UPWARD TRENDS IN PHOTOCHEMICAL OXIDANTS AND CLIMATE CHANGE IN SUMMER IN THE GREATER TOKYO REGION

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INTRODUCTION

In the greater Tokyo region, photochemical oxidant Ox (which can be considered to be basically equivalent to ozone) concentrations have shown clear upward trends during the recent decade. The occurrence frequency of higher ranks of daily maximum Ox concentrations significantly increased, whereas similar frequency shifts were also found in daytime and nighttime averages. In summer, afternoon peaks above the warning level (120 ppbv) frequently occur in the surrounding regions of big urban complexes.

Several reasons for these trends have been discussed. Major ones are

1) the rapid increase in emission of precursor pollutants in Asian countries (e.g., [1]),
2) changes in emission amounts of nitrogen oxides and VOCs as well as their ratio [2],
3) an increase in ultraviolet (UV) radiation observed in the central region of the country [3],
4) the effect of warming on the chemical reactions forming Ox [2], and
5) presumed changes in local circulations due to the development of urban heat islands [4].

These hypotheses may partially explain the Ox trends, but none of them was quantitatively evaluated.

Decadal changes in the Ox concentration during summer are analyzed, with a focus on its relation with the local climate in the Kanto Plain.

EXAMINED AREAS AND DATA

The Kanto Plain has a size about 100x100 km, and Tokyo Bay is located in the south of the plain. High Ox events occur most frequently in the Tokyo Metropolitan Area and Saitama Prefecture, which correspond to the western half of the plain (see Fig. 1). Ox concentration values from the fixed monitoring stations in these areas are used with the surface meteorological data.

Changes in the summer (June-August) Ox concentrations and the climate are analyzed by comparing those data observed during 1989-1991 with those obtained during 1999-2001. Each period consists of 276 sample days.

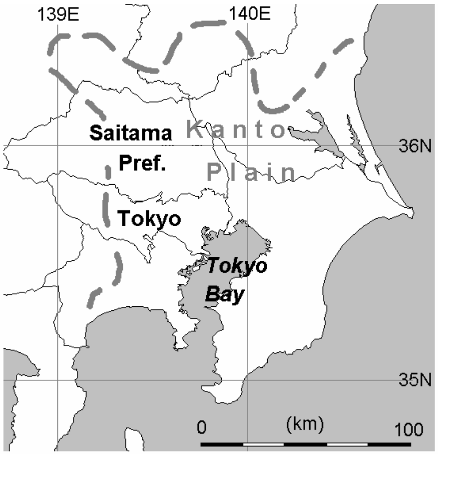

Fig. 1 The examined areas.

HIGH Ox DAYS

Here, a high Ox day was defined as a day on which the daily maximum concentration exceeded 120 ppb and lasted at least two hours over an area. Figure 2 shows the numbers of high Ox days for administratively divided areas in Tokyo and Saitama during three year periods. The numbers increased especially in the areas several tens of km inland from the shores of Tokyo Bay.

The number of high Ox days for the entire region including Tokyo and Saitama was 54 during 1989-1991, and amounted to 92 during 1999-2001.

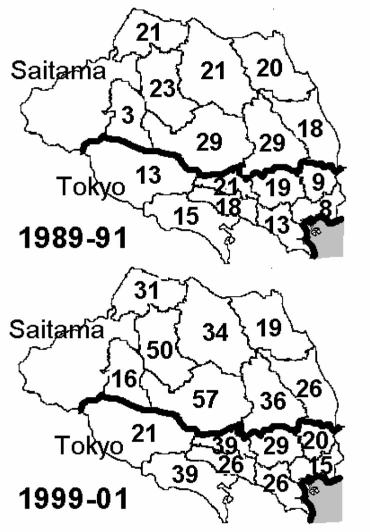

Fig. 2 Number of high Ox days in each area during respective three year periods.

