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NATIONAL AMBIENT AIR QUALITY OBJECTIVES FOR GROUND-LEVEL OZONE

SCIENCE ASSESSMENT DOCUMENT

A Report by
the Federal-Provincial Working Group
on Air Quality Objectives
and Guidelines

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Part 2 of 7

Canada

5 ENVIRONMENTAL LEVELS

The information in this chapter is based primarily on that presented in the Report of the Data Analysis Working Group (Multistakeholder NO_x/VOC Science Program, 1997).

This chapter provides information on ambient levels of ground-level ozone and the climatic conditions contributing to elevated ozone levels in different areas of Canada. The chapter begins with a discussion of background ozone concentrations. Ambient ozone data are then analyzed to explore seasonal, diurnal and weekday-weekend patterns in ozone levels, as well as long term trends. These analyses are all based on 1 hour ozone data. The chapter concludes with a discussion of ozone data for an 8 hour averaging period and an analysis of the relationship between 1 hour and 8 hour data is presented.

For a more comprehensive treatment of ozone concentrations and discussion of the factors affecting these, readers should consult the Report of the Data Analysis Working Group: Ground Level Ozone and Its Precursors, 1980-1993 (Multistakeholder NO_x/VOC Science Program, 1997). This same report should also be consulted for information on ambient levels of NO_x and VOC in Canada.

5.1 BACKGROUND OZONE CONCENTRATIONS

Ozone concentrations at remote rural sites are measured in order to estimate background levels in the absence of (significant) anthropogenic ozone. Background ozone at remote sites is a product of natural sources of the gaseous precursors, long range transport of ozone, and contributions from stratospheric intrusion. The natural background level of ozone at remote sites provides a lower limit target for ozone reduction through the control of anthropogenic nitrogen oxide (NO_x) and volatile organic compound (VOC) emissions.

5.1.1 Literature Review

A review of the literature provided estimates of background ozone concentrations for a number of countries in both the northern and southern hemisphere.

Background concentrations are estimated from sites considered to be representative of the well-mixed boundary layer. Several parameters were considered in selecting sites which could provide appropriate data. Broadly taken, the characteristics of the selected sites were that they should be remote from anthropogenic sources, exhibit minimal diurnal variation, be representative of continental air masses, and be representative of the free troposphere.

There are two general characteristics of ozone concentrations at remote sites. First, they generally exhibit diurnal trends of less than about 5 ppb. Second, the highest ozone concentrations occur in late winter or early spring. The literature review indicates that, based on comparisons of current concentrations with those estimated for the late 1800s, there are no locations truly unaffected by anthropogenic ozone. One possible exception is American Samoa, which currently has the lowest observed ozone level in the world (Oltmann & Levy, 1994; Oltmann & Komhyr, 1986). It has been proposed that anthropogenic activities have resulted in an increase in surface ozone concentrations which are estimated globally to be two to four times greater than pre-industrial levels (Bozo & Weidinger, 1995; Cartalis & Varotsos 1994; Altshuller, 1987; Bojkov, 1986; Singh, et al. 1978). Historical data and modelled estimates of average daytime ozone concentrations under conditions not affected by anthropogenic emissions give a range of 10-20 ppb.

Given the prevalence of anthropogenic sources of precursor emissions and the near-complete mixing throughout the boundary layer, the origin of sampled air masses ought to be considered, (e.g. by using trajectory analysis). Unfortunately, very little of the ozone from remote sites is reported with the necessary concurrent meteorological information.

Literature Estimates of Daily Maximum One Hour Ozone Concentrations

Table 5.1. provides estimates of average daily maximum ozone concentrations (for all months). Not all studies accounted for the occasional impact of polluted air masses, thus the ranges reported occasionally extend to greater than 50 or 60 ppb. For example, the estimate for the western United States summertime daily maxima range is from 50 to 78 ppb, which is indicative of the infrequent impact of polluted air masses from anthropogenic source regions or isolated events such as forest fires (Altshuller & Lefohn, 1996). The range of reported daily maximum ozone for continental air masses in the northern hemisphere is 30 to 60 ppb. Estimates of daily maximum concentrations, from studies using trajectory analysis to identify the least affected remote sites, fall at the lower end of the range, 30 to 40 ppb. Higher concentrations may be observed during late spring or early summer due to stratospheric intrusion.

Table 5.1 Average Daily Maximum Ozone Concentrations in the Northern Hemisphere

Reference	**Location**	**Range of Daily Maximum Hourly Ozone (ppb)**
Angle and Sandhu, 1986	Northern Alberta, Canada	27 - 66
Altshuller and Lefohn, 1996	Western U.S., summertime	50 - 78
Colbeck and Harrison, 1985	Stodday, UK	41.5 - 50.6
Evans et al., 1983	U.S. National Forests	33 - 49
Kelly et al., 1982	South Dakota, U.S.	34 - 36
Legge et al., 1991	Rocky Mountains, Alberta, Canada	64.2
Singh et al., 1978	Continental U.S.	17 - 75
	Hawaii, U.S.	30 - 59
	Germany	18 - 52

Estimates of Average Monthly Concentrations

For data records greater than one year, the average of the monthly means is often reported to evaluate seasonal differences in ozone concentrations. Higher values are typically found in the late winter through early spring months. Monthly means from a number of remote sites have been shown to fall in the range of approximately 20 to 45 ppb. Higher values are observed at high elevation sites.

A spring through early summer ozone maximum was observed at many rural and remote sites in the Northern Hemisphere mid-latitudes in the late 1850s to early 1900s (Lisac & Grubisic, 1991; Feister & Warmbt, 1987; Mukammal et al., 1985; Meagher et al., 1987). In the 1980s and 1990s, the spring maximum has also been observed at a number of remote sites (Angle & Sandhu, 1989; Meagher et al., 1987; Scheel et al., 1990; Singh et al., 1978). However, at some remote sites, a summer maximum is becoming more evident as a result of an increase in the importance of photochemical production of ozone from precursor emissions (Hough & Derwent, 1990). The spring maximum is believed to be influenced by the annual cycle of stratospheric ozone production and stratospheric intrusion (Junge, 1962; Logan, 1985). Although at some sites, the relative importance of stratospheric/tropospheric processes versus photochemistry is decreasing (Follows & Austin, 1992) or small (Altshuller, 1987; Liu et al., 1987; Fabian & Pruchniewicz, 1976), there are other sites where seasonal and regional differences of stratospheric/tropospheric processes can strongly influence ozone concentrations (Penkett & Brice, 1986). The yearly mean flux of stratospheric ozone is highest between 30°N to 60°N latitudes (Singh et al., 1978; Fabian and Pruchniewicz, 1976). Altshuller (1987) concluded that average spring through summer background ozone contributions from stratospheric intrusion or upper tropospheric ozone were <10 ppb, while other studies suggest that stratospheric contributions to high ozone levels can be significant (Wakamatsu et al., 1989; Derwent et al., 1978).

A short study to estimate the contribution of stratospheric ozone to surface-measured ozone was carried out during February to May, 1992, at Mt. Tremblant in Québec (Besner et al., 1994). This limited study indicated that the stratospheric ozone contribution to surface ozone was about 6 to 20%. However, contrary to expectations, the lowest percentages were associated with meteorological conditions considered most conducive to stratospheric input (specifically, passages of cold fronts). In reviewing the many studies on stratospheric contribution to tropospheric surface ozone, the conclusions are fraught with large uncertainties and the results are as yet inconclusive.

Summer Season

Given the ubiquitous impact of anthropogenic emissions in the well-mixed boundary layer, it is relevant to assess background concentrations during the summer when photochemical production of ozone is most significant. The range of monthly averages for the period May through September is approximately 25 to 45 ppb. Since the spring maximum usually occurs in April to early June, and the seasonal minimum in September to November, this range in summer concentrations reflects the entire seasonal range (see above), especially in very clean areas where the seasonal amplitude is small.

Estimates of Annual Averages

The annual average hourly ozone concentrations at remote sites is typically higher than at anthropogenically influenced sites, given the strong influence of precursor emissions on the diurnal pattern of the latter. In urban areas, ozone concentrations often fall to near zero at night due to titration by NO (see section 5.3.2 for more detail). For example, the 1989 annual average at Jardin Botanique, Montréal, was 17.0 ppb with a standard deviation of 16.6. For the same year, Montmorency, a forested site north of Québec City, had an annual average of 32.9 ppb with a standard deviation of 10.8.

5.1.2 Ozone Concentrations at Remote and Rural Sites in Canada

Fifteen Canadian sites (Figure 5.1) have been identified as characteristic of regions with little anthropogenic influence that have the potential to provide estimates of background ozone levels in Canada. Not all the sites are currently in operation. The relevant metrics of the ozone concentrations at these sites are presented in Table 5.2. These statistics were selected as being indicative of the behaviour of ozone in remote areas, i.e., low daily maximum concentrations and minimal seasonal amplitude in average monthly concentrations, with highest monthly averages observed in early spring (April and May).

The typical range of monthly average concentrations observed at remote sites in Canada is 20 to 40 ppb (Column 7 Table 5.2), with 12 month average daily maxima from about 30 to 40 ppb. Typical average daily maxima are higher for the summer period (May through September) and are in the range from 35 to 50 ppb (Column 6 Table 5.2 and graphically in Figure 5.2). This illustrates the impact of higher concentrations in the spring, which occasionally extend into May, and the impact of photochemical reactions, which are more prevalent in the warmer summer months.

Those sites marked with an asterix (*) in Table 5.2, that show higher average annual maxima (in Nova Scotia, southern Québec and central Ontario), are affected by anthropogenic emissions due to long-range transport. To truly characterize the background ozone concentrations at these site would require a detailed wind or trajectory analysis.

The ozone at these remote and rural sites is influenced by elevation and mountain top sites generally exhibit higher concentrations. These higher elevation sites may be within the free troposphere and more frequently affected by stratospheric intrusion, as described in the previous section. Typically, sites above 850m experience higher ozone concentrations (Lefohn et al.1990a; Wolff et al. 1987).

Figure 5.1 Rural and Remote Sites in Canada

Table 5.2 Summary Statistics for Canadian Remote and Rural Sites

Site	Data Record (Avg. Period)	Elevation	Average of Annual Max.[1]	Average for Data Record[2]	Range of Average Daily Max. (May - Sept.)[3]	Range of Monthly Average[4] (All Months)
Alert, N.W.T.	1/92 - 12/94	210m	47.3	28	24 - 27	16 - 35
Sable Island, NS*	1/92 - 12/94	4m	129.3	34	39 - 45	27 - 47
Kejimkujik, NS*	4/85 - 12/92	155m	100.3	27	37 - 47	20 - 34
Mt. Tremblant, Que.*⁺	1/87 - 12/94	860m	107.6	34.8	46 - 54	28 - 45
Mt. Sutton, Que.*⁺	1/87 - 12/94	845m	100.0	36.9	49 - 58	28 - 46
Sutton Valley, Que.*	1/87 - 12/94	250m	86.6	29.7	41 - 49	24 - 39
Montmorency, Que.	5/88 - 12/92	790m	92.0	29	37 - 45	25 - 35
Chapais, Que.	6/88 - 12/90	381m	82.7	27	40 - 41	18 - 35
Dorset, ON*	4/81 - 12/91	na	100.5	28	41 - 55	21 - 34
Fraserdale, ON	3/90 - 12/94	205m	80.7	28	35 - 39	22 - 37
Hawkeye Lake, ON	6/83 - 12/91	na	76.0	27	36 - 48	21 - 38
ELA, ON	5/88 - 12/92	369m	73.3	33	37 - 43	26 - 40
Prince Albert NP, SK	2/94 - 09/94	na	57	~25	~30	22 - 39
Esther, AB	7/94 - 9/95	707m	64.0	26	45 - 45	18 - 34
Saturna, BC*	5/91 - 12/92	178m	65.0	25	38 - 41	

[1] Average of the maximum hourly ozone concentrations observed each year over the entire data record.

[2] Average of all hourly ozone concentrations observed for the entire data record.

[3] Range in average of daily one-hour maximum ozone concentrations for May-Sept. computed for each year.

