Proceedings of the Third International Symposium on Air Quality Management at Urban, Regional and Global Scales. pp. 1054-1066, 26-30 September 2005, Istanbul – Turkey

INTERACTION PATTERNS OF SURFACE OZONE WITH NO_x AND NMHC IN EIGHT CITIES OF AICHI AND MIE PREFECTURES, JAPAN

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ABSTRACT

Interaction patterns between surface ozone and its precursors (nitrogen oxide (NO_x) and reactive non-methane hydro carbon compounds (NMHC)) in the local scale have been statistically analyzed for eight different cities of Aichi and Mie prefectures of Japan. Selected monitoring sites represented different land habitats namely coastal-industrial (Yokkaichi, and Tsu), inland urban sites (Nagoya center, Toyota city, Toyohashi, and Okazaki), mountain-base urban (Nabari), and coastal resort city (Toba). Hourly raw ambient data on air criteria pollutants (1993-2003) of Air Quality Authority of Mie and Aichi Prefecture were used to investigate the relationships of ozone with precursors and the photochemical indicators such as NO_2/NO and NMHC/NO_x.

Decomposition analysis was done to determine the seasonally adjusted trends of the pollutants. Despite relatively low concentrations of NO_x and NMHC, coastal sites experience relatively high ozone level than the inland urban sites indicating possible meteorological effects on the ozone movements and differences in ozone deposition rates. NO_2/NO ratio plays significant influence on ozone level of the inland sites while the influence of NMHC/NO_x was significant in sites with the characteristics of high density of industries and higher population of traffic. Seasonal variations in interaction patterns show stronger relationships between ozone and precursors in the winter and weaker relationships in the summer indicating the possible meteorological effects and higher rate of pollutants dispersions in the summer. Effects of land habitats particularly the topography plays important roles in the distribution patterns of the air pollutants.

Key words: Surface ozone, Ozone precursors (NO_x and NMHC), Interaction Patterns, Urban pollution, Photochemical indicators (NO_2/NO, and NMHC/NO_x)

1. INTRODUCTION

Surface level ozone formation is a complex process that is caused, under favorable photochemical conditions, by the nitrogen oxide (NO_x) and volatile organic compounds (VOC) emitted from traffic vehicles, industrial activities, and household combustions (Health Canada, 2002; Lu and Wang, 2003). Studies show that intensity of ozone production depends on the availability of NO_2 and the favorable photochemical conditions such as solar radiation and ambient temperature enhance the production of NO_2. The availability of NO_2 depends on the rate of transformation of NO_x and reactive volatile organic compounds (also called non-methane hydrocarbons) (Cooper and Alley, 2002; Sillman , 1999). Interaction between ozone and precursors is mainly dominated by the production of secondary pollutant called NO_2 which subsequently undergoes photolytic reaction to produce ozone. Production of NO_2 in the atmosphere can be made by NO at the expense of available ozone or by reactive volatile organic compounds without consuming available ozone. However, chemistry of ground level ozone goes through a complex process of production and destruction cycle. Anthropogenic (traffic, industrial process etc.) and biogenic sources emits nitric oxide (NO) and reactive components of VOCs that are believed to undergo several chemical reactions (Health Canada, 2000; Lu and Wang, 2003; Cooper and Alley, 2002) to produce NO_2. The amount of ozone in a certain time and location depends on the ratio of NO_2 and NO in the air and also on the availability of these two compounds.

The ratio of NO_2 and NO plays a vital role in stabilizing the ozone level through the production as well as the destruction process (Lu and Wang, 2003; Saito *et al*., 2002). Saito et al. (2002) found that the ozone production level could be related to the ratio of NO_x and NMHC because reactive NMHCs could convert NO into NO_2 without consuming O_3. Volatile Organic Compounds (VOC) react with hydrogen-containing radicals ($HO_2\cdot$**)** to yield peroxy radicals (RO·**)** that contribute to the production of NO_2 through a chain of intermediate reactions.

In fact, the ratio of NO_2/NO at a certain location can be considered as an indicator of the potential of ozone production. Higher ratios of NO_2/NO indicate higher levels of ozone production, and low ratios indicate the higher potential for ozone destruction. In addition, the relationship between NO_x and NMHC also influences the ozone production processes where the ratios NMHC/NO_x could also be used as photochemical indicator to control peak ozone level at a certain location (Cooper and Alley, 2002). Meteorological factors like wind speed and direction are responsible for transporting both ozone and its precursors from its source to far distant places, but seasonal variations in ambient temperatures influence substantially on the ozone production process and its temporal behavior (Olsyzna *et al*. 1997, Aneja *et al*. 2000, and Ribes *et al*. 2004). Ambient ozone level is destroyed mainly by two ways namely, scavenging by the fresh emission of NO or by depositions of ozone on the soil and absorption by plant and vegetation (Fuentes *et al*., 1992; Grantz *et al*, 1997; Chang *et al*., 2002). Therefore, sites with different land topography would have effects on the ozone destruction rates.

