NUMERICAL STUDY ON SUMMER-TIME PHOTOCHEMICAL POLLUTION IN OSAKA AREA
-Influence of surface albedo and NMVOC-NOx ratio on oxidants production-
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Abstract
A numerical model, which is a meso-scale meteorological model (RAMS) with an online-coupled photochemical mechanism (CBM), was used to simulate typical cases of mid-summer photochemical oxidant (Ox) pollution in Osaka area.

When the surface albedo of an urban area is increased to mitigate the mid-summer thermal environment, decrease of temperature weaken sea breeze, and it may cause increase of the Ox concentration level. Sensitivity test about NOx and NMVOC emission reductions on the daily maximum Ox concentration shows that the most of the urbanized area is NMVOC-limited. In some regions in Osaka area, the reduction of solely NMVOC emission is more effective than the both of NOx and NMVOC emission reduction.

Key words: Photochemical pollution, Surface albedo, Local circulation, Numerical simulation

1. INTRODUCTION
Recently, the concentration level of photochemical oxidants in summer has been gradually increasing in Japan. Such tendency is also found in Osaka, which is one of the most populous area in Japan, although strict regulations for the industrial and the vehicle emissions have been introduced. It seems that one of the reasons of this increase is due to the change of urban climate caused by heat island effect. Narumi et al. (1) showed that there is a positive correlation between air temperature and the maximum concentration of photochemical oxidant. Since the production rate of photochemical oxidants varies according to the ratio of non-methane volatile organic compounds (NMVOC) and nitrogen oxides (NOx), the concentration decrease of oxidants is not always proportional to the reduction amount of their precursor emissions, moreover, it may lead to increase of oxidants concentrations (2).

In this study, we developed a numerical model, which is a meso-scale meteorological model (RAMS) with an online-coupled photochemical mechanism (CBM), to simulate the photochemical pollution in mid-summer in Osaka area. Numerical experiments about typical high concentration cases and the other non-episodic case were executed, and the results were compared with each other to clarify the influence of the local circulation on the air quality. From a point of view of photochemical pollution, the effect of surface albedo enhancement, which will mitigate daytime thermal environment in mid-summer, and emission reduction of precursor pollutants were also examined and discussed.

2. NUMERICAL MODEL
We used an on-line Eulerian model, which is a meteorological model coupled with a photochemical reaction mechanism for the simulation of photochemical pollution. Regional Atmospheric Modeling System (RAMS) (5) ver.4.4 was used as a meteorological model. Advection-diffusion process of pollutants was calculated by the scalar transport function of it. CB99 photochemical reaction mechanism, which is one of the Carbon Bond Mechanism (CBM) (6) families, was coupled with the RAMS code. JPROC code of CMAQ (the Community Multiscale Air Quality modeling system developed by US/EPA) was utilized to estimate the amount of actinic flux, which is required to calculate photochemical rate coefficients. Only dry deposition process was considered and the deposition velocity was assumed to be constant in time.

3. CALCULATION CONDITION
3.1 Cases of analysis
To investigate state of the photochemical pollution in Osaka area, three typical periods were simulated.

Case A: High level concentration of ozone was observed in southern part of Osaka area.
2100 JST (Japan Standard Time) August 1 2006 - 2100 JST August 3.

Case B: High level concentration of ozone was observed in northern part of Osaka area.

Case C: Low level concentration of ozone was observed in Osaka area.
2100 August 7 2007 - 2100 JST August 9 2007

For each case, simulation was executed during 48 hours, and the results of the last 24 hours were used to evaluation.

1-1 Gakuen-cho, Naku-ku, Sakai, Osaka, 599-8531, Japan
3.2 Calculation domain

Fig.1 illustrates the calculation domain. To reproduce the large-scale land-sea breeze system in Kinki area, a region of 260 km (E-W) x 450 km (N-S) is covered by 5 km mesh (Grid 1), and a 100 km x 100 km region is nested within it, where grid resolution is set to 1 km (Grid 2). Vertical extent of the calculation domain is 24.2 km, which is divided into 30 layers. The depth of the lowest layer is 50 m.

