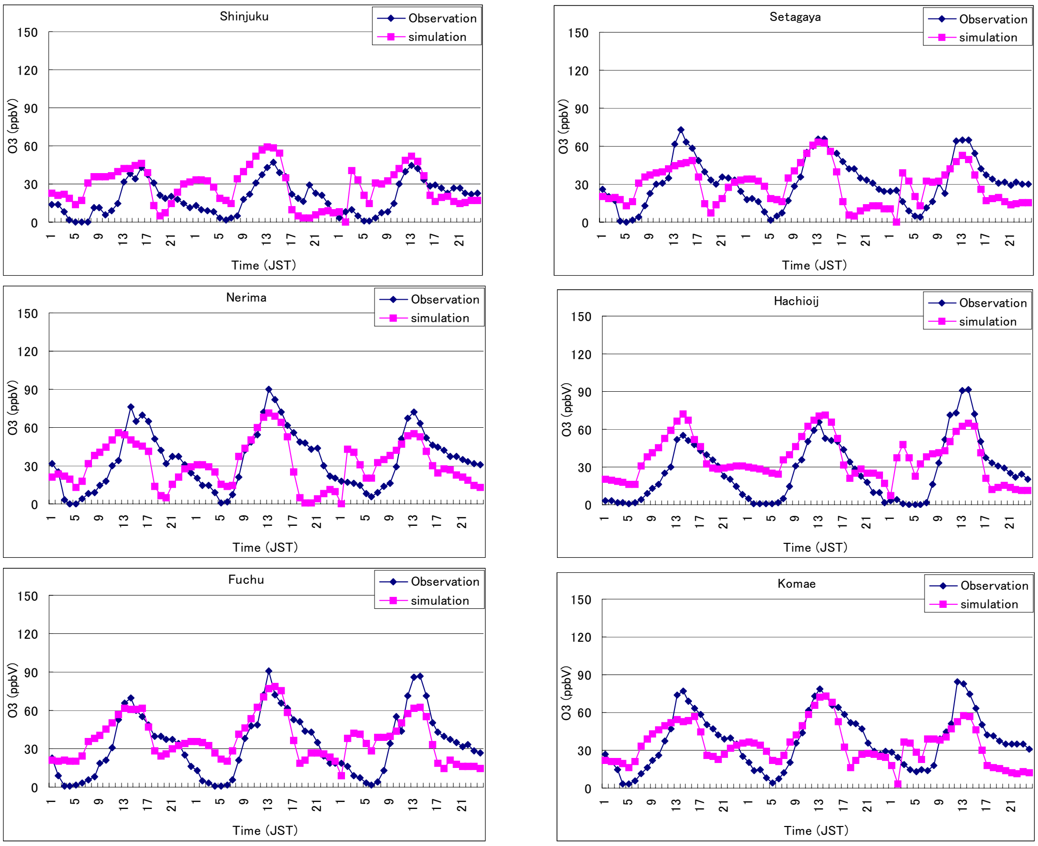


Fig.9 Ozone time series variation of observation and simulation at some stations during 4-6 August 2005

