

ANALYSIS OF RELATIONSHIP BETWEEN CHANGES OF METEOROLOGICAL CONDITIONS AND THE VARIATION OF O₃ LEVELS IN SUMMER OVER THE CENTRAL KANTO AREA

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Abstract

The increasing trend in ground ozone (O₃) concentration has recently been recognized in Japan, though concentrations of ozone precursors have been decreased. It is well known the status of atmospheric has been changing on a long term, not only over the world, but also in Japan. Therefore, one of causes is possibly imagined that is the effect of meteorological conditions. In order to confirm whether the change of meteorological conditions contribute to the Japanese O₃ trend we examine relationship between meteorological conditions and ground O₃ levels concentration over the central Kanto area of Japan using both statistical analysis and numerical model. The nested grid system of numerical experiments which cover a region of Kanto with grid resolutions of 9 km, 3 km, and 1 km respectively, have been employed to this study. The results of analysis show changes of meteorological conditions can be one of causes leading to the variation of O₃ levels concentration in this area.

Keywords: Atmospheric pollution; Urban Heat Island; MM5; CMAQ; Ozone

1. INTRODUCTION

Kanto area is the largest inland and the most highly developed, urbanized, and industrialized part of Japan. With the increasing trend of city-growth and urbanization, Kanto area also has to face air pollution problem. According to the Tokyo Metropolitan Government Environmental White Paper 2006, the concentrations of most of air pollutants are decreasing in Tokyo Metropolitan. However, the concentration of photochemical oxidant has not achieved the Environmental Quality Standards (one-hour value of 0.06 ppm or less). Possible reasons for this trend of O₃ have discussed using both models and measurements (Ohara et al., 2008; Akimoto, 2003; etc). Most of these studies indicated that the long range transported ozone and its precursors from East Asia, particularly China, have been growing rapidly during the past two decades and mainly affect the recent increase of O₃ concentration over Japan. However, there is fact that the concentration of O₃, especially warning ozone levels (1-hour O₃ ≥ 0.12 ppm), around the big cities also has been rising in the summer, though in this season the clean air flow is mainly transported by southerly winds from Pacific Ocean. This phenomenon is a very interesting issue that has not been solved yet. In this paper authors will investigate relationship between the meteorological conditions and summertime O₃ levels over central Kanto area. We firstly analysis the variation of summertime ozone levels and its possible relation with change of meteorological conditions based on measurements. Then authors will consider these relationships based on numerical simulation using MM5/CMAQ model. The results of study may add to knowledge in effect of meteorological conditions on the variation of O₃ levels over central Kanto.

2. STATISTICAL METHOD AND MEASUREMENTS

2.1 Regression analysis

In order to estimate how meteorological conditions affect the variation of O₃ levels, authors carried out a multiple linear regression analysis. This is one of the most widely used methods for predicting ozone concentrations in dependence of meteorological factors. The general equation of the model is as follows:

$$y = a_0 + a_1x_1 + \dots + a_mx_m + \varepsilon \quad (1)$$

Where, y is objective variable (ozone concentration), m is the number of independent variables (meteorological variables), x_j are independent variable, a_j are regression coefficients (estimated by least square procedure), and ε is error term associated with regression.

2.2 Data

The seasonally averaged daily maximum O₃ concentration (predictand) of monitoring sites in Tokyo area over the past 21 years (1985-2005) is used to analysis. This data was obtained from National Institute for Environmental Studies (NIES), Japan. For independent variables (predictors), determining which and how many meteorological variables need to be included in the model is somewhat subjective and difficult task because they are not really independent. For example, high temperature may associate with high solar radiation and lower

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$$O_3 = 0.79 * T - 0.48 * U, \quad R = 0.88, \quad R^2 = 78.1 \quad (2)$$

Where, R is the multiple correlation coefficient and R² (expressed in per cent) is the fraction of the variance explained by the regression.