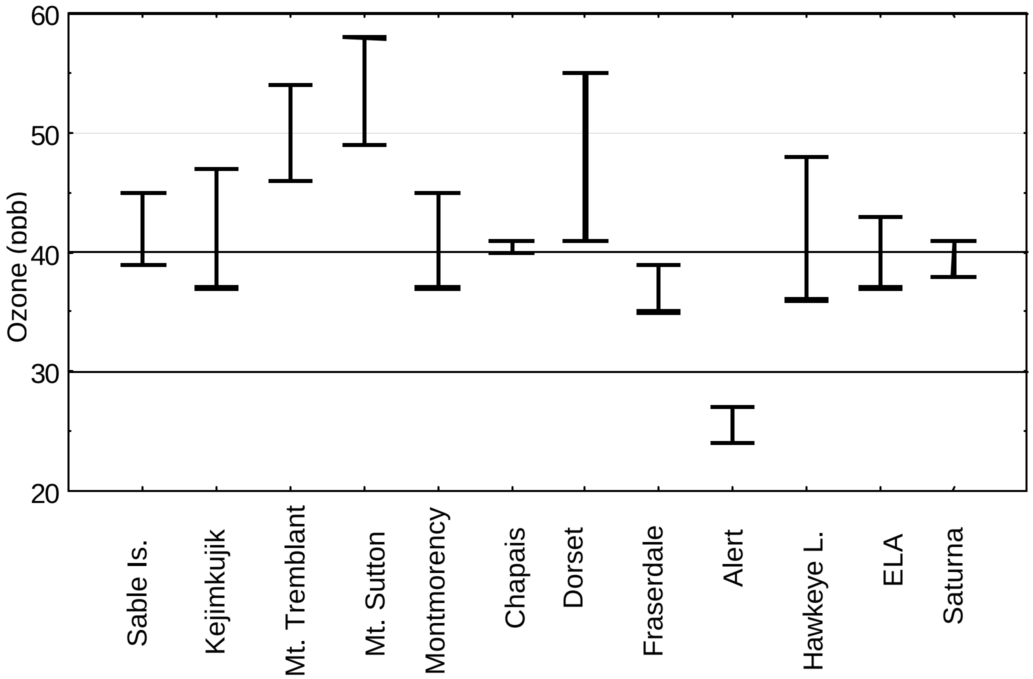
[4] Range of monthly average ozone concentrations, averaged over entire data record.

* indicates sites affected by long-range transport of anthropogenic emissions

⁺ indicates mountain-top sites

Alert, NWT may be considered as the only truly remote site at which ozone data are currently available in Canada. There are no anthropogenic sources nearby, nor is it located within major atmospheric transport corridors which could carry anthropogenic emissions to it. Another continental site with the potential to experience clean air masses is Fraserdale, Ontario.

Figure 5.2 Yearly variation in Mean Daily Maximum Hourly Ozone Concentrations (May to September) for Selected Remote and Rural Sites



5.1.3 *Summary*

Background ozone concentrations vary seasonally and geographically; thus it is not possible to identify a single value for background ozone concentrations. The ozone concentrations observed at remote sites in Canada are similar to those reported for other locations in the Northern Hemisphere (Lefohn et al. 1990b). Reasonable estimates for the range of ozone concentrations at rural remote Canadian surface sites, and typical of the Northern Hemisphere, are:

Average daily 1-hr. maxima (all months)	30 - 48 ppb
Average daily 1-hr. maxima (May - Sept.)	35 - 48 ppb
Monthly 1-hr. average (May - Sept.)	25 - 40 ppb

5.2 GEOGRAPHIC AND METEOROLOGICAL FACTORS AFFECTING OZONE IN CANADA

An overview of the impact of local meteorology and long-range transport is presented below, followed by a more detailed description of the geographic and meteorological factors contributing to ambient ozone levels in different regions of Canada.

5.2.1 Local Meteorology

Meteorological processes play a significant role in the movement of ozone and its precursors. High ozone episodes are often associated with slow moving, high pressure weather systems which concentrate pollutants and provide the higher temperatures and solar radiation that enhance ozone formation. These weather systems are characterized by sinking of air through much of the troposphere, which has the effect of trapping localized pollutants and preventing their dilution through convective mixing into the upper troposphere.

Temperature inversions associated with these events are experienced in all parts of Canada, but are especially significant in the Lower Fraser Valley region of B.C. where adjacent mountains act to further confine the air mass. With high pressure weather systems, surface winds are typically light, prompting the accumulation of pollutants near the ground. These effects are most pronounced close to the summer solstice (May-September) when ambient temperatures, sun angles and day length favour ozone formation. With the passage of cold air, the high pressure ridge breaks down permitting the entry of cooler, cleaner air and the subsequent mixing of ambient pollutants.

5.2.2 Long-Range Transport

Establishing the distinction between ozone generated locally and that occurring as a result of advection by winds into a region (known as long-range transport or LRT) is vital to understanding and controlling ambient ozone levels. Previous studies in the Windsor-Québec City corridor (Yap et al., 1988) and the Southern Atlantic region (Thorburn, 1981), have estimated that long-range transport from the United States often accounts for a significant percentage of the ozone and its precursors (NO_x and VOC) observed in these regions during episode conditions.

Ozone and its precursors can be transported over distances that range from hundreds to a few thousand kilometres. Before finally arriving at a receptor site, the pollutants entrained in the air mass may traverse several source areas, change pathways, undergo chemical changes, or experience depletion by dry deposition. Consequently, the task of identifying the contribution of local versus more distant sources is difficult, and is particularly so in areas with multiple sources of oxidants.

Source identification (local and long-range), and quantification of source strength, in situations involving multiple sources that are spread over a broad geographic region with varied emission characteristics, is done with three dimensional air quality emission based modelling. Current modelling results are discussed in the reports of the Lower Fraser Valley Modelling and Measurement Group and the Windsor-Québec City Corridor and Southern Atlantic Region Modelling and Measurement Group (Multistakeholder NO_x/VOC Science Program, 1997).

5.2.3 The Lower Fraser Valley, B.C.

This area extends from the Strait of Georgia in the west to the Fraser Canyon in the east. The valley is bound by the Coast Mountains to the north and the Cascade Range to the southeast. The population of British Columbia is highly concentrated in this lower mainland area, especially within the Greater Vancouver Regional District (with approximately 1.5 million people). Consequently, most anthropogenic emissions for the province originate here, principally, from motor vehicles and, to a lesser extent, from stationary sources, such as commercial and industrial fuel combustion, gasoline refining and retailing (Robeson & Steyn, 1990). Unlike the Windsor–Québec City corridor and the Southern Atlantic region, where significant levels of pollutants can be advected from distant sources, both ground-level ozone and precursors originate primarily in the Lower Fraser region. However, in the eastern part of the valley, NO_x, VOC and ozone can be transported from the state of Washington under appropriate meteorological conditions.

When compared with other urban areas in Canada, precursor emission rates in the Lower Fraser Valley are not especially significant (Canadian Council of Ministers of the Environment (CCME), 1990), but the geographic features of this area can produce high ozone concentrations during synoptic conditions that feature light winds and poor dispersion. Concentrations can also vary spatially within this area. At the eastern end of the Burrard Inlet, the maximum one-hour concentration in any given year averages about 100 ppb, while in the western section of Greater Vancouver District and south Vancouver, ozone levels seldom exceed 82 ppb. Bounded on the west by the waters of the Strait of Georgia and the Pacific Ocean, and with the west-facing mountains to the east, the Lower Fraser Valley experiences light winds, predominantly from the northwest in summer, and frequent easterly flows. Under strong solar radiation input, differential heating between the land and water produces sea breezes, which are quite common in summer. The cool marine air helps to moderate the temperature over the land, but, at the same time, it limits the mixing depth of the polluted air. Further, under stagnant anticyclonic conditions with light wind, the mountains act as barriers to pollutants emitted within the Lower Fraser region, channeling them instead along the valley, which ultimately leads to high levels of ozone and its precursors near the ground.

5.2.4 Alberta, Saskatchewan and Manitoba

The Prairie Region includes Alberta, Saskatchewan and Manitoba. Although this area is denoted as the prairie region, it includes the mountain range and rolling foothills in western Alberta, and the Canadian Shield of northern Saskatchewan and Manitoba. This region lies between the 49th and 60th parallels of the latitude, which places it in the central belt of the northern cool temperate zone. The climate is characterized by long, cold winters, and short, warm summers. Prevailing upper level winds are west-northwest. Because mechanisms governing ozone concentrations are dependent upon climatic variables such as temperature, solar radiation and surface albedo, ozone concentrations measured in the region exhibit different characteristics from those measured in more moderate, southerly climates. Throughout this region, there is a wide range of NO_x and VOC sources, including large industrial point sources, small to medium cities with populations less than three quarters of a million, and extensive areas of biogenic emissions.

Rural long-term averaged ozone concentration is relatively high when compared with those in cities or more southerly locations. Tropopause folding introduces stratospheric ozone into the troposphere where a variety of transport processes move it further downward. Boundary-layer mixing then delivers this ozone to the surface. Stratospheric intrusion, which is the direct injection of extremely high concentrations of ozone to the surface, seems to be rare with only one incident reported in Regina, Saskatchewan. Photochemical reactions with naturally emitted ozone precursors also contribute to rural ozone concentrations.

Background ozone transported from rural locations is largely responsible for episodes of high ozone concentrations at urban stations. However, exceedances of the current 1 hour ozone objective are infrequent, only a few hours per year in larger cities. These exceedances generally occur under hot stagnant weather conditions when photochemical reactions involving anthropogenic emissions can add to the background ozone.

5.2.5 The Windsor–Québec City Corridor

This area, located in the broad geographic region known as the Great Lakes–St. Lawrence Lowlands, is the population and industrial heartland of Canada. It holds almost 60% of Canada's population, produces about 70% of the value of manufactured goods, and has the highest densities of people, agriculture and economic activities in Canada. This corridor also has about half of Canada's large and medium-sized cities, including two of the largest metropolitan areas in Toronto and Montréal. In this area, the principal anthropogenic sources of precursor emissions are from the transportation sector, thermal power plants and a wide range of industrial sources. However, the region lies in the path of major air streams, which are responsible for a significant percentage of pollutants being transported into this area from U.S. sources. The most dominant path follows a northeasterly course through southern Ontario, up through the St. Lawrence River Valley and out to the North Atlantic.

Ozone episodes are more frequent and of longer duration than those in other parts of Canada. This is partly attributed to the usually longer and warmer summers, and frequent anticyclonic (high pressure) conditions. The region has a continental climate, although, in central and western southern Ontario, it is markedly modified by the Great Lakes. The southwestern region of Ontario experiences the longest and warmest summers, averaging 20°C. Temperatures in the large urban areas can be up to 5°C higher than the surrounding countryside, although in Toronto, the opposite effect can occur near the shore of Lake Ontario. The weakest winds occur in the summer and blow predominantly from the southwest.

5.2.6 The Southern Atlantic Region

The topography of this area is typified by rolling hills, mostly below 300 metres in elevation. Forest cover, consisting of mixed evergreen and deciduous species, is extensive. During the ozone season, this region is strongly influenced by air streams from the south and southwest that have travelled from central Canada along the St. Lawrence River Valley, or along the Atlantic seaboard, often crossing the northeastern United States. The majority of episodes of high ozone in the Southern Atlantic region are associated with the long-range transport of pollutants along one of these trajectories. During the fall, winter and early spring, winds blow predominantly from the west and the northwest (e.g. Arctic air flows).

The two regions that experience the highest ozone levels (maximum one-hour concentrations ranging from 90-110 ppb) are western Nova Scotia and southern New Brunswick. However, it should be noted that there are no monitoring sites in northern New Brunswick or eastern Nova Scotia. Based on an examination of all available data, including that from a site on Prince Edward Island, the potential for high hourly ozone concentrations probably exists throughout New Brunswick and Nova Scotia.

Significant metropolitan centres in the Atlantic region include Saint John and Moncton, New Brunswick, with populations of about 125,000 and 102,000, respectively, and Halifax, Nova Scotia, with 320,500 people (1991 census data). Mobile sources contribute to NO_x and VOC emissions in all these centres; both Halifax and Saint John also have power plants and oil refineries, which are significant local sources of NO_x and VOC. There are some additional point sources within the region outside the urban centres, including power plants and pulp and paper mills.