This study aims to characterize the interaction patterns of ozone with its precursors through analyzing the pattern of NO_2/NO, $NMHC/NO_x$ level, and their correlations with ozone.

2. STUDY METHODS

2.1 Description of the Study Areas and Data Gathering

We have chosen eight different cities of the Aichi and Mie prefecture namely, Nagoya city center, Toyota city, Okazaki, Toyohashi, Yokkaichi, Tsu, Nabari, and Toba for the study. These cities (shown in the Figure 1) represents different land habitats in terms of population; land use, commercial and industrial activities such as coastal-industrial (Yokkaichi, and Tsu), inland urban sites (Nagoya center, Toyota city, Toyohashi, and Okazaki), mountain-base urban city (Nabari), and coastal resort city (Toba).

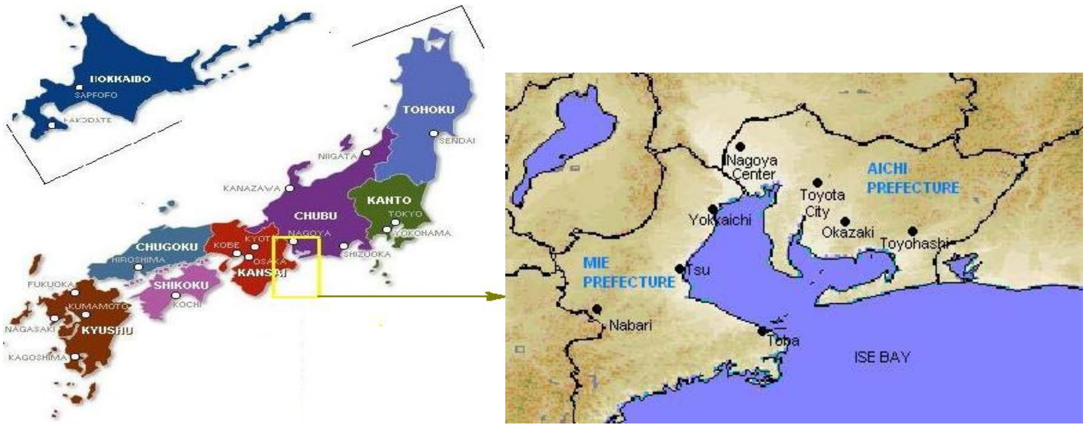


Figure 1: Maps showing Aichi and Mie Prefecture and the Approximate Locations of the Selected Monitoring Sites

Ambient air quality data of the selected monitoring stations were gathered from the Prefectural authorities of Mie and Aichi. Hourly concentration data for the period of 1993-2002 were considered for analysis. The raw data was further analyzed statistically to derive aggregated diurnal, daily, monthly, seasonal and annual values. Missing values were replaced with the 4 nearby mean values. Regression analysis of the aggregated values was done for determining the interactive characteristics of ozone and its precursors. Statistical software Minitab, MS Excel, and SPSS were used for data analysis.

3. RESULTS AND DISCUSSION

3.1 Trend Analysis of Ozone and its Precursors

Decomposition analysis of the monthly mean values of ozone was done for the periods of 1993-2002 to examine the seasonally adjusted trend as shown in Figure 2.