CLASSIFICATION OF WEATHER PATTERNS

All the days in the examined periods were classified by weather patterns with two kinds of indices. As an index of the atmospheric pressure gradient, geostrophic wind speed and direction were calculated from the sea-level pressures at 09 JST at six observatories around central Japan. The wind speed was classified into weak (<5 m/s), moderate (5-10 m/s) and strong (>10 m/s), and the wind direction into eight directions when the wind was moderate or strong, while only two directions (easterly or westerly) when the wind was weak. Another index was insolation, which was represented by an average of sunshine rates during 09-15 JST from five sites in the Kanto Plain. The insolation was classified into three ranks. Number of composite patterns became 54 (18 wind x 3 insolation classes).

Figure 3 indicates the occurrence frequencies of the weather patterns during the two periods. Number of high Ox days is also shown in each column. Total frequency of the patterns with large and medium insolations and weak geostrophic wind, which were generally connected with high Ox concentrations, sharply increased from 54 days during 1989-1991 to 82 days during 1999-2001. As the high Ox days included in those weather patterns were 21 days during 1989-1991, they were estimated to appear 32 times during 1999-2001 if a constant ratio was assumed. Actual number of high Ox days in the same weather patterns during 1999-2001 amounted to 50 days. Therefore, it is considered that 38 % (=11/29) of the increase in high Ox days was due to the increase in such days with large insolation and gentle pressure gradient in summer.

LOCAL WIND PATTERNS

The weather patterns analyzed above are related with synoptic-scale meteorology, and may be called external conditions. Internal conditions, which directly dominate the behavior of pollutants, are mainly related with mesoscale phenomena such as local winds. In the Kanto Plain, the sea breezes tend to develop on the south and east coasts and the shores of Tokyo Bay, and much influence the evolution of air pollution including Ox. As an example, air mass trajectories starting

