The spatial distribution of ozone concentrations in the Kansai region, Japan obtained from MM5/CMAQ simulation

Minori Sakamoto*, Fumihisa Seto, Akira Kondo, Shrestha Kundan lal, Akikazu Kaga, Yoshio Inoue
Osaka University, Osaka, Japan

Abstract
In this study, We investigated the spatial distribution of ozone concentrations in the Kansai region, Japan using numerical analysis technique (MM5/CMAQ system) and simple measurement technique (passive sampler), in order to estimate them in areas without monitoring stations. As a result, the ozone concentrations became high by order of May > September > July > December. These results were in good agreement with monitoring data. The transport of air pollutants from the Asian continent may cause the increases of ozone concentration in spring (May). The numerical analysis showed that the ozone concentration was lower on the Seto Inland Sea and was higher in the inland region. The measurement by Passive Sampler also showed that the ozone concentration was higher in the inland region.
Key words: ambient ozone concentration, MM5/CMAQ, passive sampler

1. INTRODUCTION

In Japan, the ambient ozone concentration gradually increased in recent years. The high concentrations of ozone are observed not only in the urban areas but also in the surrounding areas. It suggests the spread of photochemical air pollution to rural areas. In Hyogo Prefecture, the ozone concentrations are measured at monitoring stations. However, since most monitoring stations are located in urban areas (especially near the Seto inland coast), the ozone concentrations all over the Hyogo prefecture are not completely known. On the other hand, in recent years, the numerical technique has been developed and the predictive accuracy has been improved. Therefore the purpose of this study is to investigate the spatial distribution of the ozone concentration all over Hyogo prefecture, Japan by MM5/CMAQ system. The measurement of ozone concentration by passive sampler was performed at 10 sampling sites during the same period.

2. NUMERICAL ANALYSIS

2.1. Outline of numerical analysis

The MM5/CMAQ system was used in this study. The MM5 is a limited-area, non-hydrostatic and terrain-following sigma-coordinate model designed to simulate or predict mesoscale and regional-scale atmospheric circulations (Dudhia et al., 2005; Grell et al., 1995). The CMAQ is an Eulerian-type air quality model that simulates concurrently the atmospheric and land processes affecting the transport, transformation and deposition of air pollutants and their precursors, on both regional and urban scales. (Byun et al., 1999) The MM5 initial and boundary conditions are derived from Final analysis data of NCEP for the wide area covering East Asia and from GPV-MSM data for the Japan region. The emission data are provided by EAGrid2000-JAPAN (Kannari et al., 2007) for the Japan region. SAPRC99 gas-phase chemistry mechanism (Carter, 2000), AERO4 aerosol module and RADM aqueous phase chemistry (Chang et al., 1987) are used for the CMAQ. About the East Asia, the emissions in 2008 were estimated using the consumption of the primary energy of each country based on the BP Statistical Review of World Energy June 2008 (BP, 2008). About Japan area, they were estimated using the measurement data of the roadside air pollution monitoring station in Hyogo Prefecture.

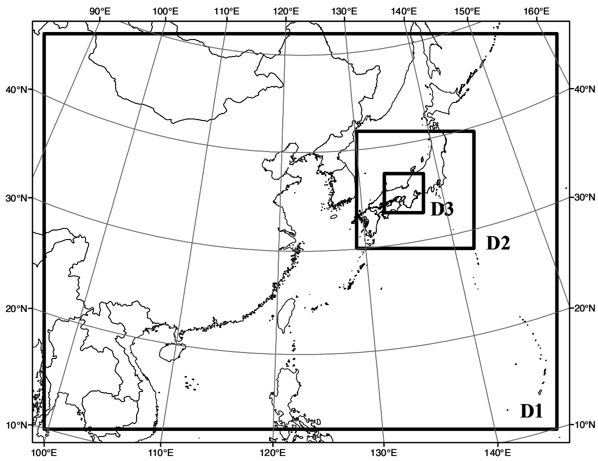

Fig. 2.1 Nesting of model domains

Table 2.1 Model grid specifications

	MM5			CMAQ		
Domain	1	2	3	1	2	3
x-grid	118	85	85	105	72	72
y-grid	94	85	85	81	72	72
grid size[km]	54	18	6	54	18	6

2.2. Area and period for simulation

The simulation domain is shown in Fig. 2.1. The domain consists of D1, D2 and D3. The number of meshes and grid size of each domain are shown in Table 2.1.The simulation period is shown in Table 2.2.