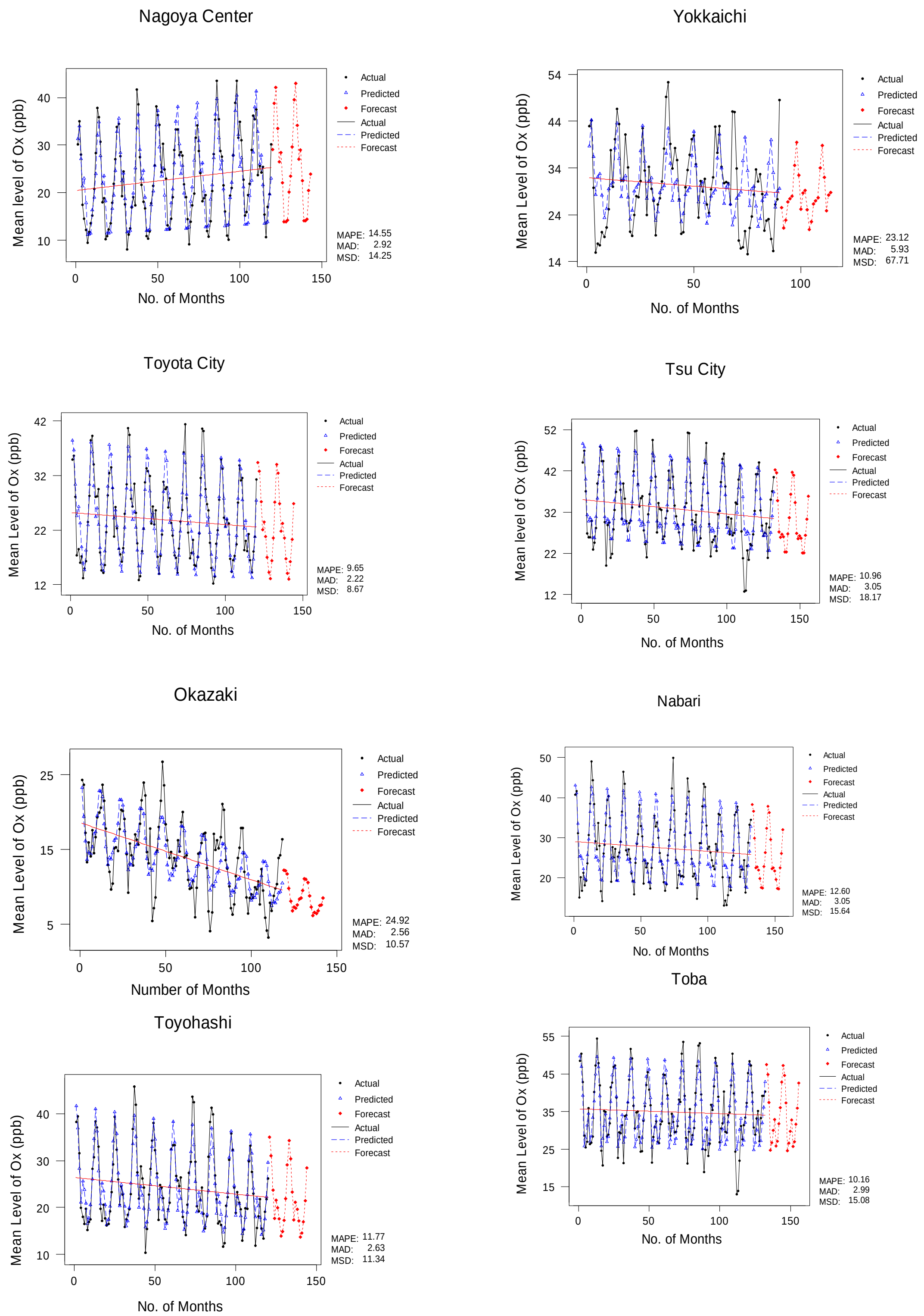


Figure 2: Seasonally Adjusted Trend of the Monthly Mean Level of Ozone (O_x)

Amongst the selected sites, higher mean level of ozone and lowest mean level of NO, NO_2, NO_x, and NMHC existed at coastal resort site of Toba, while opposites were found at the Okazaki (includes several national highway interchanges) where higher amount of precursor pollutants from traffic contributes to the added level of precursors. Red lines in the figure indicate the average trend of the monthly mean level of ozone. Table 1 shows the trend equations predicting the monthly mean levels of ozone and precursors at the selected sites.

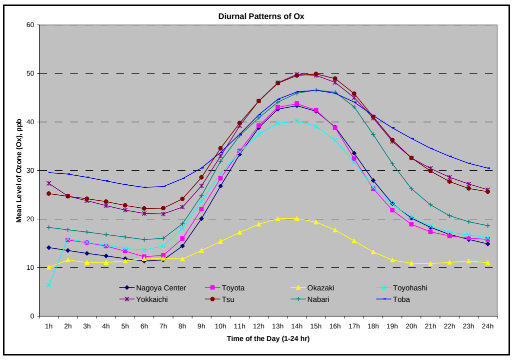
Table 1: Trend Equations Predicting the Monthly Mean Levels of ozone and precursors

Sites	Trend Equations	Significance (MAPE) Value
Nagoya Center	O_x (ppb) = 20.55 + 0.0424*t; NMHC (ppb)= 356.80 – 1.50*t NO (ppb)= 14.67 – 0.022*t	O_x:34.96 NMHC:21.38 NO:87.52
Toyota City	O_x (ppb) = 25.23 - 0.022*t; NMHC (ppb)= 262.67 – 0.48*t NO (ppb)= 8.49 + 0.014*t	O_x:9.65 NMHC:11.75 NO:14.26
Okazaki	O_x (ppb) = 18.59 - 0.076*t; NMHC (ppb)= 392.29 – 1.30*t NO (ppb)= 122.15 – 0.066*t	O_x:24.92 NMHC:10.99 NO:12.28
Toyohashi	O_x (ppb) = 26.39 - 0.035*t; NMHC (ppb)= 206.74 – 0.48*t NO (ppb)= 9.59 + 0.013*t	O_x:11.77 NMHC:11.13 NO:14.29
Yokkaichi	O_x (ppb) = 31.92 - 0.036*t; NMHC (ppb)= 157.88 – 0.35*t NO (ppb)= 2.28 + 0.064*t	O_x:23.12 NMHC:15.49 NO:35.97
Tsu	O_x (ppb) = 35.07 - 0.035*t; NMHC (ppb)= 176.75 – 0.74*t NO (ppb)= 3.35 + 0.014*t	O_x:10.96 NMHC:20.13 NO:18.77
Nabari	O_x (ppb) = 29.08 - 0.025*t; NMHC (ppb)= 142.93 + 0.35*t NO (ppb)= 2.87 + 0.028*t	O_x:12.60 NMHC:12.59 NO:14.26
Toba	O_x (ppb) = 35.71 - 0.013*t; NMHC (ppb)= 129.97 – 0.068*t NO (ppb)= 2.23 + 0.047*t	O_x:10.16 NMHC:53.92 NO:10.16