3.3 Initial and boundary conditions

The initial values of the meteorological field were estimated by the objective analysis of ISAN/RAMS preprocessor from NCEP GPV, JMA aerological and ground surface data. Nudging technique was used to give boundary values. Objective analysis data were given at 12 hrs intervals to the outermost 5 grids of Grid 1. Land use data used was 30 s resolution dataset of USGS. From preliminary analysis, all of the initial and the boundary concentrations were set to zero, which shows best agreement with observations. The time step of simulation was set to 20 s for Grid 1, and 5 s for Grid 2.

3.4 Emission data

EAGRID-2000-JAPAN\(^5\) was used as an emission data. The spatial resolution and temporal resolution of the data is 1 km and 1 hr, respectively. "Transportation" data (including car, ship and airplane) defined in hourly data. "Residential and commercial" and "Industrial" data is calculated from annual total amount and monthly/hourly emission patterns. Natural NMVOC emission amount from plants (BVOC) is estimated by using solar radiation and temperature measurements for each day.

4. POLLUTION ANALYSIS OF TYPICAL MID-SUMMER DAYS IN OSAKA AREA

4.1 Evaluation of model performance

Correlation coefficient (COR), Root Mean Square (RMS) and Mean Bias Error (MBE) between model outputs and observations were estimated to evaluate the prediction accuracy of meteorological field. About Ox concentration prediction, Normalized Gross Error (NGE), Normalized Gross Bias (NGB) and unpaired Highest-Prediction Accuracy (HPA) were used as accuracy indices, to which guideline values are set by US/EPA. Cut-off value of 60ppb was used to estimate NGE and NGB.

\[
\text{NGE} = \frac{1}{N_T} \sum_i \sum_j \left| \frac{O(i,j) - P(i,j)}{O(i,j)} \right| \leq 0.35
\]

\[
\text{NGB} = \frac{1}{N_T} \sum_i \sum_j \left| \frac{O(i,j) - P(i,j)}{O(i,j)} \right| \leq 0.15
\]

\[
\text{HPA} = \left| \frac{O_{\text{max}} - P_{\text{max}}}{O_{\text{max}}} \right| \leq 0.20
\]

where, \(O(i,j)\) and \(P(i,j)\) is observed and predicted concentration at monitoring station i for hour j, respectively. \(O_{\text{max}}\) and \(P_{\text{max}}\) are their maximum values over all points and hours. \(N_T\) is total number of station-hours.

Comparison between observed and predicted values was made at 7 air pollution monitoring stations (Fig.1). The indices of agreement (COR, RMS and MBE) about meteorological variables (Temperature and wind speed) are listed in Table 1. Predicted temperature shows good agreement with measurements. The correlation coefficients about wind speed are not as good as those of temperature. As the correlation values found in other works\(^6\) distribute from 0.24 to 0.71, our result can be regarded as reasonable. The evaluation indices about Ox concentration are shown in Table 2. NGE and HPA are within the range of EPA guideline. On the other hand HPA is -0.216, which means that the prediction slightly overestimates.

4.2 Patterns of Photochemical pollution in Osaka area

Fig.2 shows the distribution patterns of Ox concentration at 1400JST for Case A to C.

Case A: In daytime, precursor pollutants such as NOx and NMVOC are transported from the coastal area to the inland area by sea breeze, however, in this case, eastern synoptic wind prevents penetration of sea breeze. A convergence line is formed in Osaka plain, and precursor pollutants stagnate around it.
Case B: Although a convergence line is formed early in the morning in this case, sea breeze develops as the surface temperature increases. Pollutants are advected along the Yodogawa River and transported to the inland area. High concentration appears along the Yodogawa River, but Ox concentration is low compared to the case which a convergence line persists in the afternoon.