T-test based on student' distribution was done to test the equation (2). The result show regression coefficients of temperature and wind speed are statistical significant. The P-values for all coefficients are less than 0.05(P-value < 0.05). High multiple correlation coefficient (R=0.88) was found between two variables (temperature and wind speed) and the peak O₃ concentration. The peak O₃ concentration predicted by statistical regression model was plotted against the observed values as shown in Fig. 2. The results of high correlation from this analysis show that the peak O₃ concentration strongly affected by meteorological conditions. In the summer about 78% of the variation of the peak O₃ may be accounted for by changes in temperature, and wind speed.

Trends of the peak summertime O₃ concentration was estimated by multiple linear regression analysis. Upward positive trends are found during each period, from the 1980s to the 1990s and during the 2000s. The high increases are detected in the summer with the averaged peak O₃ concentrations are 43.76, 53.08, and 57.37 ppb for the 1980s, 1990s, and 2000s, respectively. This indicates that meteorological conditions in Tokyo tend to increase the peak O₃ concentration. The peak O₃ trends due to the changes in meteorological variables are smaller than observed ozone trends (the averaged peak O₃ concentrations are 41.04, 51.77, and 61.80 ppb for the 1980s, 1990s, and 2000s, respectively). Any remaining variability could be attributed to other causes such as long range transported ozone and its precursors from East Asia, chemical reaction production, other meteorological variables which did not includes in statistical regression model.

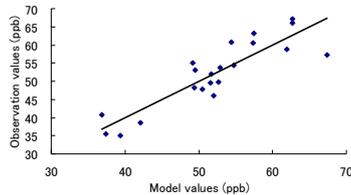


Fig. 2. Averaged daily maximum O₃ concentration observed and predicted by the regression equation for summer season in Tokyo

4.2 Relation between O₃ levels and meteorological conditions based on numerical simulation

4.2.1 Relation between the daily maximum ozone concentration and meteorological conditions

The changes of O₃ levels are expressed as the sum of the long-term and short-term change in the meteorological conditions, precursor changes, etc. To understand the daily maximum variations in O₃ concentrations caused by short-term changes in the meteorological conditions, the numerical simulation will be used to analysis. These are temperature, wind speed and daily maximum ozone concentration which extracted from MM5/CMAQ simulation. Meteorological variables are averaged values of simulation in domain 3(Fig. 1) during 8:00 ~ 15:00 JST and ozone data is daily maximum value of simulation in domain 3. To avoid effect of ozone precursor changes, in this study emission data is fixed the same for all over simulation days. Applying the same procedure of regression analysis above, the statistical model for standardized value of daily maximum O₃ concentrations in August is as follows:

$$O_3 = 0.5 * T - 0.59 * U, \quad R = 0.77, \quad R^2 = 59.2 \quad (3)$$

T-test based on student' distribution was also done to test the equation (3). The result show regression coefficients of temperature and wind speed are statistical significant (P-value < 0.05). As a result of the multiple linear regression method performed for one month in summer (August) shown in Fig 3, an R²=59.2 was obtained which suggests that 59.2% of the variation of the daily maximum ozone may be accounted for by changes in temperature and wind speed. It can be examined from equation (3) temperature effect on ozone is positive while wind speed effect is negative. There are some reasons to explain this relationship. The first of these is related to the increase in photolysis rates of ozone production with increasing temperature, while wind speed is important factor for the dispersion of O₃ concentration. A second reason is attributed to stagnant meteorological patterns associated with high temperature and weak wind. More detail analysis will be discussed below.

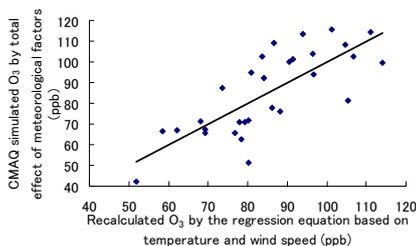


Fig. 3. Daily maximum O₃ concentration simulated and estimated by the regression equation against based on temperature and wind speed in August for central Kanto area.