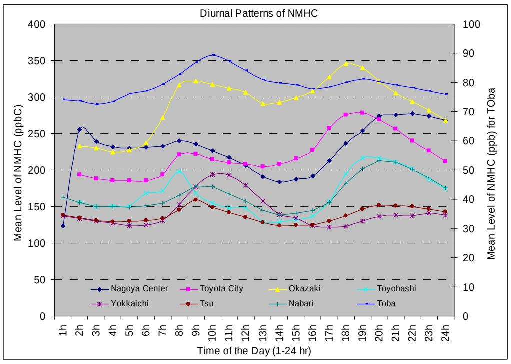
As shown in the Table 1, except for Nagoya center, all other sites exhibits a slightly downward trend in the monthly mean level of ozone but despite decreasing trend of NO level at Nagoya Center, monthly mean of Ox is increasing. The monthly mean level of NO is in slightly increasing trend in all the sites except for Nagoya center and Okazaki site. Monthly mean level of NMHC is also is decreasing trend in all the sites except for Nabari considered due to additional contributions of NHMC from biogenic sources.

3.2 Diurnal Patterns of Ozone (O_x) and its Precursors

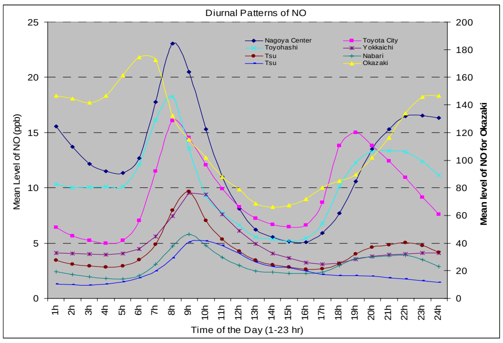
Figure 3.1 shows the typical patterns of diurnal variations of ozone and its precursors at the selected sites of different land habitats. A day time increase and night time decrease in ozone levels were observed at all the sites. A peak level of ozone also appeared at about the same time of the day (14:00-15.00 hr) at all sites implying that ozone peak level was reached due to local photochemical processes, and an ozone lean level was reached in the late morning due to scavenging of ozone by freshly emitted NO during the morning traffic rush (06:00- 07:00 hr). Peak levels of NO were found between 09:00-10:00 hrs in the morning contributed mainly by the traffic rush hours. Distinct afternoon lean and evening peak levels of NO were found respectively at about 15:00-16:00 hr and 20:00-22:00 hrs respectively at all the sites. Morning peak levels of NO_2 and NMHC also reached simultaneously at about 09:00 hrs and proceeded to the peak level of NO by about one hour in all the sites but the evening peaks of NO_2 and NMHC reached at about 20:00 hrs at all the sites. However, comparatively higher mean level of NO, NO_2, and NMHC were observed at the sites of Aichi prefecture compared to the sites of Mie prefectures considered due to higher of traffic as well as industrial activities in the Aichi prefecture.



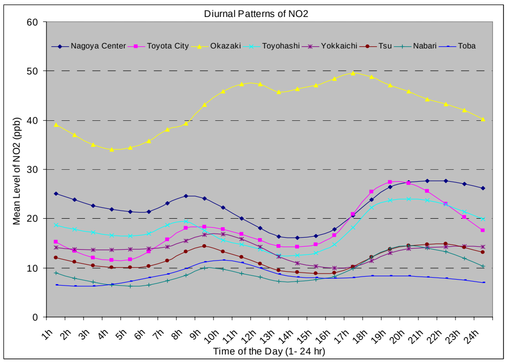
(a) Ozone (Ox)



(b) Non-methane Hydrocarbon (NMHC)



(c) Nitric Oxide (NO)



(d) Nitrogen Dioxide (NO_2)

Figure 3.1: Diurnal Patterns of Ozone (O_x)