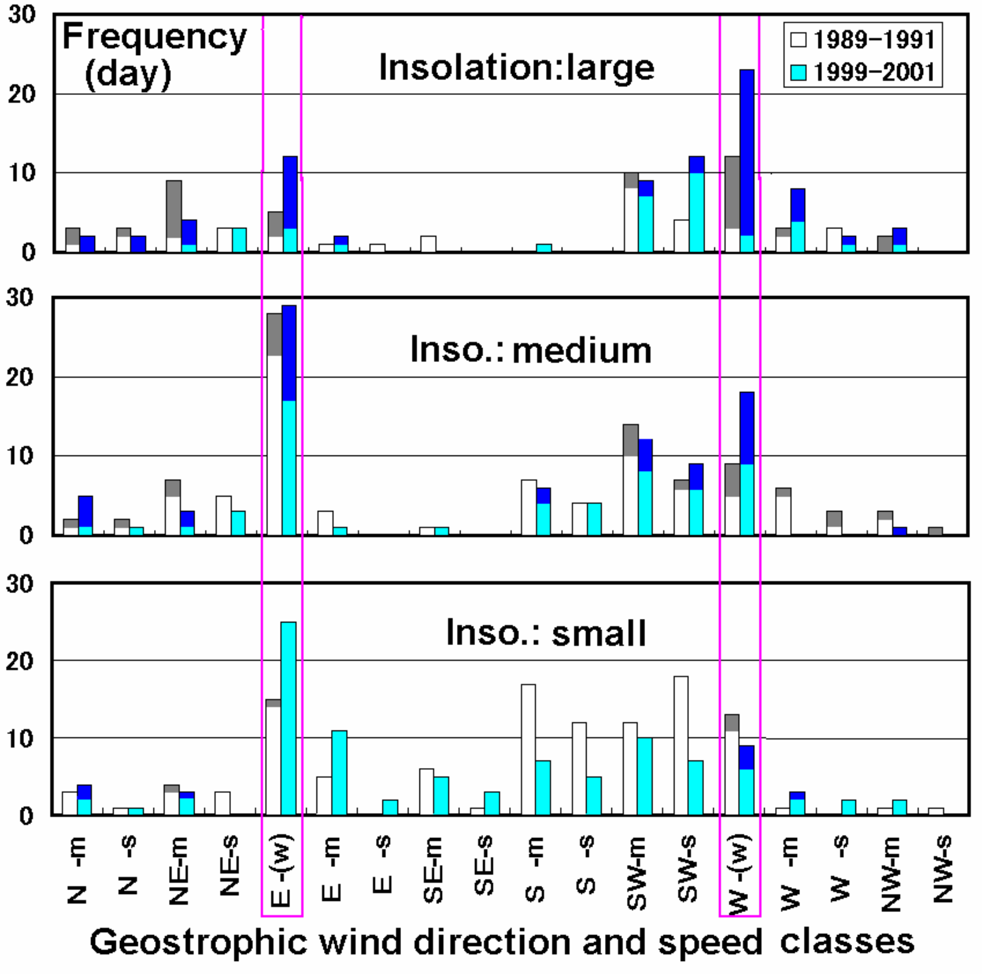

Fig. 3　Occurrence frequency of the weather patterns and high Ox days (shadowed portion at the top of each column).

from the Tokyo Observatory at 09 JST were calculated for the days included in the group [Inso.: large, Geostrophic wind: W-(w)] shown in Fig. 3 by a simple method. The result, shown in Fig. 4, suggests that the sea breeze from Tokyo Bay transports pollutants inland without exception.

Therefore, relationship between the sea breeze and high Ox days was examined for the summer months in the two periods same as above.

Local wind systems, particularly developing on the shores of Tokyo Bay, were classified by the criteria shown in Fig. 5 into

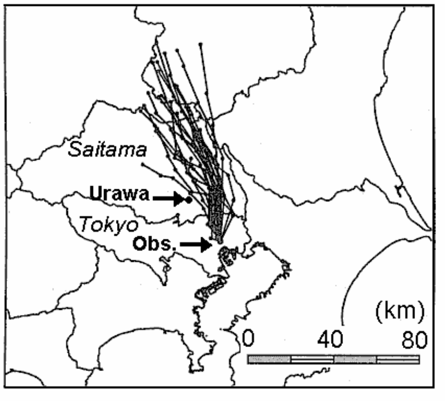

Fig. 4　Trajectories during 09-14 JST for the weather pattern group [Inso.: large, Geostrophic wind: W-(w)].

Synoptic prevailing: days that deviated from C1,
Non sea breeze: days that deviate from C2,
Sea breeze-like: days that deviate from C3, and
Sea breeze: days satisfying C1 through C3.
* The Tokyo Observatory is located near the shore of Tokyo Bay, and Urawa about 20 km northwest of it (see Fig. 4).

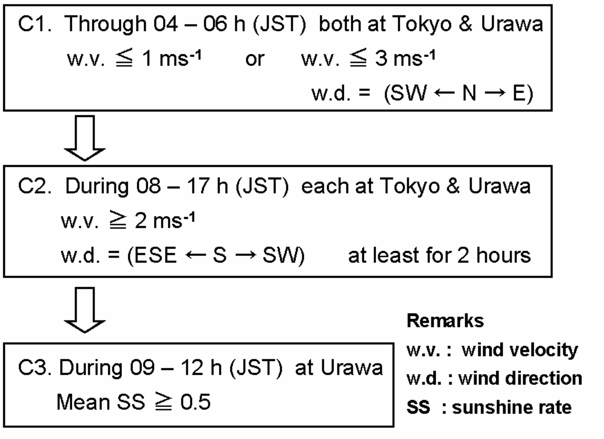

Fig. 5 Criteria for the judgment of local winds on the shores of Tokyo Bay.