Table 2.2 Simulation period

	Start	End
May(spring)	Apr. 28, 2008	Jun. 2, 2008
July(summer)	Jun. 30, 2008	Aug. 4, 2008
September(autumn)	Sept. 1, 2008	Sept. 29, 2008
December(winter)	Dec. 1, 2008	Jan. 5, 2009

3. MEASUREMENT OF OZONE CONCENTRATION By PASSIVE SAMPLER

Monthly ambient ozone concentrations were measured for one year using the Ogawa passive sampler in Hyogo Prefecture. The sampling sites are shown in Fig.3.1. Ten sampling sites were selected from each grid divided into 10km mesh. The sampling period is from April 2008 to March 2009. The ozone concentration was analyzed by using ion chromatography.

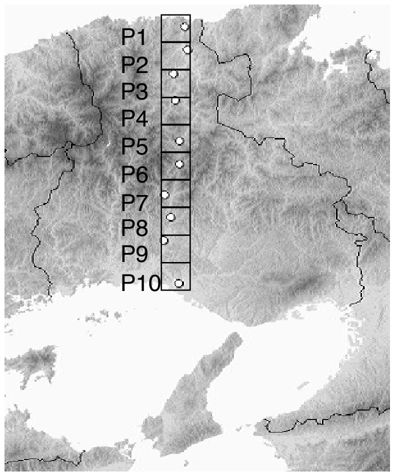

Fig.3.1 The sampling sites

4. RESULT AND DISCUSSION

4.1. Result of MM5 Simulation

The observation data of three monitoring stations in Hyogo Prefecture, Kobe (latitude 34.69, longitude 135.21, Fig.4.1 W1), Toyooka (latitude 35.54, longitude 134.82, Fig.4.1 W2) and Himeji (latitude 34.81, longitude 134.68, Fig.4.1 W3), were used for the verification of the simulation accuracy. The accuracy of temperature and wind speed were estimated by the technique of Emery et al. (2001). The following statistical indicators of accuracy were used: Mean Bias Error (MBE), Mean Absolute Error (MAE), and Root Mean Square Error (RMSE). The simulated mean temperature T_{sim} and wind speed WS_{sim}, the observed mean temperature T_{obs} and wind speed WS_{obs}, R (Correlation Coefficient), MBE, MAE, and RMSE are shown in Table 4.1.

As an example, the time series of temperature in May of at Himeji is shown in Fig.4.2.

The results were able to reproduce the observed temperature better than the observed wind speed. The simulated temperature tend to be lower than the observed one. The simulated wind speed tend to be larger than the observed one.

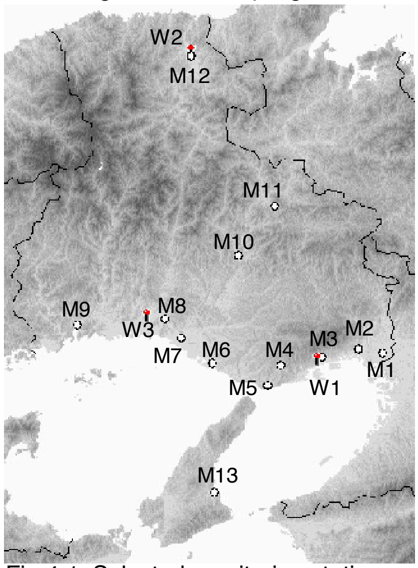

Fig.4.1 Selected monitoring stations

4.2. Result of CMAQ Simulation

The monthly mean ozone concentration in May, July, September and December of D3 are shown in Fig.4.3. The mean ozone concentrations in Hyogo Prefecture tend to be higher in the inland region than around the Seto Inland Sea coast. The mean ozone concentrations for each period were low on Seto Inland Sea. It was considered that large ozone titration by nitrogen monoxide contained in the ship exhaust gases