Figure 3.2 shows the diurnal variations in the ratio of NO_2 and NO that follow a distinct pattern during the whole day and also showed a relationship with the variations in ozone levels. The ratio (NO_2/NO) reaches at the minimum level during the morning traffic rush when maximum level of NO emitted from the traffic and photochemical process begins. But the minimum levels reached first (about 08:00 hr) at the all the Aichi sites while the minimum levels reached at about 09:00 hrs at all the sites of Mie prefecture. However, the ratio starts increasing along with the consumption of NO_2 due to its photochemical conversion into O_x as well as simultaneously lesser amount of emissions of NO and NMHCs during the traffic lean period (11:00 to 17:00 hr). As the ozone production level starts decreasing after the late afternoon, NO_2 level starts building up and the ratio reaches to the peak level at about 17:00-18:00 hr considered to be due to two reasons: (a) emission of NO from the evening traffic rush and other industrial and commercial sources; (b) emitted NO undergoes through the catalytic reaction process with the existing ozone to convert it again into NO_2 and O_2 molecule. However, the peak ratio starts decreasing again gradually during the night may be due to relatively less traffic emissions.

Figure 3.3 presents the diurnal patterns of the ratio NMHC/NOx for the selected sites. Similar to the ratio NO_2/NO, NMHC/NOx also follows a pattern of morning lean and afternoon peak level mainly attributed by the emissions patterns from traffic and industrial activities in the region but the magnitude of the ratio varies between the sites of the Aichi and Mie prefectures. This indicates that NMHC contributes in higher proportion in ozone productions processes at all the sites of Mie prefecture compare to the sites of Aichi prefecture.