Figure 6 exhibits the result of this classification. It can be seen that recently the occurrence ratio of high Ox days increased for the sea breeze and the sea breeze-like days, the latter of which meant that the diurnal wind patterns were similar to that of the sea breeze although the sunshine duration was small. Not only the high Ox days but the days with these wind patterns basically increased. If the ratio of high Ox days to sea breeze days were assumed to be invariable from that for 1989-1991, high Ox days were expected to appear 41 times during 1999-2001. As the actual number of the high Ox days for the sea breeze days during 1999-2001 was 52, 39 % (=7/18) of the increase in high Ox days was considered to result from the increase in such situations as the sea breeze develops. This conclusion coincides well with that reached in the preceding section.

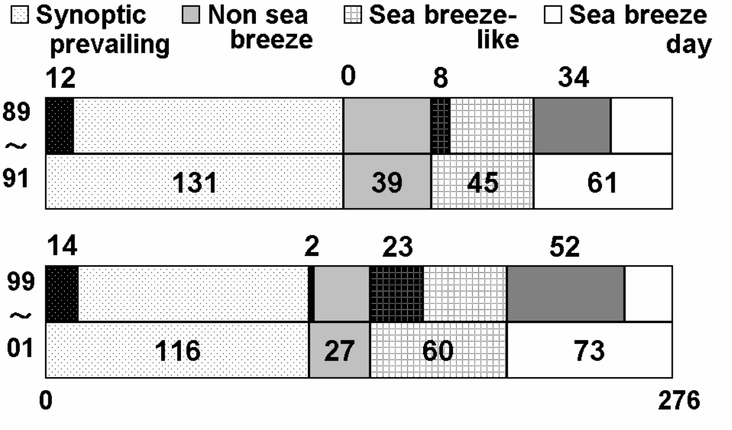

Fig. 6 Occurrence ratios of local wind systems classified by the criteria shown in Fig. 4 (lower portion in each belt), and the high Ox days in each category (dark part in upper portions).

ADDITIONAL ANALYSIS OF THE SEA BREEZE

On the basis of the judgment of the sea breeze following the flow in Fig. 5, the time of wind shift to southerly, or the onset time of the sea breeze, at Tokyo and Urawa was determined for every sample days as far as the sea breeze was detected. Differences in the onset time between Tokyo and Urawa was of special interest, because it corresponded to the advancing speed of the sea breeze front, and related with afternoon Ox increases in inland areas.

As shown in Fig. 7, recently the time lag of the sea breeze onset between Tokyo and Urawa generally reduced. Two typical groups can be selected from these sea breeze days, one for which the time lag was 0-2 hours (denoted by STL) and the other 3-5 hours (denoted by LTL), while the time of sea breeze onset at Tokyo is restricted to 10-12 JST in order to exclude irregular patterns. From this point of view, the STL days appeared 10 times and the LTL days 21 times during 1989-1991. During the 1999-2001 period, STL increased to 22 days, while LTL decreased to 12 days. These changes might be associated with the changes in the weather patterns mentioned above. In addition, changes in local conditions, such as urbanization of coastal regions, might also influence the behaviors of the sea breeze, [5].

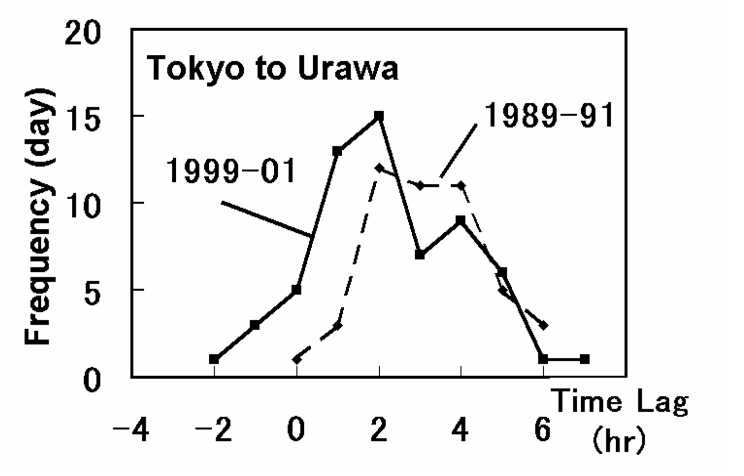

Fig. 7 Differences in the onset time of the sea breeze between Tokyo and Urawa.