5.2.7 Summary

Both meteorological processes and geographic/topographic features are important factors affecting ambient ozone levels. The meteorological conditions that are necessary for the occurrence of high ozone concentrations are well documented; they involve slow moving, anticyclonic (high pressure) weather systems. These systems, characterized by slow wind speeds, and sinking of air through the troposphere, are conducive to trapping air pollutants near ground level and preventing their dispersion and dilution. Since ground level ozone is a photochemical pollutant, the formation of ozone is maximal over the summer season (May-September), when higher ambient temperatures, more intense solar radiation and longer day lengths favour greater photochemistry. Therefore, ozone episodes are generally associated with climatic and meteorological conditions that lead to both enhanced ozone production and limited dilution/dispersion. Geographic and/or topographic features of a region can exacerbate this situation by affecting either of these processes.

In addition to these factors, some regions of Canada, namely the Windsor-Québec Corridor and the Southern Atlantic Region, are affected by the long range transport of ozone and its precursors from source regions, both within Canada and the United States.

5.3 OZONE CLIMATOLOGY

Ambient monitoring of ozone is performed throughout Canada under the National Air Pollution Surveillance (NAPS) network, a collaboration of federal, provincial and municipal monitoring agencies. There were 153 Canadian ozone monitoring stations reporting data from 1986-93. Of these sites, 112 were located in urban or suburban areas and 41 in rural locales. As discussed in Section 5.1.2, few sites with long-term data sets were located in remote rural locations.

Ozone data were analyzed to illustrate seasonal, diurnal and day-of-the-week patterns in ozone levels. A detailed analysis of all sites in Canada was conducted (Fuentes and Dann, 1993), and only sites representative of different land use (urban, suburban, rural, rural-remote) and different geographical regions are featured here. Most figures deal with the 1986-93 time period and include only the months of May to September. The focus on the “summer” season reflects the months with elevated photochemical ozone, and on the time of year when primary receptors (humans and vegetation) are most at risk due to greater exposure to ambient ozone.

Generally, only sites with more than 75% data capture were used: however, because of a scarcity of monitoring sites in some areas, sites are shown that were not operational in all years between 1986 and 1993. Monitoring at many of the non-urban sites was carried out as part of specific research programs and the data have not been provided to the National Air Pollution Surveillance (NAPS) archive. The province of Québec has operated an extensive rural ozone monitoring network of 16 sites since 1989, but currently data for only five Québec rural sites are in the NAPS database.

Ozone concentration percentiles (5, 10, 25, 50, 75, 90, 95, 98, 99, 99.9), and mean and standard deviation values were calculated for selected stations representative of most cities and regions, as shown in Table 5.3. These ozone statistics are provided for all data between 1986 and 1993 (May to September). Ozone data for several stations were grouped to represent regions (See Table 5.3: Southern Atlantic-AT, Montréal-MO, rural Québec-QE, Toronto-TO, southwestern rural Ontario-SW, Prairies-PR and Vancouver/LFV-VA, Michigan-MI and northern Ohio-OH) or unique site types (elevated: Toronto’s CN Tower-CN and Whiteface Mountain-WF; Ontario lakeshore-LS; rural-remote: Hawkeye Lake-HA and Experimental Lakes Area, (ELA)-EL). Urban sites used for the group analyses were selected primarily on the basis of data completeness, although sites with mean NO concentrations greater than 25 ppb were excluded. Because of the strong gradient in ozone concentrations in Vancouver, only sites in the eastern portion of the city and in the Lower Fraser Valley were included in the Vancouver group. The regional analysis is not presented here; readers are referred to the Report of the Data Analysis Working Group (Multistakeholder NO_x/VOC Science Program, 1997).

For the Canadian sites, mean ozone concentrations ranged from 6.1 ppb (Vancouver-Robson and Hornby) to 44.3 ppb (Long Point). As shown in many studies, mean and median ozone concentrations are highest at rural sites and lowest at downtown urban sites (McKendry, 1993). A look at the lower end of the distribution also shows this difference between rural and urban sites. 25th percentile values of 0-5 ppb are not uncommon at urban sites in B.C. (Vancouver) and Southern Ontario (Toronto, Ottawa), whereas the highest 25th percentile ozone concentration of 28 ppb was recorded at the rural Long Point site. The highest maximum hourly ozone concentrations in the database is 213 ppb, recorded at the Vancouver, Hamilton and Paisley site in 1988. A number of sites in Toronto and southwestern Ontario have experienced maximum ozone concentrations of 170 ppb or greater. The elevated site at Toronto's CN Tower (440 m above the ground) recorded a median ozone concentration of 37 ppb and a 25th percentile value of 24 ppb.

Table 5.3 Ozone Concentration Percentiles (ppb) for May-Sept. 1986 to 1993 - Selected Canadian Sites

Station	City/Province	Address	Reg'n	Start	Stop	% Data	5th	10th	25th	50th	75th	90th	95th	98th	99th	99.9th	Max.	Mean	Std Dev.
10102	St. John's, Nfld.	354 Water Street		5/1/1989	9/30/1993	49	3	6	12	18	25	32	38	49	59	86	97	19.3	11.4
10201	Cormack, Nfld.	Cormack		5/1/1989	9/30/1993	47	10	12	17	23	29	36	40	46	50	61	70	23.6	9.4
20201	North Cape, PEI	North Cape		9/17/1992	9/30/1993	14	16	18	22	27	33	41	49	55	59	88	89	28.6	10.0
30115	Halifax, NS	CFB Shearwater		5/1/1986	9/30/1993	63	6	10	17	25	35	44	50	58	64	80	100	26.3	13.6
30501	Kejimkujik, NS	National Park	AT	5/1/1986	9/30/1992	82	8	11	17	25	34	44	52	64	71	96	150	26.8	13.8
40202	Saint John, NB	Post Office		5/1/1986	9/30/1991	67	2	9	12	20	30	44	51	64	70	100	116	24.7	15.5
40203	Saint John, NB	Forest Hills	AT	5/6/1986	9/30/1993	92	4	9	15	23	32	41	50	60	68	90	113	25.0	14.1
40401	Fundy Nat. Park, NB	Hastings Tower	AT	6/9/1989	9/26/1993	47	16	18	23	30	39	50	58	67	75	92	117	32.4	13.2
40501	Point Lepreau, NB	Main Gate	AT	7/15/1986	9/30/1993	69	0	1	10	24	36	50	60	76	86	122	145	26.0	18.9
40601	Blissville, NB	Airport Road	AT	7/2/1987	9/30/1993	67	0	3	10	20	32	46	56	70	80	114	137	24.3	17.5
40701	Norton, NB	Ball Park	AT	6/5/1989	9/30/1993	50	0	2	12	23	34	45	52	62	69	88	107	24.1	16.0
50102	Montréal, QC	Jardin Botanique	MO	5/1/1986	9/25/1993	82	0	0	10	20	30	40	50	60	70	90	130	18.9	16.5
50103	Montréal, QC	Pointe-Aux-Trembles	MO	5/1/1986	9/30/1993	86	0	0	10	20	30	40	50	60	70	100	130	19.7	17.1
50104	Montréal, QC	1125 Ontario Est	MO	5/1/1986	9/30/1993	91	0	0	10	20	30	40	50	70	70	100	120	19.2	17.1
50110	Montréal, QC	Parc Pilon, Mtl.-Nord	MO	6/1/1986	9/30/1993	84	0	0	10	20	30	50	60	70	80	110	160	20.7	19.2
50113	Montréal, QC	Pie X & Cardinal	MO	5/1/1986	9/30/1993	75	0	0	10	20	30	50	60	70	80	110	130	23.0	19.0
50115	Montréal, QC	1001 Boul Maisonneuve O.		5/1/1986	9/30/1993	89	0	0	0	10	10	20	30	40	50	70	90	9.4	11.5
50116	Montréal, QC	3161 Joseph, Verdun	MO	5/1/1986	9/29/1993	92	0	0	10	20	30	40	60	70	80	100	120	20.7	18.1
50119	Montréal, QC	699 Cure Poirier		6/3/1986	9/30/1993	70	0	0	10	20	30	40	50	60	70	100	130	20.7	17.5
50307	Québec, QC	Parc Cartier Breboeuf		5/1/1986	9/30/1993	87	0	0	0	10	20	30	40	50	50	70	80	13.5	12.4
51501	St. Zephrin, QC		QE	5/21/1987	9/30/1993	46	5	10	16	23	36	50	60	69	71	90	95	26.6	15.8
52001	Charette, QC		QE	5/1/1989	9/30/1993	40	0	10	10	20	30	40	50	60	70	110	140	22.4	15.3
52201	St. Simon, QC		QE	6/2/1989	9/30/1993	40	0	10	10	20	40	50	60	70	70	90	100	25.4	16.6
52301	Faustin, QC		QE	5/1/1990	9/30/1993	35	10	20	20	30	40	50	60	70	80	90	100	31.4	14.7

Table 5.3 Ozone Concentration Percentiles (ppb) for May-Sept. 1986 to 1993 – Selected Canadian Sites

Station	City/Province	Address	Reg'n	Start	Stop	% Data	5th	10th	25th	50th	75th	90th	95th	98th	99th	99.9th	Max.	Mean	Std Dev.
52401	La Peche, QC		QE	5/1/1989	9/30/1993	37	0	10	10	30	40	50	60	70	70	90	100	27.0	16.6
54001	Montmorency, QC		QE	5/31/1988	9/30/1992	49	9	13	19	26	35	44	50	59	66	87	99	27.7	12.7
60101	Ottawa, ON	88 Slater St.		5/1/1986	9/30/1993	85	1	2	5	9	16	24	29	36	41	57	78	11.5	9.2
60104	Ottawa, ON	Rideau & Wurtemburg		5/1/1986	9/30/1993	96	2	4	11	20	31	44	53	64	71	95	127	22.7	15.9
60204	Windsor, ON	467 University Ave. West		5/1/1986	9/30/1993	96	1	3	10	23	38	55	67	80	88	112	159	26.6	20.7
60302	Kingston, ON	Napier Street		6/14/1988	9/29/1993	48	0	2	14	26	39	55	66	80	88	112	140	28.1	20.0
60403	Toronto, ON	Evans & Arnold Ave.		5/1/1986	9/30/1993	95	0	1	5	15	29	46	57	70	78	100	157	19.7	18.5
60410	Toronto, ON	Lawrence & Kennedy	TO	5/1/1986	9/30/1993	97	0	1	8	20	33	48	59	73	83	112	162	23.0	19.1
60413	Toronto, ON	Elmcrest Road	TO	5/1/1986	9/30/1993	97	0	0	5	19	33	50	62	77	86	113	148	22.4	20.4
60415	Toronto, ON	Queensway W & Hurontario	TO	5/1/1986	9/30/1993	96	0	2	8	20	34	49	61	75	84	113	177	23.5	19.2
60417	Toronto, ON	26 Breadalbane St.		5/1/1986	9/30/1990	59	1	2	9	19	32	48	60	74	83	111	159	22.9	18.8
60418	Toronto, ON	Junction Triangle	TO	5/1/1986	9/30/1993	93	1	3	8	21	36	51	64	77	86	112	178	24.6	20.0
60419	Toronto, ON	CN Tower	CN	5/1/1986	9/30/1993	92	6	12	24	37	53	71	82	94	103	138	196	39.9	22.7
60421	Toronto, ON	Yonge St. & Finch St.		6/1/1988	9/30/1993	71	0	2	9	21	34	49	61	76	87	117	177	24.0	19.4
60512	Hamilton, ON	Elgin & Kelly		5/1/1987	9/30/1993	87	0	2	9	21	35	50	61	75	83	108	137	24.1	19.2
60513	Hamilton, ON	Vickers Rd. & East 18th St.		5/1/1986	9/30/1993	98	0	3	12	25	40	56	67	79	85	107	131	28.0	20.4
60514	Hamilton, ON	Nash Rd. & Kentley Dr.		5/1/1986	9/30/1993	96	0	2	11	24	39	54	64	76	86	108	128	26.8	20.1
60607	Sudbury, ON	Science Centre North		5/1/1988	9/30/1993	73	8	12	19	28	38	51	60	71	77	95	113	30.1	15.6
60707	Sault Ste. Marie, ON	Wm. Merrifield School		5/1/1987	9/30/1993	82	2	5	13	23	33	43	50	59	65	84	102	24.0	14.6
60807	Thunder Bay, ON	615 James St. S.		5/12/1987	9/30/1993	85	0	1	7	18	27	36	42	49	54	68	77	18.5	13.2
60901	London, ON	King & Rectory		5/1/1986	9/30/1993	96	2	5	15	27	41	56	66	77	84	108	137	29.5	19.6
61004	Sarnia, ON	Front St. At CN Tracks		5/1/1986	9/30/1993	97	3	7	16	25	38	53	63	77	86	112	170	28.3	18.4
61005	Sarnia, ON	MTC Shed	SW	5/1/1986	9/30/1993	96	8	12	19	29	42	58	71	84	93	114	146	32.6	19.2
61201	Cornwall, ON	Bedford & Third St.		5/1/1986	9/30/1993	97	3	6	14	24	36	48	57	68	75	94	127	26.3	16.7
61302	St. Catherines, ON	Argyle Crescent		5/1/1988	9/30/1993	73	1	4	14	27	42	57	67	76	82	105	132	29.5	20.1