Case C: Unlike the other two cases, sea breeze has been dominating this area from the previous night. When sea breeze endures in nighttime, precursor pollutants are transported to inland area successively. Though the air temperature in Osaka reached up to 35°C in daytime, Ox concentration does not so much increases because the concentrations of precursor pollutants are relatively low in the morning.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Evaluation indices of the predicted values (Temperature and wind speed)</th>
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<tbody>
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<td></td>
<td>Temperature</td>
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<tr>
<td></td>
<td>COR</td>
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<tr>
<td>Kokusetsu-Osaka</td>
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<td>0.259</td>
<td>-0.216</td>
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</table>

5. INFLUENCE OF SURFACE ALBEDO AND NMVOC-NOx RATIO ON THE PRODUCTION OF OXIDANTS

To investigate the influence of surface albedo and NMVOC-NOx ratio on the production of oxidants, we executed sensitivity analysis on Case A (2-3 August 2006).

5.1 Effect of surface albedo

In the sensitivity test, the value of surface albedo in the area assigned to "urban" category in USGS land use data was changed from 0.15 (the default value) to 0.3 and 0.6. Note that the amount of actinic flux depends on surface albedo and it will also affect photochemical reactivity, but this relationship was not taken into account in this analysis because we focused on the influence of the surface albedo on the meteorological field.

The decrement of air temperature, wind speed and oxidant concentration are shown in Fig.2. When the surface albedo increases, air temperature in urban area decreases due to the suppression of radiation heating of the ground surface. Because photochemical reactivity depends on air temperature, Ox concentration is expected to decrease; however, the result is contrary to it. Increase of concentration is found especially near the ends of convergence line. The reason of it is that the decrease of air temperature near the ground surface weaken the wind speed of sea breeze, and it leads to the suppression of dilution of Ox concentration.

5.2 Effect of emission reduction

Cases of 15 % and 30 % reduction were investigated about NOx and NMVOC emissions, respectively. The decrease amounts of the daily maximum Ox concentration at the evaluation points are shown in Fig.8. From the results, it is found that maximum Ox concentration is reduced in every case. The decrease amount of the concentration is approximately proportional to the amount of emission reduction. For both of 15% and 30% reduction cases, NMVOC is more effective than NOx except Tondabayashi. When both of NOx and NMVOC are reduced, the effect on the Ox concentration is neither additive nor synergistic; moreover it is found that it is effective to reduce only NMVOC emission for Ox reduction in some regions. It is well known that the daily maximum Ox concentration depends on NMVOC/NOx concentration ratio because of the non-linear relationship of photochemical reaction. For example, in suburban region, such as Tondabayashi, NMVOC/NOx is large so the reduction of NOx is effective. On the other hand, near the urban central region, such as Kokusetsu-Osaka, NMVOC/NOx is small so the reduction of NMVOC leads to the decrease of Ox concentration.

6. SUMMARY

A numerical model, which is a meso-scale meteorological model (RAMS) with a online-coupled photochemical mechanism (CBM), was used to simulate the photochemical pollution in Osaka area. Numerical experiments about typical high concentration observed cases and the other non-episodic case were executed. The results show that the daytime pattern of Ox concentration distribution depends on the accumulation of the precursor pollutants which is determined by the balance between the synoptic wind and the sea breeze.

A series of sensitivity analysis was also executed to investigate the photochemical Ox pollution in Osaka area. When the surface albedo of the urbanized area is increased to mitigate the mid-summer thermal environment, temperature decrease weaken sea breeze, and it may cause increase of the Ox concentration level. Sensitivity test about NOx and NMVOC emission reductions on the daily maximum Ox concentration shows that the most of
the city area is NMVOC-limited. In some region, the reduction of solely NMVOC emission is more effective than the reduction both of NOx and NMVOC.

Fig.2 Distributions of Ox concentration in Osaka area at 1400 JST.

Fig.3 Distribution of decrease amount about temperature(left), wind speed(center) and Ox concentration(right).

Fig.4 Decrease amount of daily maximum Ox concentration by NOx and NMVOC reduction.

References