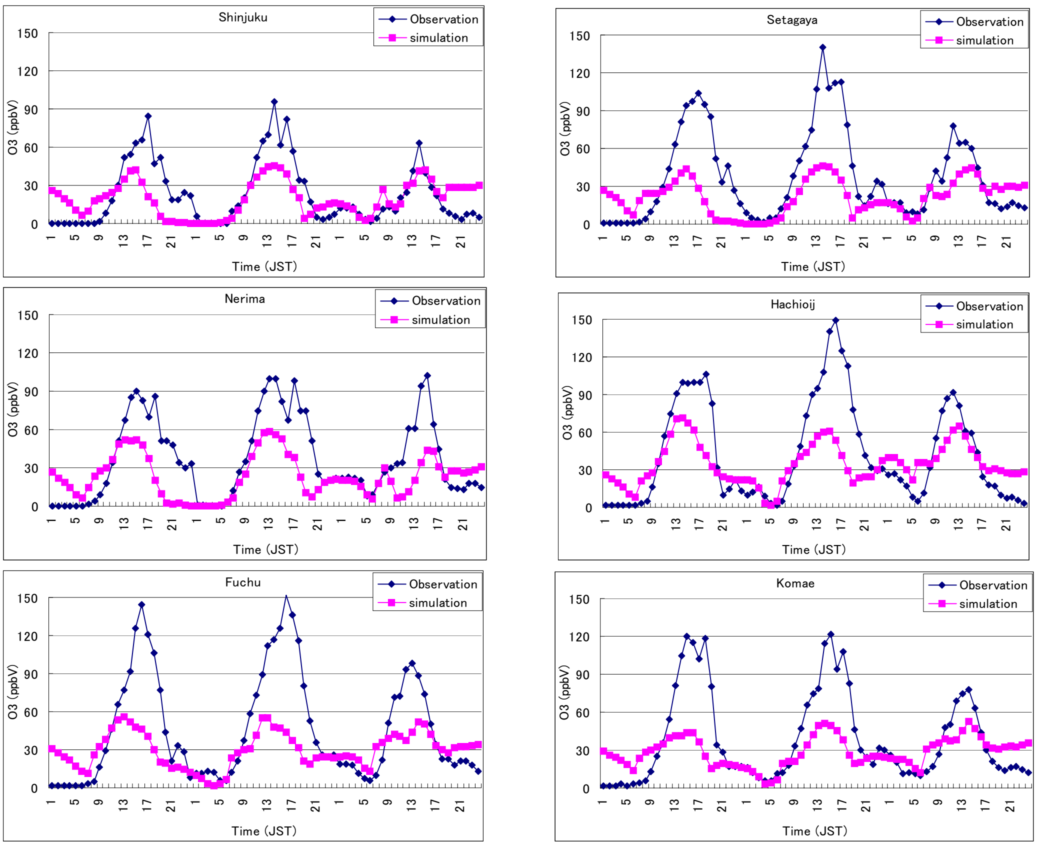
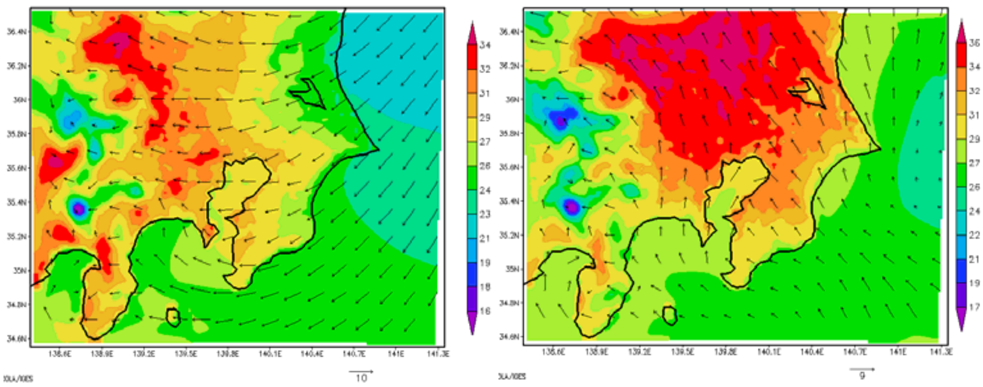
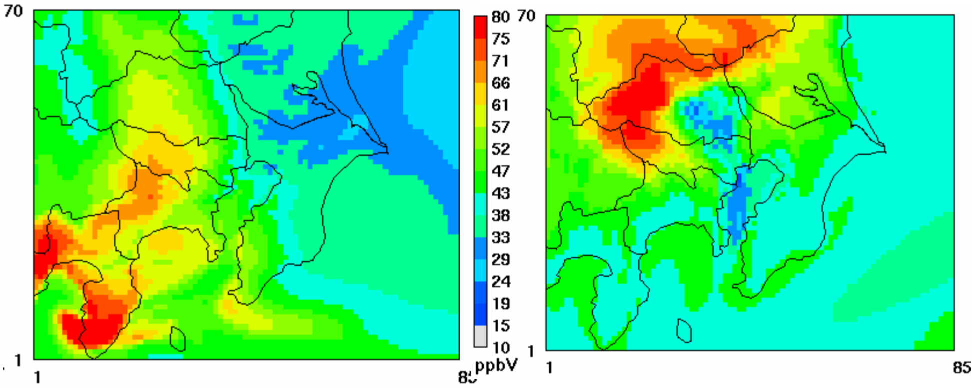


Fig.10 Ozone time series variation of observation and simulation at some stations during 20-22 July 2005



July 22 August 6

Fig.11 The MM5 simulated Temp (^{o}C) & wind in D2 at 14 JST



July 22 August 6

Fig.12 The CMAQ simulated Ozone concentration (ppbV) in D2 at 14 JST

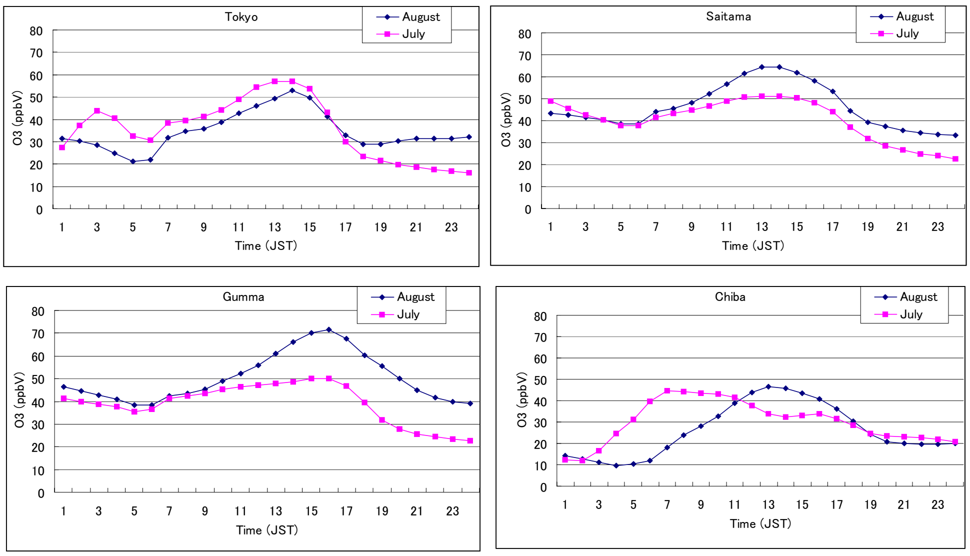


Fig.13 Comparison of averaged O3 simulation between mild day and hot day

6. CONCLUSIONS

The MM5/CMAQ model applied to simulate influence of urban climatic change on atmospheric pollution. In general, CMAQ simulated O3 concentration showed a good agreement with the observation for both two periods. The results indicate that the high temperature and weak wind speed under UHI event lead to significantly increase averaged O3 concentration of Tokyo city. Compare with mild day, the O3 concentration in hot and clear day can increase 10 (ppbV) at Tokyo city. From this research, it is said that effect of UHI event on atmospheric environment is very significant.

However, the peak O3 concentration is lower than observation for the August case. Some reasons which could cause these discrepancies such as meteorological condition predicted by MM5, initial and boundary conditions for O3, NOx and VOC, emission data and so on, these factors also need to be considered in generation and distribution of O3 concentration.

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