Table 5.3 Ozone Concentration Percentiles (ppb) for May-Sept. 1986 to 1993 – Selected Canadian Sites

Station	City/Province	Address	Reg'n	Start	Stop	% Data	5th	10th	25th	50th	75th	90th	95th	98th	99th	99.9th	Max.	Mean	Std Dev.
61501	Kitchener, ON	Edna & Frederick		5/1/1986	7/5/1990	53	1	4	11	22	37	54	66	78	88	109	118	26.1	19.9
61502	Kitchener, ON	West Ave. & Homewood		7/6/1990	9/30/1993	42	2	6	16	28	41	55	64	74	80	97	118	29.6	18.5
61602	Oakville, ON	Bronte Rd. & Woburn Cr.		5/1/1986	9/30/1993	95	0	2	10	24	39	54	65	79	88	118	183	26.7	20.8
61701	Oshawa, ON	Ritson Rd. & Olive Ave.		5/1/1986	9/30/1993	92	2	4	12	23	34	48	60	75	86	112	185	25.3	18.2
61802	Guelph, ON	Exhibition & Clark St.		5/1/1986	9/30/1993	91	2	6	16	27	42	57	68	80	87	103	117	30.2	19.8
62001	North Bay, ON	OPP. Station		5/1/1989	9/30/1993	61	3	6	16	26	37	50	59	69	76	90	103	27.7	16.8
62101	Huron Park, ON	College Of Agriculture		5/1/1986	9/30/1991	62	9	13	20	31	45	61	71	82	90	112	127	34.1	19.1
62201	Merlin, ON	MOE Water Pump Stn.	SW	5/1/1986	9/30/1993	96	6	10	19	31	45	61	72	85	93	119	133	33.8	20.3
62401	Parkhill, ON	PUC Bldg.	SW	5/1/1986	9/30/1993	97	6	11	19	30	44	60	71	84	94	116	144	33.3	20.0
62501	Tiverton, ON	Con. Rd. 2 Lot A	LS	5/1/1986	9/30/1993	97	10	15	23	33	46	63	76	91	100	126	156	36.6	19.8
62601	Simcoe, ON	Experimental Farm	SW	5/1/1986	9/30/1993	89	10	14	22	33	47	62	71	84	93	119	190	36.0	19.3
62701	Long Point, ON	Provincial Park	LS	5/1/1986	9/30/1993	87	15	20	28	41	57	74	86	101	113	136	189	44.3	22.3
62901	Niagara Falls, ON	Allendale Ave.		5/18/1988	9/30/1993	60	6	10	19	31	46	63	73	85	92	116	139	34.2	20.6
63001	Burlington, ON	Hwy. 2 & N. Shore Blvd.		5/1/1986	9/30/1993	96	2	4	12	24	39	54	65	77	85	114	167	27.4	19.8
63101	Alliston, ON	509 Victoria Street E.		5/1/1986	9/30/1993	95	2	4	13	24	36	50	60	70	77	95	177	26.2	17.5
63201	Stouffville, ON	Hwy. 47 & Hwy. 48	TO	5/1/1986	9/30/1993	94	7	11	18	27	39	52	63	76	84	113	161	30.0	17.3
63301	Dorset, ON	Hwy. 117 & Paint Lake Rd		5/1/1986	9/30/1991	66	6	9	18	29	41	55	66	77	83	100	138	31.1	18.0
63401	Hawkeye Lk., ON	Hawkeye Lake	HA	5/1/1986	9/30/1991	56	4	8	16	25	35	48	56	65	70	82	95	26.7	15.4
64001	ELA., ON	Experimental Lakes Area	EL	5/9/1988	9/30/1992	50	14	17	23	30	39	47	53	59	63	74	81	31.6	11.8
64101	Algoma, ON			5/17/1988	9/30/1992	57	12	15	21	29	40	52	62	74	83	100	108	31.7	15.6
64201	Chalk River, ON			5/17/1988	9/30/1992	44	7	11	18	26	37	48	58	70	77	90	96	28.6	15.2
64401	Egbert, ON			7/26/1988	9/30/1992	54	11	14	21	31	43	57	67	76	82	98	138	33.5	16.9
70118	Winnipeg, MB	Jefferson & Scotia		5/1/1986	9/30/1993	91	2	5	12	22	33	44	50	59	64	77	98	23.5	15.0
70119	Winnipeg, MB	65 Ellen Street	PR	5/1/1986	9/30/1993	84	1	3	9	18	29	39	46	53	59	74	100	20.2	14.0
70203	Brandon, MB	1430 Victoria Ave. E.		5/1/1987	9/10/1993	77	6	9	16	24	34	44	50	57	61	70	78	25.7	13.4
80110	Regina, SK	2505 11th Avenue	PR	5/1/1987	9/30/1993	85	3	6	11	19	28	36	41	46	50	62	99	20.3	11.6

Table 5.3 Ozone Concentration Percentiles (ppb) for May-Sept. 1986 to 1993 - Selected Canadian Sites

Station	City/Province	Address	Reg'n	Start	Stop	% Data	5th	10th	25th	50th	75th	90th	95th	98th	99th	99.9th	Max.	Mean	Std Dev.
80209	Saskatoon, SK	Idylwyld Dr. & 33rd St.	PR	5/1/1986	9/30/1992	80	4	6	13	20	29	38	43	47	50	59	68	21.4	11.8
90122	Edmonton, AB	127 St. & 133 Avenue	PR	5/1/1986	9/30/1993	99	1	2	10	21	34	45	51	58	62	75	102	22.9	15.9
90130	Edmonton, AB	10255 - 104th Street		5/1/1986	9/30/1993	100	3	5	11	20	30	39	44	49	53	64	93	21.3	12.7
90222	Calgary, AB	39 St. & 29 Ave. NW	PR	5/1/1986	9/30/1993	99	3	6	15	27	38	48	52	58	62	77	106	26.9	15.4
90227	Calgary, AB	611-4th Street SW		5/1/1986	9/30/1993	99	2	3	8	17	27	36	41	46	50	61	79	18.3	12.4
90701	Fort MacMurray, AB	Macdonald Drive		7/1/1986	9/30/1993	80	2	5	11	21	33	45	51	60	65	77	128	23.2	15.3
100108	Vancouver, BC	250 West 70th Avenue		5/1/1986	5/6/1993	69	0	1	3	12	23	31	36	42	47	62	81	14.0	12.2
100110	Vancouver, BC	E. Hastings & Kensington	VA	5/1/1986	9/30/1993	95	0	1	5	12	22	31	36	43	49	76	105	14.6	11.9
100111	Vancouver, BC	Rocky Pt. Park	VA	5/1/1986	9/30/1993	96	0	0	1	11	26	38	46	57	64	98	149	15.6	16.2
100112	Vancouver, BC	Robson/Hornby		5/1/1986	9/30/1993	93	0	0	1	3	10	16	20	25	28	42	57	6.1	6.8
100118	Vancouver, BC	2550 West 10th Avenue		5/1/1987	9/30/1993	81	0	0	1	11	24	34	39	46	52	71	88	14.2	13.7
100120	Vancouver, BC	Willingdon & Penzanc, Burnaby	VA	5/1/1986	9/30/1993	94	0	1	5	14	25	34	40	48	55	83	105	16.4	13.2
100121	Vancouver, BC	75 Riverside Dr. NVan.		5/1/1986	9/30/1993	90	0	1	4	10	17	25	30	36	41	63	93	11.7	9.9
100122	Vancouver, BC	Sunnyside Road, Anmore	VA	5/1/1986	9/30/1993	97	2	3	8	16	27	38	46	56	65	101	156	19.0	14.6
100123	Vancouver, BC	West End Welsh Road, West Van.	VA	5/1/1986	9/30/1993	77	0	0	2	8	20	30	36	42	46	71	95	12.2	12.2
100124	Vancouver, BC	475 Guildford Way, Port Moody	VA	5/1/1986	9/30/1993	98	0	1	3	12	23	35	42	53	61	96	167	15.3	14.5
100125	Vancouver, BC	8544 116th Ave., Delta	VA	5/16/1986	9/30/1993	89	0	1	5	14	23	31	35	41	46	66	96	15.0	11.5
100126	Vancouver, BC	Ring Road, Burnaby	VA	5/7/1986	9/30/1993	96	4	7	13	20	28	37	43	52	59	87	194	21.6	12.4
100127	Vancouver, BC	19000 & 72nd Ave., Surrey	VA	5/1/1986	9/30/1993	93	2	4	10	18	29	39	46	55	61	86	159	20.5	14.1
100128	Vancouver, BC	Williams & Aragon, Richmond		7/1/1986	9/30/1993	89	0	1	4	15	26	34	40	46	51	68	93	16.5	13.3
100129	Vancouver, BC	Hamilton & Paisley		6/8/1987	9/30/1993	80	0	0	3	12	25	36	44	55	64	96	213	15.8	15.3
100130	Vancouver, BC	Sperling & Sprott Ave.		5/2/1986	9/30/1992	71	0	0	1	5	19	30	36	43	48	65	94	10.9	12.5
100131	Vancouver, BC	Seymour Falls, North Vancouver		5/5/1986	9/30/1993	82	2	4	9	17	27	38	45	55	63	88	119	19.5	13.8

Table 5.3 Ozone Concentration Percentiles (ppb) for May-Sept. 1986 to 1993 - Selected Canadian Sites

Station	City/Province	Address	Reg'n	Start	Stop	% Data	5th	10th	25th	50th	75th	90th	95th	98th	99th	99.9th	Max.	Mean	Std Dev.
100303	Victoria, BC	1250 Quadra St.		5/1/1986	9/30/1993	51	0	0	8	16	24	32	37	43	46	60	78	16.7	11.5
100701	Kelowna, BC	1000 Klo Rd.		7/1/1987	9/30/1993	53	0	0	10	20	32	40	47	53	56	70	93	21.4	14.8
101001	Abbotsford, BC	Airport		5/1/1986	9/30/1991	68	0	1	6	19	32	43	51	62	72	97	118	21.1	17.1
101101	Chilliwack, BC	Works Yard	VA	5/1/1986	9/30/1993	84	0	0	3	14	28	41	49	60	68	87	104	17.9	16.5
101201	Pitt Meadows, BC	Airport	VA	5/1/1986	9/30/1993	90	0	0	3	15	27	38	45	54	60	83	154	17.2	15.3
102001	Saturna, BC			5/28/1991	9/30/1992	22	13	16	21	26	34	41	46	52	56	65	74	27.8	10.0

5.3.1 Monthly Variation in Daily Mean and Maximum Ozone Concentrations

Averages of daily mean and daily maximum one hour ozone concentrations were calculated for each month to examine seasonal variations in the data. These monthly averages revealed pronounced seasonal variations of ozone at individual stations and regions throughout Canada (Figures 5.3 to 5.6). Considerable variations were observed in the time of year when maximum ozone levels are attained. Sites in Vancouver (Figure 5.3) recorded the lowest mean and maximum ozone levels in the country during the months of October through February. Daily mean ozone peaked in April and May at the sites and declined slowly in the following months. Daily maximum ozone also peaked in April and May but there was little change from May through September at the western Vancouver sites, when the mean daily maximum ozone was in the range of 45 to 50 ppb.