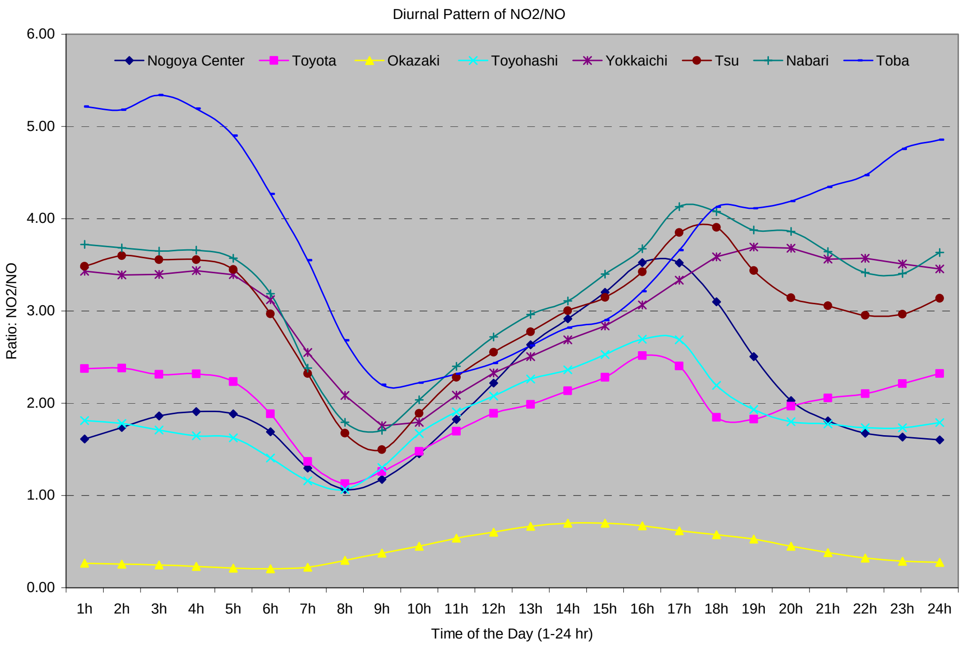


Figure 3.2: Diurnal Patterns of NO_2/NO

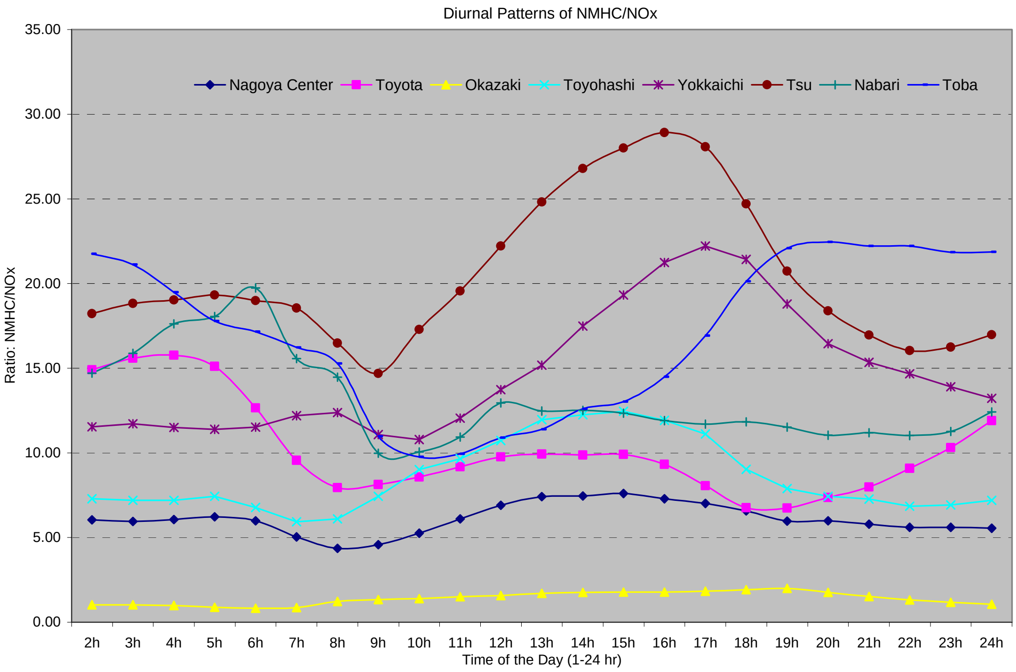


Figure 3.3: Diurnal Pattern of NMHC/NOx at different Sites

Regarding the daily production and destruction of ozone at the selected sites, local ozone production rates (ranged from 1.39 to 4.54 ppb/hr) are relatively higher than that of ozone destruction rates (ranged from 1.39 to 3.10 ppb/hr). Despite highest rate of emissions of ozone precursors, at Okazaki, both production and destruction rate of ozone were the lowest perhaps due to wind transportation of the precursors to distance places before being converted into ozone. Opposites was the phenomena at Toba, where despite relatively lower level of precursor emission, higher level of ozone was observed as the precursors are transported from the urbanized cities by the north-west blown wind to this site.

3.3 Seasonal Variations of Ozone and Precursors

In general, stronger correlations exist between the parameters in the winter (December to February) compared to the summer (June to August) at all the sites although the degree of such relationships differs between the sites. Higher NO_2/NO ratios were observed at all the sites during the spring season and lower in the winter considered due to higher level of NO emissions from traffic and heating systems. Table 2 shows the mean of daily mean values of ozone, NMHC/NO_x, and NO_2/NO of different sites during different seasons (winter, spring, summer, and autumn). As shown in the Table 2, a higher mean level of ozone was observed during the spring season irrespective of the sites. Amongst the sites, higher mean levels of ozone were observed at the coastal cities of Yokkaichi, Tsu, and Toba.

Table 2: Mean of daily mean levels of O_3, $NMHC/NO_x$, and NO_2/NO

Sites	Parameters	Winter	Spring	Summer	Autumn
Nagoya Center	O_x (ppb)	16.17 ±8.01	32.88±11.60	25.77±12.85	16.11±10.10
	$NMHC/NO_x$	8.36±6.55	12.50±7.13	16.69±9.44	9.38±6.09
	NO_2/NO	2.62 ±3.08	6.82±11.81	6.24±11.79	3.45±4.46
Toyota	O_x (ppb)	17.99±6.62	33.35±10.12	25.39±11.94	18.49±8.83
	$NMHC/NO_x$	6.73±2.41	10.37±4.25	13.75±4.58	9.96±3.91
	NO_2/NO	2.04±0.96	3.70±1.14	3.14±1.11	2.57±1.17
Okazaki	O_x (ppb)	15.22±4.81	18.46±6.80	11.52±6.09	10.79±4.99
	$NMHC/NO_x$	2.17±1.40	2.19±118	2.53±1.28	2.23±1.09
	NO_2/NO	0.47±0.32	0.61±0.36	0.45±0.22	0.41±0.25
Toyohashi	O_x (ppb)	19.92±7.95	35.79±9.90	22.84±10.82	18.936±8.25
	$NMHC/NO_x$	5.33±3.12	7.81±4.56	10.20±4.75	8.0±5.04
	NO_2/NO	1.06±0.90	2.69±1.74	2.08±1.21	1.36±1.10
Yokkaichi	O_x (ppb)	26.56±10.66	39.45±13.31	29.39±14.19	24.57±12.23
	$NMHC/NO_x$	6.55±3.06	8.38±3.86	10.85±4.43	8.63±3.99
	NO_2/NO	4.27±4.87	5.31±4.39	5.46±5.26	4.92±6.72
Tsu	O_x (ppb)	29.50±10.20	43.26±12.09	30.67±13.66	27.25±10.09
	$NMHC/NO_x$	6.45±3.06	11.40±9.51	14.19±9.41	9.0±5.28
	NO_2/NO	3.38±1.54	4.42±1.49	4.30±3.07	3.86±2.93
Nabari	O_x (ppb)	24.36±8.99	38.55±10.02	25.35±11.84	21.17±8.47
	$NMHC/NO_x$	8.74±2.03	14.65±6.13	22.47±6.92	15.10±6.10
	NO_2/NO	3.21±1.12	4.60±1.60	4.19±1.69	3.86±1.55
Toba	O_x (ppb)	32.98±9.43	46.61±11.30	29.70±14.04	30.09±10.53
	$NMHC/NO_x$	7.28±4.57	11.71±10.18	15.79±15.04	9.52±7.67
	NO_2/NO	3.74±1.41	4.11±2.42	4.47±3.89	5.09±5.65