Averaged diurnal variations of Ox concentration at selected monitoring stations were obtained for STL and LTL separately. Figure 8 illustrates the result for two sites. At the Nerima-kita station which was located near the middle point of the Tokyo Observatory and Urawa, the daily maximum Ox concentration did not change for STL, but that for LTL sharply increased during the decade. The high Ox in the latter case probably occurred due to the pollutants accumulated longer before the sea breeze reached. However, the high Ox in this areas did not much contribute to the increase in high Ox days, because the LTL days decreased. Increase in high Ox days mainly occurred in further inland areas. Kumagaya was located in the northern part of Saitama. Daily Ox maxima there increased both for STL and LTL. These changes in Ox concentration might not be explained by climate changes only.

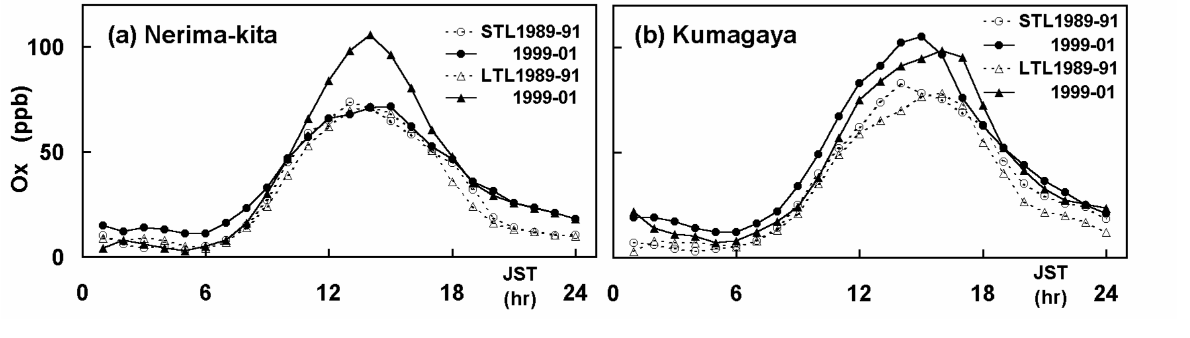

Fig. 8 Diurnal variations of Ox concentration at (a) Nerima-kita and (b) Kumagaya for the two periods and for the different sea breeze groups (see legend).

CONCLUDING REMARKS

Recent increase in high Ox events during summer months in the greater Tokyo region (Tokyo and Saitama Prefecture) was statistically analyzed. As a result of comparative analyses of Ox concentrations and meteorological data during two periods, 1989-1991 and 1999-2001, increase in such days with light pressure gradient and large insolation was clarified from the synoptic-scale climate data, and also clarified increase in the sea breeze days from the local wind data. On the other hand, high Ox days, characterized by daily maximum Ox concentration exceeding the warning level 120 ppb, increased from 54 days during 1989-1991 to 92 days during 1999-2001. It was estimated that about 40 % of the increase in high Ox days was explained only by the change in the above-mentioned summer climate.

Although such hypotheses have been proposed in recent years that increase in UV radiation, and rise in air temperature, might contribute to the Ox increase, the changes in UV and temperature can have occurred at least partly as a natural result of the climate change shown above. The remainder of the increase of high Ox days of about 60 % may be attributed to other factors such as

(1) increase in UV radiation due to the decrease in stratospheric ozone and improvement in PM pollution in the lower atmosphere,

(2) temperature rise related with urban heat islands and global warming, and

(3) other reasons mentioned in the introduction.

In particular, effects of possible changes in the precursor pollutants are currently investigated by numerical models, both for explaining the decadal trends and for predicting effects of assumed emission reduction.

It is not clear whether the climate change detected by the present analyses is a link in the global change or a local change in the northwest Pacific region of a shorter cycle. It will be necessary to watch trends in another decade.

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