The Calgary and Edmonton sites experienced more pronounced seasonal variation in average daily maximum ozone, with a peak in the month of May. Although average daily maximum and average daily mean ozone concentrations reached their lowest levels at these urban sites during November to January, average concentrations were higher than those recorded in the Vancouver urban area. For these two sites, monthly averages for daily means exceeded 25 ppb in May and the corresponding averages for daily ozone maxima exceeded 50 ppb.

Springtime maxima in ozone concentrations are often observed at remote rural sites in Canada (see Section 5.1; Robichaud & Jacques, 1991; Robichaud, 1993; Leduc & Gagnon, 1992; Fuentes & Dann, 1995; Bottenheim et al., 1994). The observation of springtime ozone maxima at urban sites is contrary to the notion that urban peaks in ozone are a function primarily of elevated photochemical ozone, since production of the latter peaks in the summer. Higher ozone concentrations measured during the spring may reflect the impact of ozone transport from the stratosphere. In western Canada, the tropopause is closest to the ground surface during the spring. As a result, intrusion of ozone-rich air from the lower stratosphere to the upper troposphere can occur. Some researchers (Liu et al., 1987; Logan, 1987) have proposed that because of the longer lifetime of ozone in the winter, the accumulation of anthropogenic precursors may contribute to the spring ozone maximum. The decline in ozone concentrations during the summer months at these locales can be attributed to enhanced sink processes engendered by ozone photolysis and uptake by vegetation. As shown in Figure 5.4, other prairie sites and two sites in northern Ontario also experienced April to May peaks in mean and mean daily maximum ozone. Unlike the prairie urban sites, the Hawkeye Lake site registered an increase in average daily maximum ozone in July. The Experimental Lakes Area site showed the smallest divergence between the daily mean and daily maximum plots.

Figure 5.3 Monthly Averages of Daily Mean and Daily Maximum One Hour Ozone (ppb) (1986 to 1993) – British Columbia and Alberta

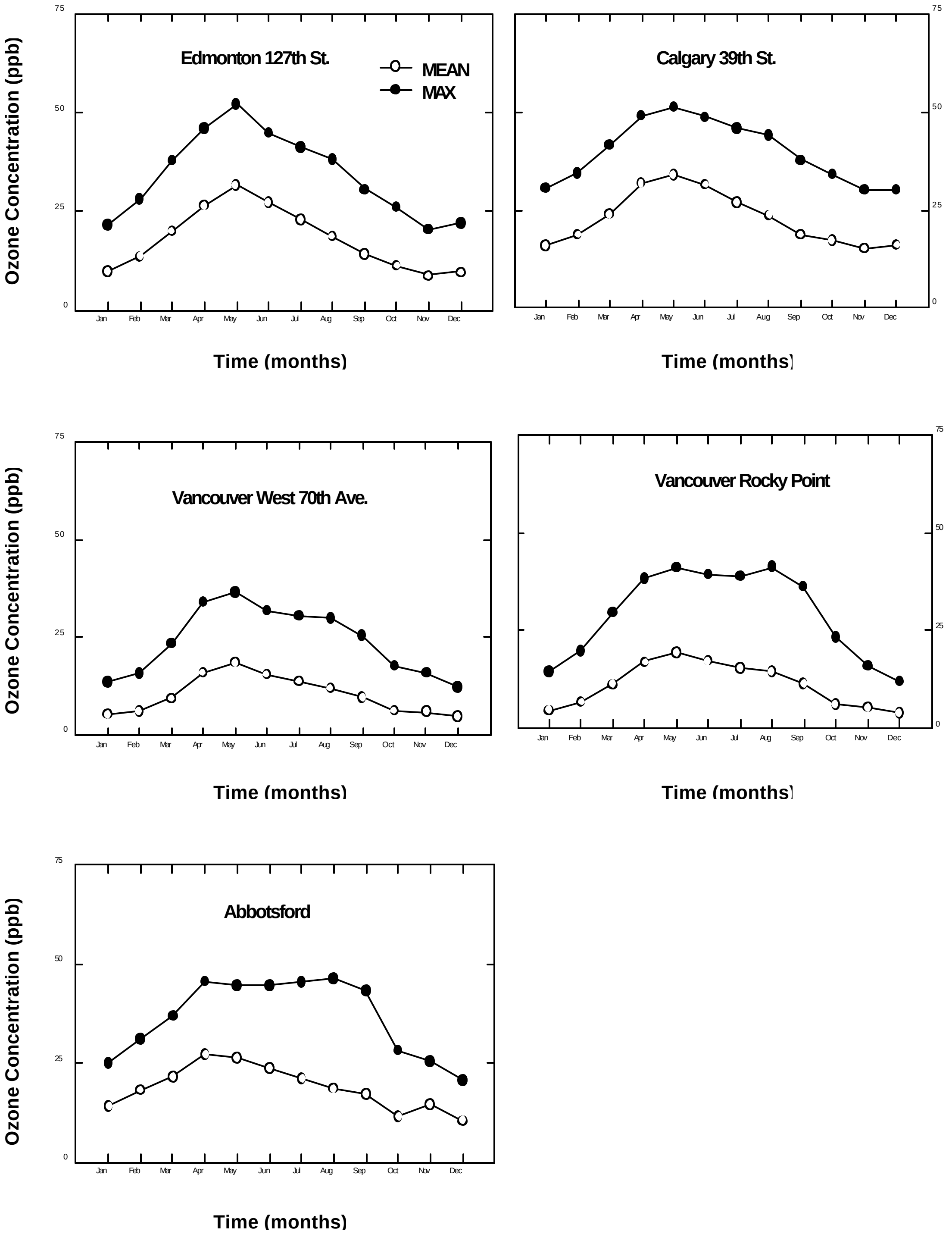
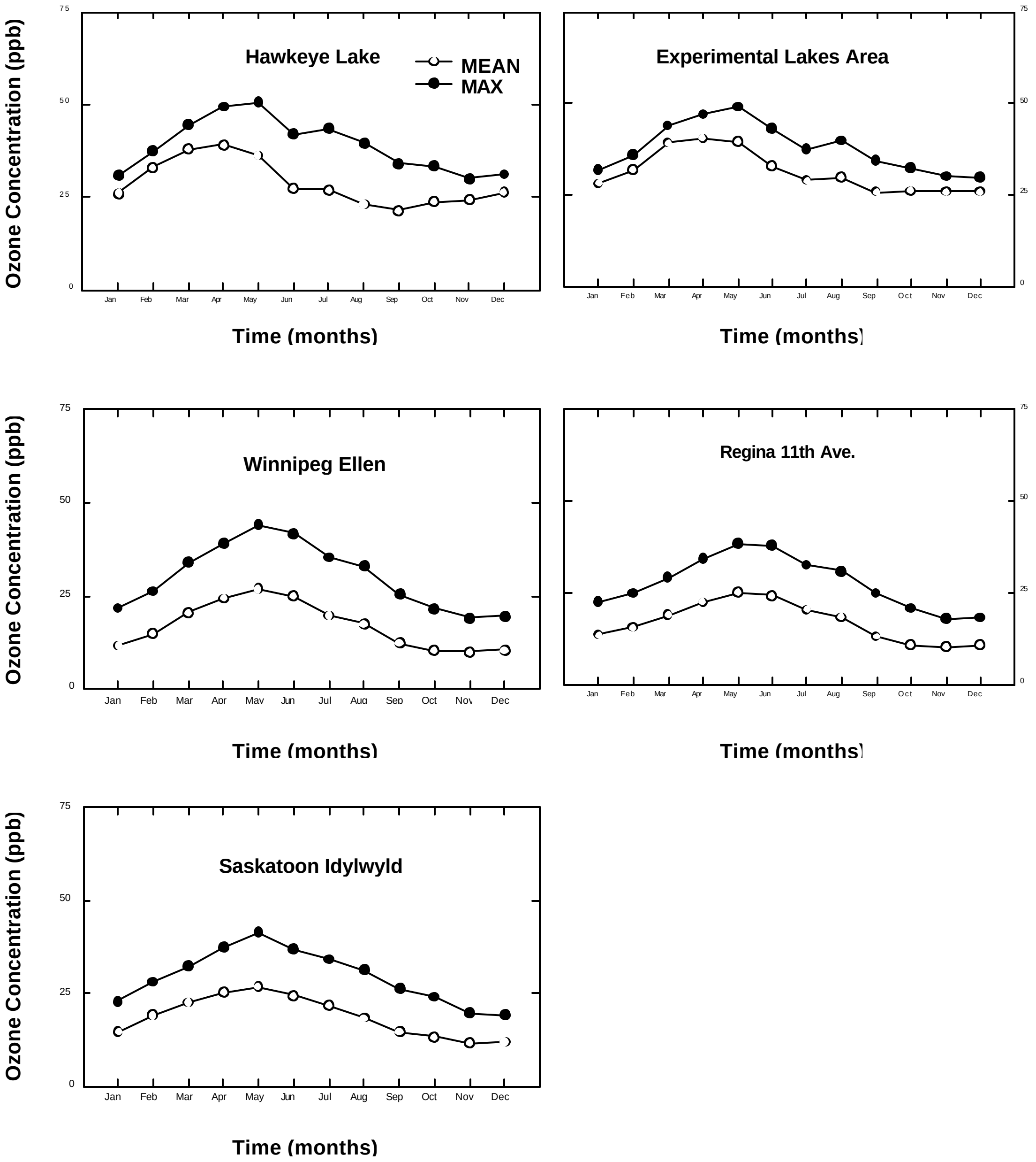


Figure 5.4 Monthly Averages of Daily Mean and Daily Maximum One Hour Ozone (ppb) (1986 to 1993) – Saskatchewan, Manitoba and Northern Ontario



Urban and rural stations in environments under considerable anthropogenic influence showed the highest monthly concentrations from June to August (see Figure 5.5). In southwestern rural Ontario, the long-range transport of pollutants can contribute significantly to enhanced ozone levels measured during June to August. Summer-time maximum ozone concentrations were significantly higher than those recorded at the western sites. All the sites shown in Figure 5.5 recorded maximum monthly ozone concentrations in July, with mean daily maxima ranging from 55 to 65 ppb. The elevated CN Tower site showed a larger amplitude than any of the surface sites in the seasonal pattern of both mean and daily maximum ozone.

The Montréal urban sites (Figure 5.6) also experienced the highest monthly ozone in July, although mean and daily maximum ozone concentrations were lower than at the Toronto sites. The rural site of St. Zephrin (located between Montréal and Québec City; 1989 to 1993 data only) showed a much different seasonal pattern, with maximum monthly ozone recorded in March and little variation in the daily maximum between March and August. Mean and mean daily maximum ozone concentrations were substantially higher at this site, as compared to the Montréal sites, for the months of March through June.

Little seasonal variation in the monthly averaged ozone concentrations occurred in the Southern Atlantic region, as represented by the data for Saint John and Kejimkujik (Figure 5.6). In contrast to the Toronto and Montréal sites, ozone levels at the Saint John site remained high during winter. The overall seasonal pattern of ozone in Saint John is similar to that of the Kejimkujik site, indicating that the Southern Atlantic region of Canada is influenced by air masses whose ozone concentrations differ markedly from those affecting Ontario and Québec.