Table 4.1 Simulation and observation results and statistical indicators

	Benchmark	Kobe				Toyooka				Himeji			
		May	July	Sept.	Dec.	May	July	Sept.	Dec.	May	July	Sept.	Dec.
T_{sim} [°C]		17.1	25.4	23.2	7.7	16.7	26.5	22.8	6.2	17.5	26.5	23.7	5.2
T_{obs} [°C]		19.6	28.1	25.2	9.6	17.7	27.4	22.6	7.0	18.4	27.6	23.9	7.2
R		0.85	0.54	0.85	0.87	0.94	0.83	0.92	0.91	0.93	0.75	0.89	0.8
MBE [°C]	<±0.5	-2.46	-2.65	-2.04	-1.83	-1.04	-0.89	**0.24**	-0.86	-0.88	-1.1	**-0.21**	-2.02
MAE [°C]	< 2.0	2.76	2.76	2.65	2.14	**1.66**	**1.81**	**1.39**	**1.71**	**1.5**	**1.81**	**1.63**	2.4
WS_{sim} [m/s]		4.4	4.6	3.5	4.1	3.4	3.1	2.3	3.8	3.6	3.4	2.7	2.9
WS_{obs} [m/s]		4.0	3.2	3.8	3.3	2.0	1.7	1.4	1.5	3.0	2.5	2.6	2.2
R		0.48	0.28	0.43	0.41	0.7	0.54	0.47	0.59	0.5	0.44	0.28	0.56
MBE [m/s]	<±0.5	**0.45**	1.44	**-0.33**	0.86	1.43	1.39	0.95	2.32	0.6	0.95	**0.14**	0.69
RMSE [m/s]	< 2.0	2.46	2.42	2.37	2.5	**1.99**	**1.97**	**1.47**	2.84	**1.72**	**1.8**	**1.64**	**1.75**

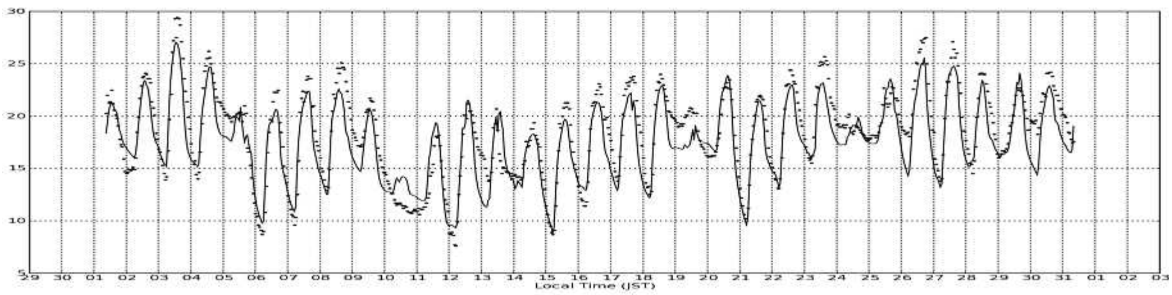

Fig.4.2 Time series of temperature in May at Himeji

caused the reduction of the ozone concentrations. On the other hand, in the Pacific Ocean and the Sea of Japan, ozone concentrations were higher than land. In this simulation, since the emission on the Pacific Ocean and on the Sea of Japan was not included, it is considered that ozone titration was smaller and the ozone concentration became high.

In order to compare the simulation result with the observations data, 13 monitoring stations were selected (in Fig4.1 M1-M13). The correlation coefficient of ozone concentration was in May (0.58), July (0.60), September (0.48), and December (0.54). The correlation coefficient of NO_2 concentration was in May (0.48), July (0.23), September (0.38), and December (0.59).

As an example, the time series of temperature in May of at M7 is shown in Fig.4.4.

The simulation result and the observations data of the mean ozone concentration were in May (simulation 36.2, observation 45.5ppb) > September (simulation 31.8, observation 28.6ppb) > July (simulation 29.9, observation 27.9ppb) > December (simulation 19.9, observation 15.5ppb).

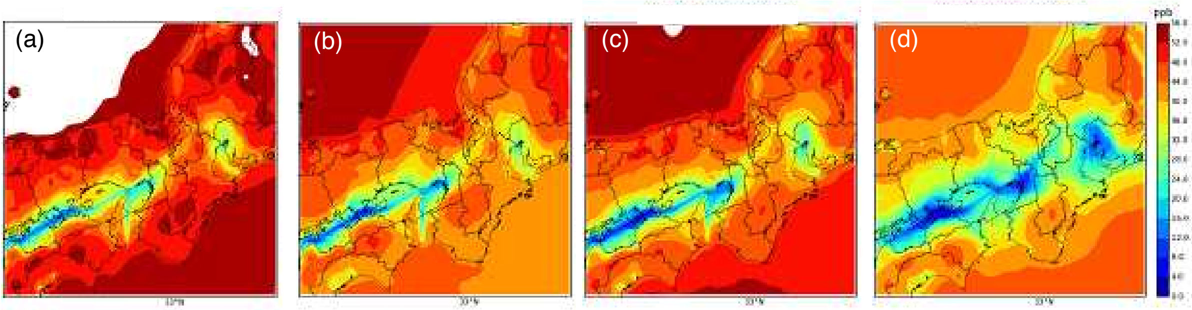

Fig 4.3 Mean ozone concentration in DOMAIN3
(a) May (b) July (c) September (d) December