Despite higher level of NO emissions at the Nagoya center, and Okazaki, lower levels of ozone were observed at these sites indicating the scavenging of accumulated ozone by freshly emitted NO at the busy roads and several highway interchanges, and also wind transport of precursors to the distanced sites before being converted into ozone. A higher ratio of $NMHC/NO_x$ during the summer indicates higher contribution of NMHC from biogenic and anthropogenic sources in ozone production process.

3.4 Correlations Analysis of the Interaction Patterns between Ozone and its Precursors

Regarding the correlations between ozone and its precursors, the ratio of NO and NO_2 strongly influence the ozone production and destruction process but the strength of such correlations varies with the land habitats. Coastal resort site of Toba showed relatively higher correlations (R^2=0.73) followed by the other sites (0.46<R^2=0.64). All the sites showed the linear relationships between NO_2 and NO. Significant correlations existed between NO_2 and NO in the range of (0.40<R^2 <0.73) which indicates that photochemical conditions (temperature, solar radiations etc.) are more or less similar in the whole region.

Highly significant correlations were found between NO_x and NO (R^2 >0.91) at Nagoya center, Toyota city, Okazaki, and Toyohashi sites of Aichi prefecture indicating that NO emissions remains the dominant precursors to ozone at these sites. Strong relations were also found in other sites of Mie prefectures ($0.78<R^2<0.87$) indicating that traffic and other industrial emissions remains the predominant sources of precursors albeit in a lower scale for ozone productions in the region. Moderate correlations also exist between NO_x and NMHC ($0.22<R^2<0.46$) at all sites except for Toba where very weak correlations (R^2=0.14) exists. This reveals that contribution of NMHC on the ozone production is also higher in the more urbanized cities with characteristics of higher traffic density, industrial emissions sources, and higher number of gasoline stations compared to the less urbanized site of Toba with characteristics of relatively less traffic.

However, considering the slopes of the linear relationships between ozone and NO_2/NO as the intensity of the ozone production rates, Toyohashi, Toyota city, Okazaki, Nabari, and Tsu city sites showed the relatively higher intensity for ozone production (slope > 3.00) while for other sites showed relatively lower intensity and the slope values remain below 1.0. This indicates that influence of the ratio of NO_2 and NO on the ozone production is significantly higher at the more urbanized sites compared to the other sites. On the other hand, linear relationship between ozone and NMHC/NOx at all the sites showed very low slope values (<1.0) indicating insignificant influence of NMHC on the ozone production processes.

3.5 Seasonal Relationship in Interaction Pattern among Precursors

A stepwise multiple regression analysis between Ox and its precursors as well as meteorological parameters (wind direction, wind speed, and temperature) was done to examine the partial correlation coefficients of the parameters influencing the relationship. We considered partial correlations coefficients over 0.1 (10%) as significant parameters influencing the relationships with O_x. Table 3 shows the parameters that significantly influence the relationships for different seasons.

Significantly strong relationships between NO_x and NO existed at all sites with slight variations in different seasons ($R^2>0.60$) indicating that dominant sources of NO emissions remain same all over the year. Correlations between NO_2 and NO at all the sites showed a moderate relationships ($0.21<R^2<0.48$) but varied with the land habitats. Regression results between ozone and NO_2/NO for different seasons have been presented in the Table 4.

Table 3: Parameters Influencing the Ozone Level (Partial Coefficients in Parentheses)