Figure 5.5 Monthly Averages of Daily Mean and Daily Maximum One Hour Ozone (ppb) (1986 to 1993) - Toronto and Southern Ontario

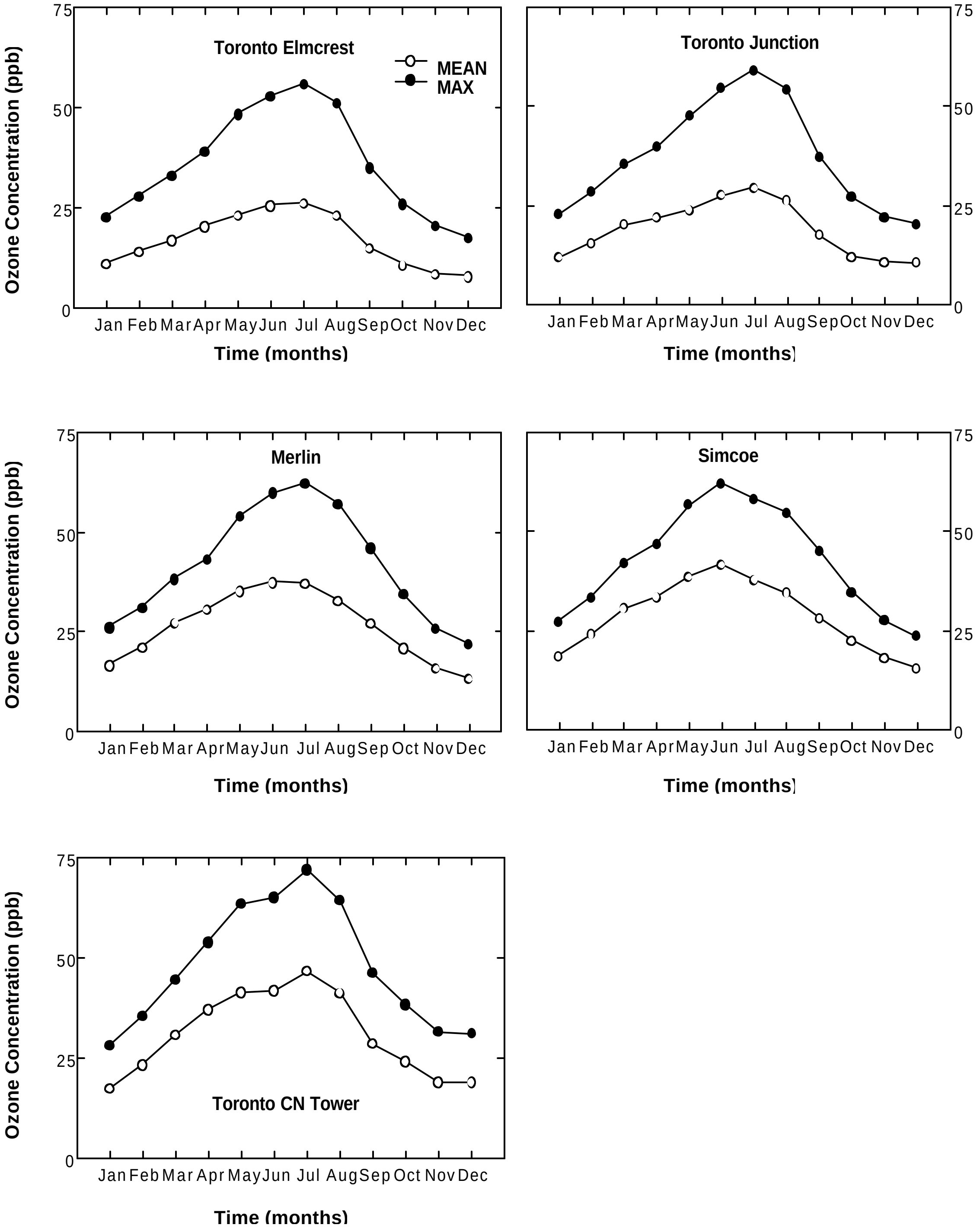
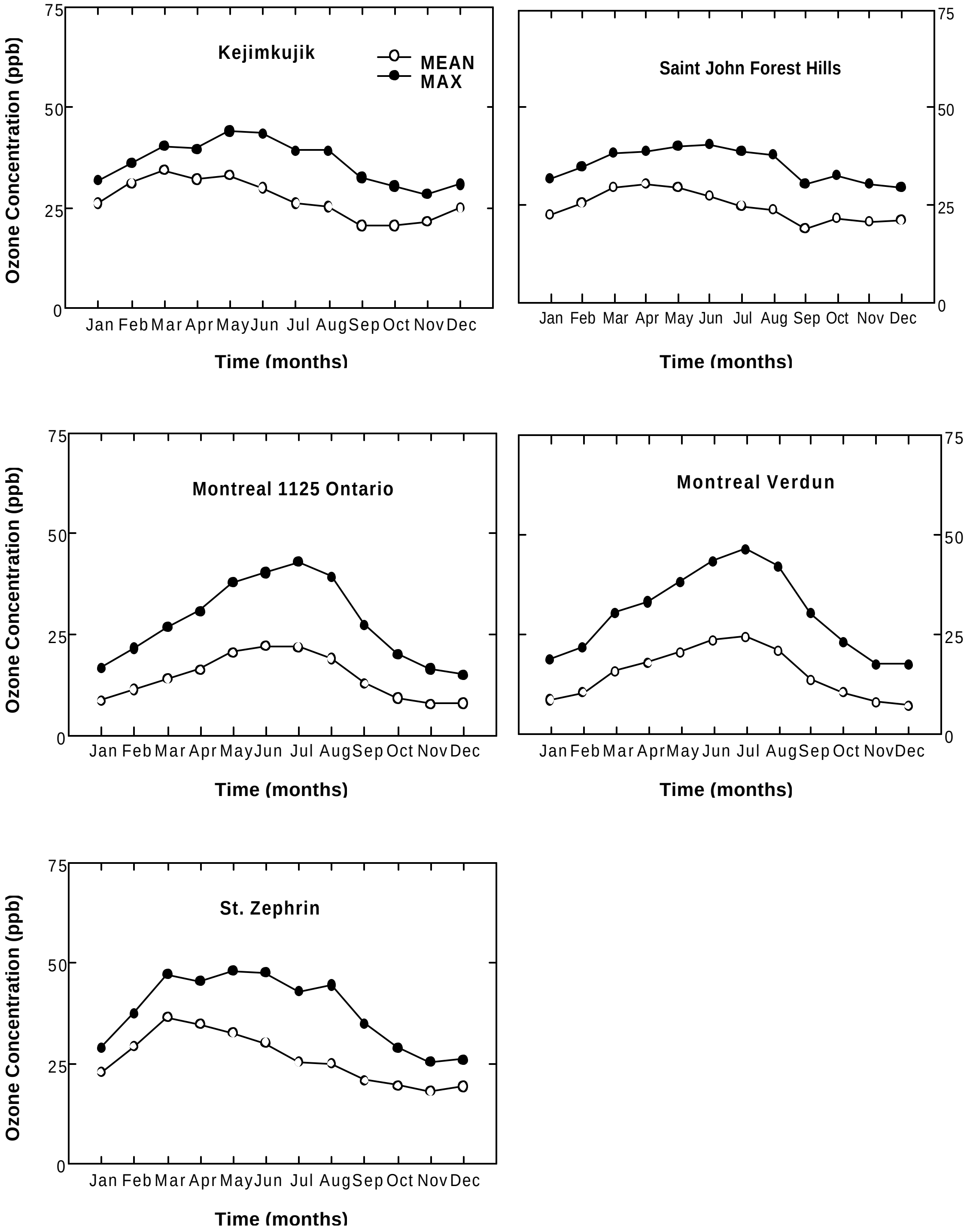


Figure 5.6 Monthly Averages of Daily Mean and Daily Maximum One Hour Ozone (ppb) (1986 to 1993) - Montréal and Southern Atlantic



5.3.2 Diurnal Variation in Ozone Concentrations - Summer and Winter

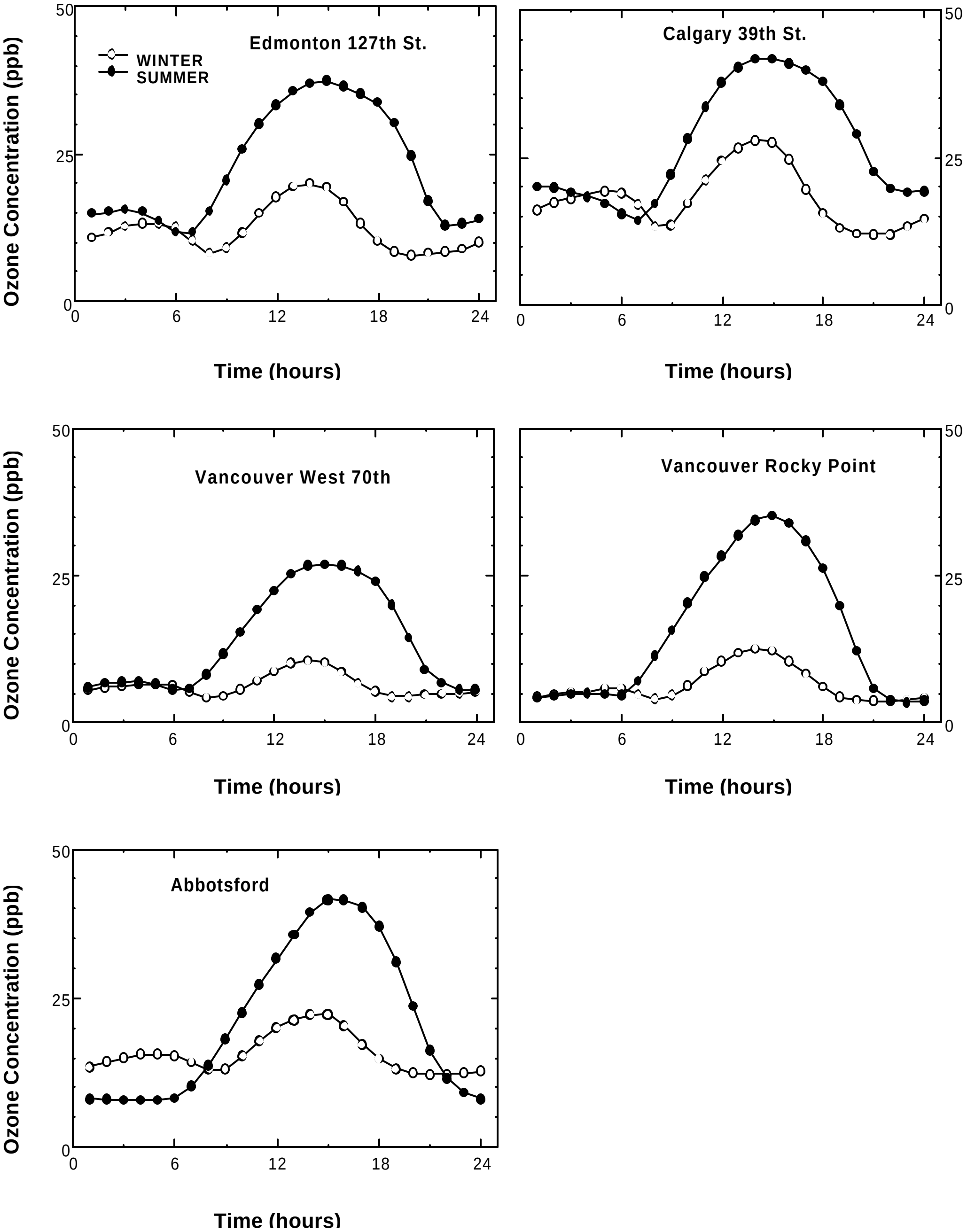
Hourly ozone data for winter and summer time were aggregated separately to compute seasonal averages. “Winter” months were defined to comprise November to March, while “summer” months were defined to include May to September. As expected, large differences exist in the amplitude of diurnal ozone concentration cycles for winter- and summer-time (see Figures 5.7 to 5.10). Ozone levels during winter remain low due to limited photochemistry and exhibit smaller diurnal variations. Most urban sites record mean winter ozone concentrations in the range of 15 to 20 ppb. The rural remote sites of Hawkeye Lake and ELA and the two Southern Atlantic sites had mean winter ozone concentrations of 25 to 30 ppb. The Saint John and Kejimkujik sites showed the smallest variation between summer and winter diurnal profiles, while sites in southern Ontario, Toronto and Vancouver showed the greatest divergence between the summer and winter profiles.