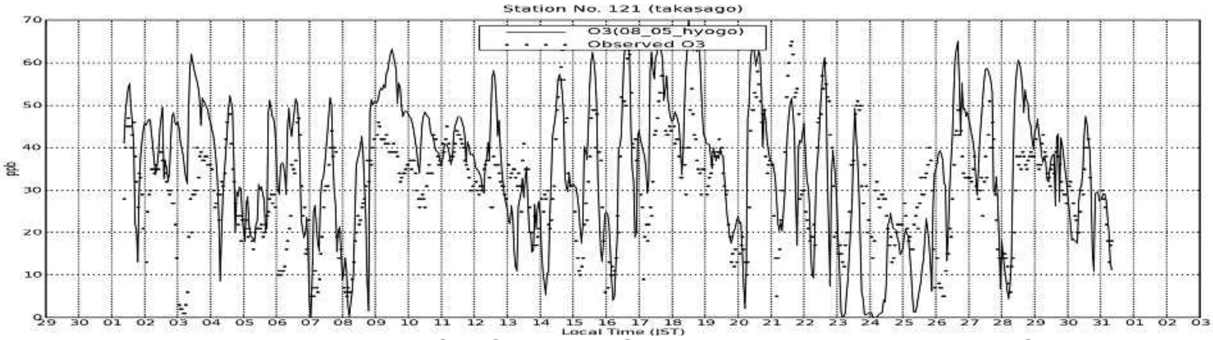

Fig.4.4 Time series of observed and CMAQ-predicted O3 concentrations(ppb) in May at M7,Solid line (simulation),dashed line(observation)

4.3. Result of Measurement by Passive Sampler

The results of ozone concentrations measured by the passive sampler are shown in Table 4.2. The ozone concentrations tended to be higher in spring at all sites. The ozone concentrations were higher in the inland region. These results were in agreement with the result of numerical analysis.

Table 4.2 Mean ozone concentration

sampling site	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
P1	41.1	36.9	24.3	20.9	19.9	21.8	16.7	17.5	18.7	19.2	25.2	30.6
P2	38.6	41.5	34.8	31.2	28.7	25.5	17.2	14.8	16.3	16.1	24.0	30.7
P3	44.4	43.4	29.0	N.D.	25.4	22.9	19.9	17.8	18.6	19.1	24.9	32.3
P4	33.8	36.5	27.4	20.4	18.2	16.5	14.7	14.3	13.9	14.5	21.7	28.0
P5	42.7	48.8	35.3	37.2	30.0	30.6	21.4	19.5	18.2	21.8	26.5	38.6
P6	46.0	46.4	35.7	31.8	28.5	26.9	22.5	22.3	18.3	23.4	31.0	37.2
P7	43.7	44.0	32.1	27.5	22.2	23.1	20.1	17.5	15.4	20.5	25.7	33.5
P8	40.6	39.7	32.9	31.3	24.1	30.5	19.9	18.4	15.3	17.6	23.3	31.1
P9	40.6	45.2	35.1	34.2	29.8	31.9	20.9	18.8	14.8	16.9	24.2	31.6
P10	38.8	44.1	39.3	40.5	35.8	39.0	24.4	19.0	15.4	17.7	23.1	33.6
Average	41.0	42.6	32.6	30.5	26.2	26.8	19.8	18.0	16.5	18.7	25.0	32.7

5. CONCLUSION

We investigated the spatial distribution of ozone concentrations in the Kansai region, Japan using numerical analysis technique. The MM5/CMAQ system was used in this study. The measurement of ozone concentration by passive sampler was performed at 10 sampling sites during the same period.

The MM5 results were able to reproduce the observed temperature better than the observed wind speed. The simulated temperature tend to be lower than the observed one. The simulated wind speed tend to be larger than the observed one.

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