Sites	Winter	Spring	Summer	Autumn
Nagoya Center	NO (0.15), NMHC/NOx (0.43)	NO_2 (0.3), Temp (0.25), NO_2/NO (0.13), WS (0.11), NO (0.1)	NO_2/NO (0.19), NO (0.29), WS (0.23), NO_2 (0.18)	NO_2/NO (0.39), NO (0.15), WS (0.17), NMHC (0.13)
Toyota	NO_2/NO (0.31), NO(0.20), WS(0.20)	NO_2/NO (0.31), NO2(0.48)	NO_2/NO(0.67), NO_2 (0.28), CO(0.17)	NO_2/NO (0.59), NO_2 (0.14),
Okazaki	NO(0.55), WS (0.23), NMHC/NOx (0.15), NO_2/NO (0.14)	NO_2/NO (0.18), NO_2 (0.16), WS (0.34)	NO_2/NO (0.21), NO_2 (0.49), W S (0.18)	NMHC/NOx (0.19), NO(0.32), NO_2 (0.16), WS (0.23)
Toyohashi	NO_2/NO (0.44), WS (0.12), NO(0.14), NO_2 (0.13)	NO_2/NO(0.59), NO (0.29), NMHC/NOx (0.28)	NO2/NO (0.80), NO_2 (0.18), NO (0.14), NMHC (0.18), NMHC/NOx (0.18)	NO_2/NO (0.74), NO_2 (0.20), NO (0.27), NMHC/NOx (0.20), NMHC (0.16).
Yokkaichi	NO_2(0.44), NO (0.14), WS (0.11)	NO_2 (0.32), NO (0.18)	NO (0.28), NO_2/NO (0.15)	NO (0.27), NO_2 (0.18), NO_2/NO (0.16), WD (0.12)
Tsu	NO_2 (0.24), WS (0.15), NMHC (0.15)	NO_2(0.22), NO (0.19)	NO (0.51), NMHC (0.22)	NO (0.27), NMHC/NO_x (0.15), NO_2 (0.12)
Nabari	NO_2 (0.37), WS (0.29), NO_2/NO (0.24)	NO_2 (0.41), NO_2/NO (0.30), WS (0.28)	NO_2/NO (0.27), NO (0.23)	NO_2/NO (0.42), NO_2 (0.22), WS (0.16)
Toba	NO_2 (0.83)	NO_2 (0.23), NO (0.11)	NO(0.37), NO_2 (0.21), WD (0.17)	NO_2 (0.18), WD (0.14), NO (0.11)

Table 4: Relationship of NO_2/NO and NMHC/NO_x with O_x for Different Seasons (R^2 values)

Seasons	NO_2/NO		NMHC/NO_x	
	Winter	Summer	Winter	Summer
Nagoya Center	0.37	0.00	0.60	0.18
Toyota	0.56	0.48	0.26	0.09
Okazaki	0.02	0.07	0.00	0.00
Toyohashi	0.75	0.50	0.12	0.00
Yokkaichi	0.11	0.12	0.21	0.08
Tsu	0.34	0.11	0.25	0.13
Nabari	0.33	0.31	0.00	0.00
Toba	0.07	0.06	0.22	0.02

It was found that, except for Okazaki, Yokkaichi, and Toba, significant correlations ($0.30<R^2<0.75$) existed between ozone and NO_2/NO in the winter at Nagoya center, Toyota, Toyohashi, Tsu, and Nabari. However, less seasonal variations were found at Toyota, Toyohashi, Tsu, and Nabari. Both Okazaki city and Yokkaichi city acts as sources of ozone precursors as Yokkaichi city includes major industrial installations of the region and Okazaki city includes several interchanges of national highways that passes huge volumes of traffics everyday. Although Toba is a coastal resort city but it produces less ozone precursors but the effects of meteorological factors significantly influences on the variations of ozone as well as precursors levels. Regarding the interaction pattern between ozone and the ratio NMHC/NO_x, significant effects of NMHC/NO_x on ozone production process were found at Nagoya city center, Yokkaichi, Toyota city, and Tsu in the winter season only. For all other seasons, no significant relationships were found for all the sites indicating that influence of NMHC in ozone production processes are less compared to NO_2/NO.

4. CONCLUSION

Characteristics of interaction pattern of ozone (O_x) and its precursors (NO, NO_2, NO_x, and NMHC) at eight different land habitat sites of Aichi and Mie prefectures showed some interesting relationship between ozone and the photochemical indicators (NO_2/NO, and NMHC/NO_x) in terms of the trend, diurnal variations, and seasonal effects at different sites. The ozone production and destruction processes are greatly influenced by the interactions between the precursors (e.g. NO-NO_2, NMHC-NO_x) and the strength of such interactions is dominant at most urbanized sites. In all the sites, ozone interaction behavior is significantly influenced by the variations in NO_2/NO ratio but strength of such interactions varies with seasons, and with respect to land habitats. The small range in the ratios of NO_2 and NO in all the sites (mean value of $NO_2/NO < 5.0$) and moderate slopes between ozone and NO_2/NO indicates the similar dominant sources of precursors (e.g. traffic emissions) and generally lower level of ozone. However, relatively higher daily production rates over destruction rates in ozone level also indicates the potential of gradual increase in the long term ozone level in the region.

ACKNOWLEDGEMENTS

Authors acknowledge and thank Japan Society for Promotion of Science (JSPS) for providing funds and Bioresources faculty of Mie University for logistic supports in carrying out of this study.

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