Most urban sites recorded comparable summer and winter nighttime ozone levels. The rural Ontario sites (Parkhill, Merlin, Hawkeye Lake and ELA) recorded higher summer ozone for most hours of the day, with summer-time ozone values approaching winter-time values between 06:00 and 07:00. The elevated CN Tower site showed the largest mean divergence between summer and winter diurnal ozone profiles with an average hourly difference of more than 25 ppb. These variations in diurnal ozone result as a consequence of longer summer days with warm temperatures and the availability of sufficient levels of solar radiation necessary for the ozone photochemistry.

At urban sites, ozone concentrations were much lower during nighttime than daytime. Overall daily mean ozone concentrations in rural locations were greater than those recorded in nearby urban sites and diurnal profiles were much smoother, with higher nighttime ozone concentrations. The shape and amplitude of diurnal ozone concentration cycles are strongly influenced by atmospheric conditions, site location and prevailing NO_x levels. Even in well-defined and "self-contained" airsheds, such as the one in British Columbia’s Lower Fraser Valley, diurnal ozone patterns varied appreciably within small spatial scales (Figure 5.7). In this instance, the diurnal ozone differences among these three stations resulted because of site positioning with respect to ozone precursor sources. The Vancouver West 70th site measured lower diurnal ozone levels, with peak summertime values around 25 ppb, compared to the site downwind of Vancouver (Abbotsford) which recorded summertime diurnal maximum values of approximately 40 ppb. Peak ozone levels occurred one hour later at Abbotsford than at Rocky Point (16:00 vs. 15:00) and persisted through 17:00. Advection of ozone and its precursors from the city is undoubtedly contributing to enhanced ozone levels at Abbotsford.

Of the sites in Alberta and British Columbia, (Figure 5.7) the Calgary site showed the largest diurnal variation in summer-time ozone with maximum average concentrations of over 40 ppb. This value is comparable to the Abbotsford afternoon maximum. The long-range transport of pollutants to these sites in western Canada has a negligible effect on locally measured ozone. It is likely that most ozone measured in these jurisdictions comes from background tropospheric and stratospheric sources, and locally produced ozone.

Figure 5.7 Hourly Average Ozone Concentrations (ppb) for Summer and Winter (1986 to 1993) – British Columbia and Alberta



The most dynamic ozone patterns in Canada, with respect to their spatial distributions and temporal variations, are experienced in southwestern Ontario. Substantial spatial and temporal ozone changes occur because of the combined influence of precursors existing within the region and the long-distance transport of ozone and its precursors. Southwestern Ontario is geographically situated downwind of major ozone precursor source areas in the Great Lakes region. Additionally, meteorological conditions conducive to elevated ozone levels generally result in southwesterly flows. A rural upwind site (Simcoe), one urban site within the city of Toronto (Junction) and two urban downwind sites (Stouffville and Oshawa) are shown in Figure 5.11 to illustrate the spatial and diurnal variations of ground-level ozone observed in southwestern Ontario.

Figure 5.8 Hourly Average Ozone Concentrations (ppb) for Summer and Winter (1986 to 1993) – Saskatchewan, Manitoba and Northern Ontario

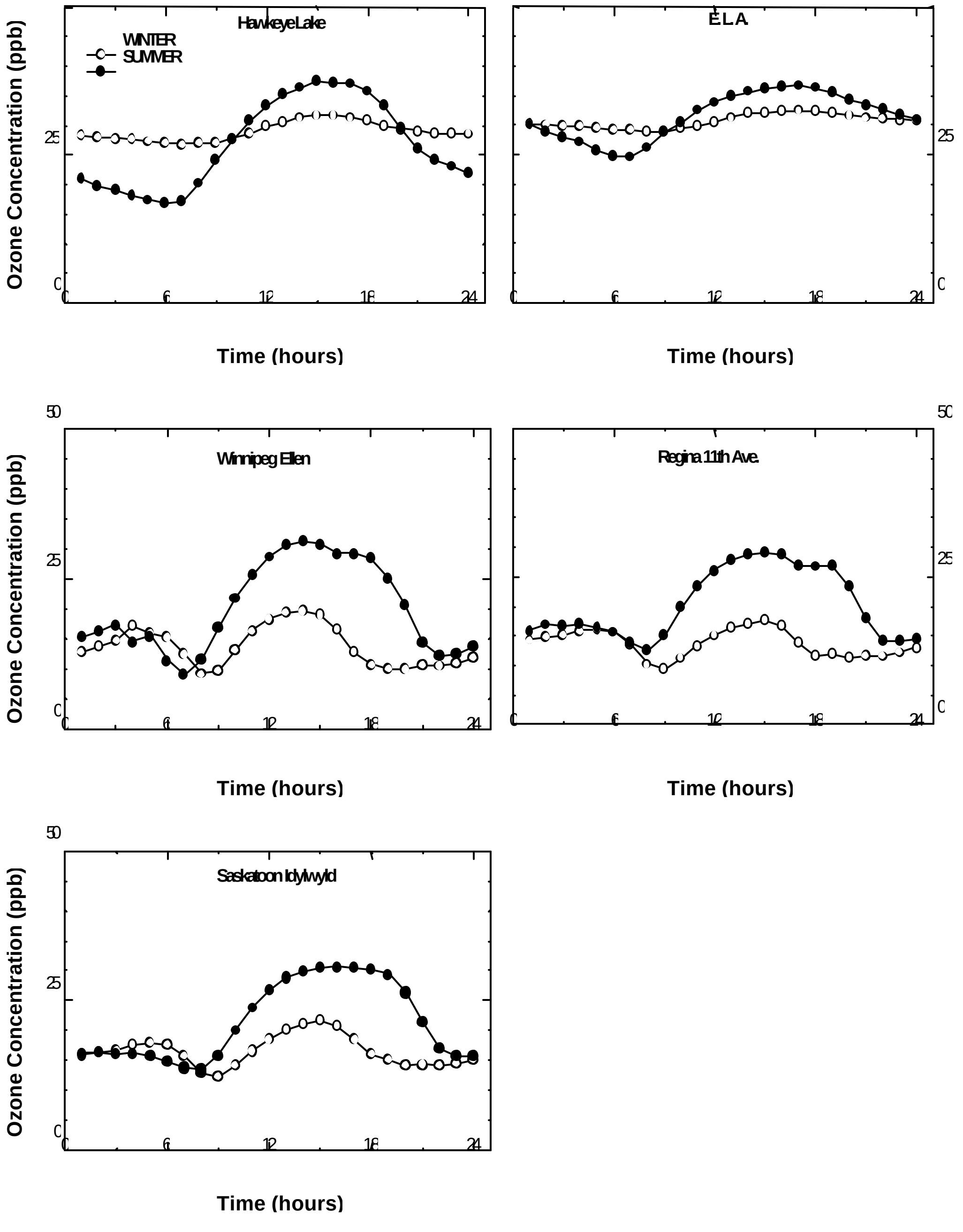
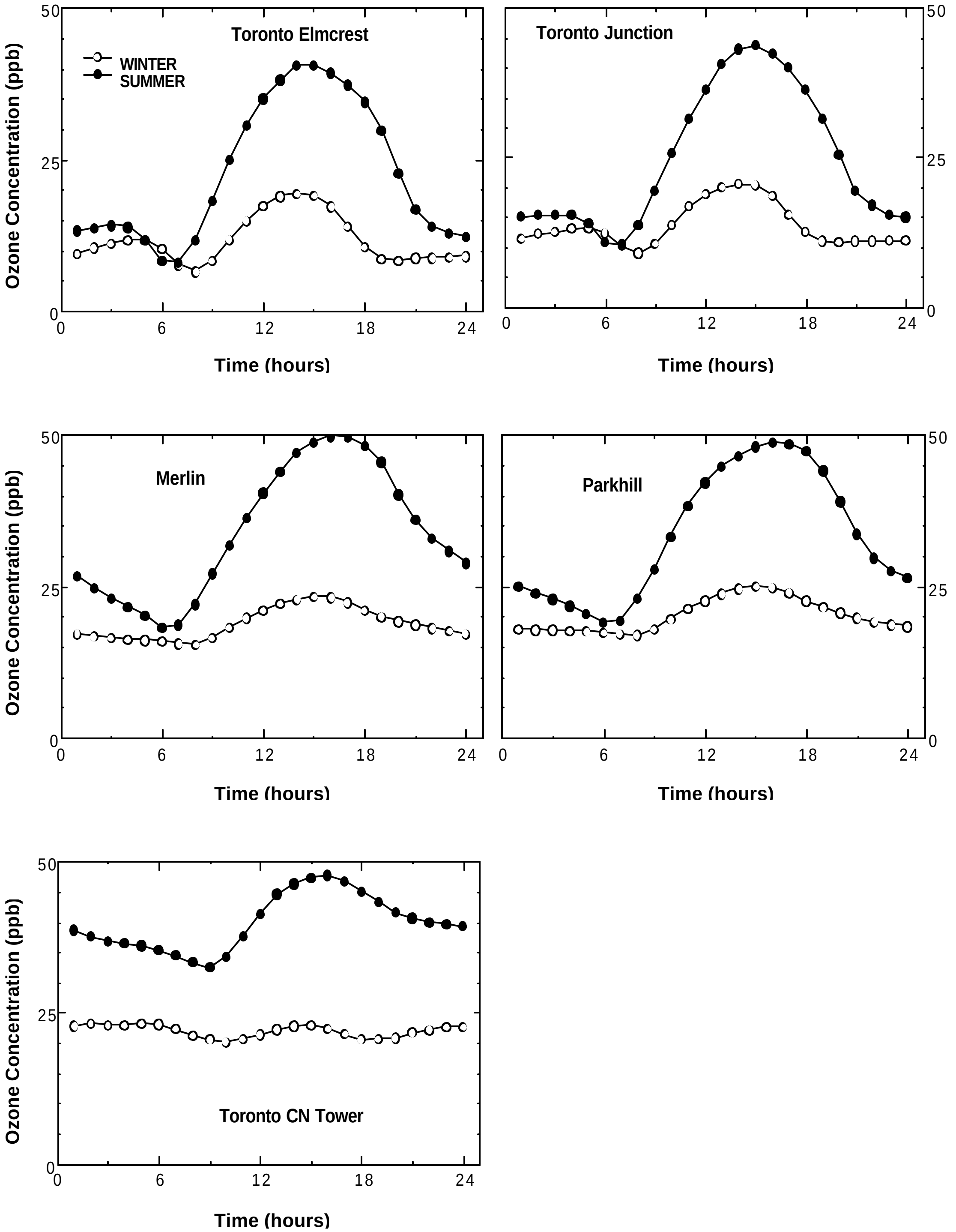


Figure 5.9 Hourly Average Ozone Concentrations (ppb) for Summer and Winter (1986 to 1993) - Toronto and Southern Ontario



At the Simcoe site, ozone levels remained at about 25 ppb and maximum values reached almost 50 ppb during the day. In contrast, the Junction site showed substantially lower nighttime ozone concentrations with minimum values reaching 10 ppb. The Stouffville and Oshawa sites recorded nighttime ozone concentrations higher than Junction but lower than Simcoe. Of these sites, Junction and Stouffville experienced similar maxima (40 ppb). Peaks occurred at the same hour of the day (15:00), but higher concentrations persisted at Stouffville after 17:00. The Oshawa site, although downwind of the Toronto area, recorded average daily maximum ozone values that were approximately 5 ppb lower than Junction.

Summer-time ozone diurnal patterns for Montréal were similar to those for other sites (Figure 5.10); however, diurnal ozone averages were lower in Montréal than in Toronto. McKendry (1993) showed that ozone values in Montréal are lower than in surrounding areas and the city acts as a net ozone sink. Minimum nighttime concentrations approach 10 ppb and maximum daytime levels of approximately 35 ppb sites occur at 14:00. The St. Zephrin site records daily maximum ozone of 40 ppb with a peak at 15:00. It is not clear why Montréal sites experience lower diurnal ozone levels compared to stations elsewhere in the Windsor–Québec City corridor. An examination of nitrogen oxide data for the Montréal area reveals concentrations of the same order of magnitude as for other large cities. One possible reason for apparently lower ozone values in Montréal is that the data are reported to a precision of only 10 ppb.