4.2.2 Relation between simulated ozone concentration and urban heat island (UHI)

Urban heat island has long been known as one of environmental problems in cities over the world, especially big cities like Tokyo of Japan. To examine relationship between UHI phenomenon and air pollution in summer, we select the result of simulation on August 4, 2005 which associated with daytime UHI event over Tokyo area for analysis. This day, the Pacific subtropical high pressure system expands to the west, the Kanto area was covered by its ridge and the weather was fine. The descending air flow located at the ridge of high pressure system played an important role in high O₃ formation. Fig. 4a shows the spatial distribution of the temperature at 2-m height and 10-m high winds from the MM5 simulation in domain 3 at 12:00 JST. It can be observed that there exists a region of temperature higher than 36°C over central Kanto area and the horizontal wind speed is a little weak. This high temperature condition is conducive to photochemical reactions that produce O₃ pollution. Moreover, the high temperature associated with UHI causes pressure deficiency over city and creates a circular pressure gradient pattern around the city as shown in Fig. 4b. In this situation, the sea breeze from Tokyo Bay (S-SE), Sagami Bay (SW-S) and Kashima sea (E) merged and combined with flow from suburban. This system remained without moving for some hours. Dispersion of ozone will be limited under that calm condition, and therefore, there is more O₃ formation and accumulation leading to high O₃ concentration over city as shown in Fig. 4c. Although the difference of temperature between land and sea is very high, the sea breeze cannot pass through city due to of persistence of UHI. Interaction between UHI and sea breeze also is important condition in high O₃ formation over Kanto area, it can be described by vertical cross of circulation vector from the shore to suburban AA' as shown in Fig. 4d. The contrast of temperature between urban and suburban area creates urban heat island circulation (HIC). At surface, the flow from suburban meets sea breeze at city and goes up. This updraft of HIC acts like 'block' preventing the penetration of sea breeze inland, therefore there is more O₃ accumulation over city area and extreme pollution levels can result.

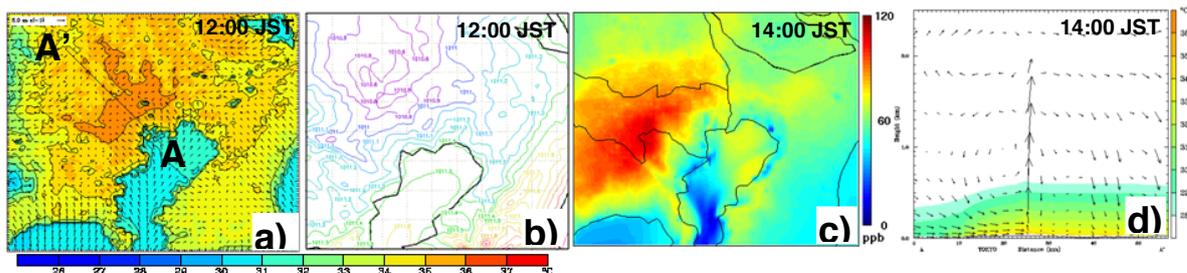


Fig. 4. Results of simulation from MM5/CMAQ model on August 4; (a) simulated 2-m temperature (°C), 10-m wind; (b) surface pressure (mb); (c) O₃ concentration (ppb); (d) circulation vector in the plain of the cross section AA'

5. CONCLUSIONS

We have implemented statistical regression analysis and the numerical MM5/CMAQ model in order to investigate the contribution of meteorological conditions to O₃ levels concentrations in the summer. The results of study showed that there is a close relationship between changes in meteorological conditions and the variation of O₃ levels concentration over the central Kanto area. The increasing trend in O₃ concentration has recently been recognized in Japan and one of the causes is possibly imagined that is changes in meteorological conditions.

Results also indicated that the significantly high ozone appears on the days associated with urban heat island. High temperature and calm conditions under UHI can cause high O₃ levels in this area. UHI and its interaction with sea breeze strongly affect O₃ concentration. Although the difference of temperature between land and sea is favorable for developing sea breeze in summertime, the sea breeze cannot pass through city due to persistence of UHI. Therefore, dispersion of ozone will be limited and high O₃ concentration can be understood.

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