Diurnal ozone patterns in New Brunswick and Nova Scotia displayed less variation as compared to sites in other parts of Canada (Figure 5.10). This observation applies to both urban and rural environments. For example, ozone data recorded in Saint John displayed little diurnal variation, the difference between maximum and minimum ozone levels amounting to less than 10 ppb. Minimum ozone concentrations stay at around 20 ppb, and maximum levels reach 30 ppb. The diurnal ozone patterns experienced in Saint John resemble those observed in rural environments where substantial ozone is also measured at night. Diurnal ozone levels at the Kejimkujik site showed larger variation with time of day. Nighttime ozone levels are comparable to Saint John and daily maximum values reach 35 ppb. Although smooth diurnal ozone patterns emerge in these data when averaged over long periods, the New Brunswick and Nova Scotia sites are occasionally affected by the long-distance transport of pollutants. This effect of pollutant transport is manifested by intrusions of air masses with ozone concentrations exceeding 100 ppb. These high ozone levels are often measured at night, when there is no local photochemistry.

Figure 5.10 Hourly Average Ozone Concentrations (ppb) for Summer and Winter (1986 to 1993) -Montréal and Southern Atlantic

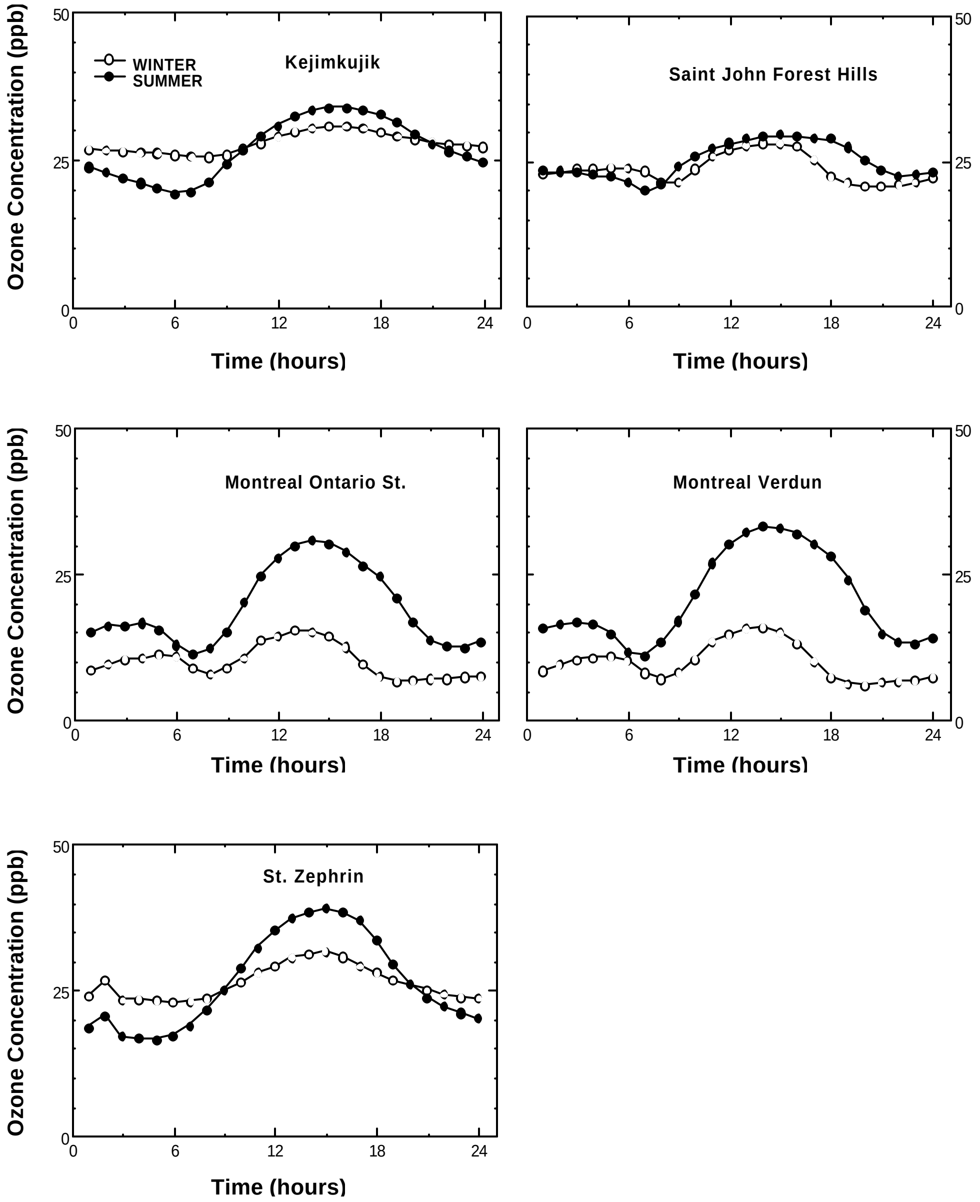
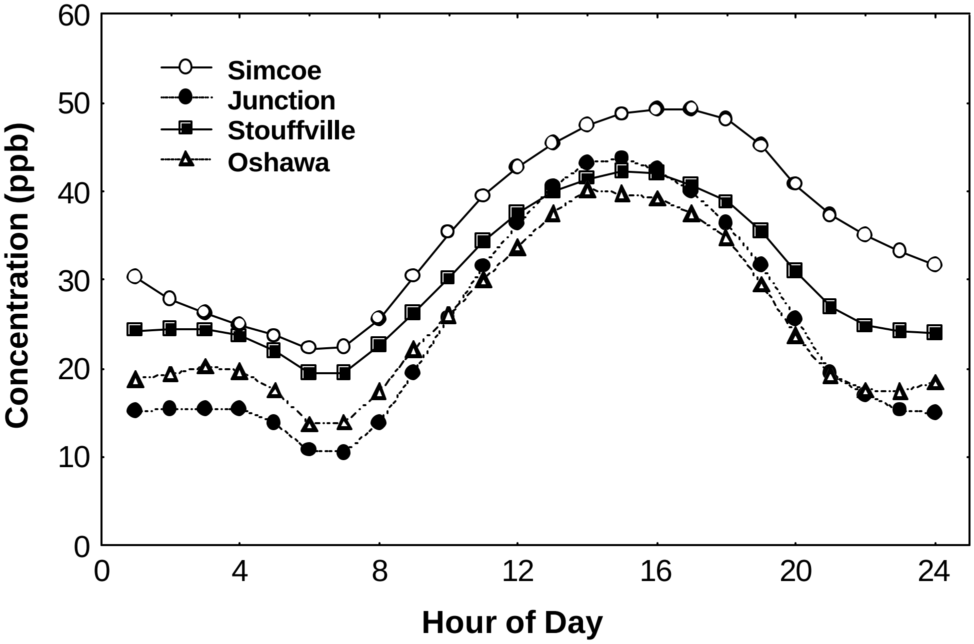


Figure 5.11 Hourly Average Ozone Concentrations (ppb) for Summer (1986 to 1993) - Toronto-Area Sites



5.3.3 The Weekly Cycle of Ozone Daily Maximum and Mean Concentrations

It is known that the ozone precursor emissions have strong temporal variations on several time scales, although many of these are not thoroughly documented. For example, the main source of NO— vehicle traffic—shows a very strong diurnal cycle with a maximum generally in the daylight hours. Superimposed on this is a further modulation, especially in urban areas, related to the maximum traffic flow in the morning and evening rush hours. In addition, this diurnal variation of emissions is different on weekends to that occurring on weekdays. Fewer people go to work on Saturdays, making the morning rush hour weaker, but shopping trips increase automobile traffic during the day. On Sunday, the pattern is very different again, with little early morning traffic and a steadier flow during the rest of the day. These changes in the precursor emission patterns suggest that especially during the daylight hours, ozone concentrations might show significant differences in weekend versus weekday behaviour. Several approaches were taken by the Data Analysis Working Group (Multistakeholder NO_x/VOC Science Program, 1997) to investigate this possibility. Only the results of some of the analyses are reproduced here.

First, at all stations with long records, the average of the daily maximum for each day of the week was determined. This analysis showed that, indeed, at many sites, the average maximum ozone was higher on Saturday and Sunday than on weekdays, particularly those in the large urban centres. More specifically:

- At many sites in the major urban centres (Montréal, Toronto and Vancouver), the mean maximum ozone on the weekend is 10 to 20%—and sometimes 20 to 35%—higher than on weekdays.
- At other large urban centres, the mean maximum ozone is elevated by up to 20% on weekends.
- Winnipeg and Saskatoon are exceptions, with very little difference on weekends.
- At non-urban sites in southern Ontario but in regions potentially affected by the transport of ozone and its precursors from nearby urban centres, there is a consistent weekend increase in the daily maxima of about 4 to 8%—except for Cornwall, with essentially no change.
- In the Atlantic provinces, the weekend change is small, at between -2 and +3%.

Ozone data for selected sites were then aggregated to represent diurnal variations during weekdays (Tuesday through Thursday) and weekends (Saturdays and Sundays) for the summer months and the results are shown in Figures 5.12 to 5.15. Previous studies (Fuentes & Dann, 1993; Pryor et al., 1995; Altshuler et al., 1995) have shown substantial differences between weekdays and weekends in urban diurnal ozone profiles. Reduced NO concentrations on weekends are the primary reason for the different profiles, and the effect should therefore be most pronounced at monitoring sites in major urban centres; particularly those located close to busy, main traffic arteries. As shown in the Figures, a number of major urban sites with high NO concentrations (e.g. Montréal - Ontario, Montréal - Verdun and Vancouver - West 70th) experience the largest increase in afternoon maximum ozone when weekends are compared to weekdays. These sites also show a large increase in ozone between the hours of 05:00-10:00

on weekends. Most sites show higher ozone concentrations during daylight hours on weekends versus weekdays. ELA and Abbotsford show slightly higher (statistical significance not tested) afternoon ozone concentrations on weekdays and Hawkeye Lake, Kejimkujik and Saint John show little difference between weekday and weekend profiles.

It should be noted that this examination of ozone behaviour on weekends versus weekdays is based on the concurrent NO and NO_2 data and does not include consideration of the daily and weekly cycle of VOC concentrations. Such measurements are not available on the same time scales as for ozone and NO_x. Where information on VOC concentrations has been available, some investigators have been able to show that changes in VOC concentrations also influence the diurnal and weekly cycles of ozone (Altshuler et al., 1995).

5.3.4 Summary

Analyses of the monthly variation in ozone concentration (monthly averages of daily mean and daily maximum 1 hr. values) revealed pronounced seasonal variations in ozone concentrations at individual sites and regions across Canada, as well as variations in the time of year when maximum ozone levels are observed. Concentrations clearly peak much earlier in Western Canada (May) than they do in Central Canada (July). In southwestern rural Ontario, summertime maximum ozone levels are significantly higher than those recorded at other Canadian sites. Much less seasonal variation in ozone concentrations occurs in the Atlantic Region. Higher ozone concentrations measured during the spring may reflect the impact of ozone transport from the stratosphere. In Western Canada, the tropopause (boundary between the stratosphere and the troposphere) is closest to the ground during the spring. As a result, occasional intrusion of ozone-rich air from the lower stratosphere can occur.

Analyses of the diurnal cycle show that at urban sites, ozone concentrations are much lower during nighttime than daytime. Overall daily mean ozone concentrations in rural locations are greater than those recorded in nearby urban sites and diurnal cycles are much smoother, with higher nighttime ozone concentrations. The shape and amplitude of hourly ozone concentrations is strongly influenced by atmospheric conditions, site location and prevailing NO_x levels. Sites with high NO levels experience significantly higher mean afternoon maximum ozone on weekends (when NO concentrations are lower) than on weekdays. At these sites, the increase in ozone is observed during all daylight hours on weekends. This is attributed to the lower NO emissions and hence less titration of ozone. This “weekend effect” is also present, but not as strong, at rural sites close to urban areas, and diminishes rapidly with distance downwind. There are substantial year-to-year variations in ozone maxima at the different sites. Much of this variability is a result of yearly change in meteorological factors.

Figure 5.12 Hourly Average Ozone Concentrations (ppb) for Weekdays and Weekends (May to September, 1986-1993)- Alberta and British Columbia

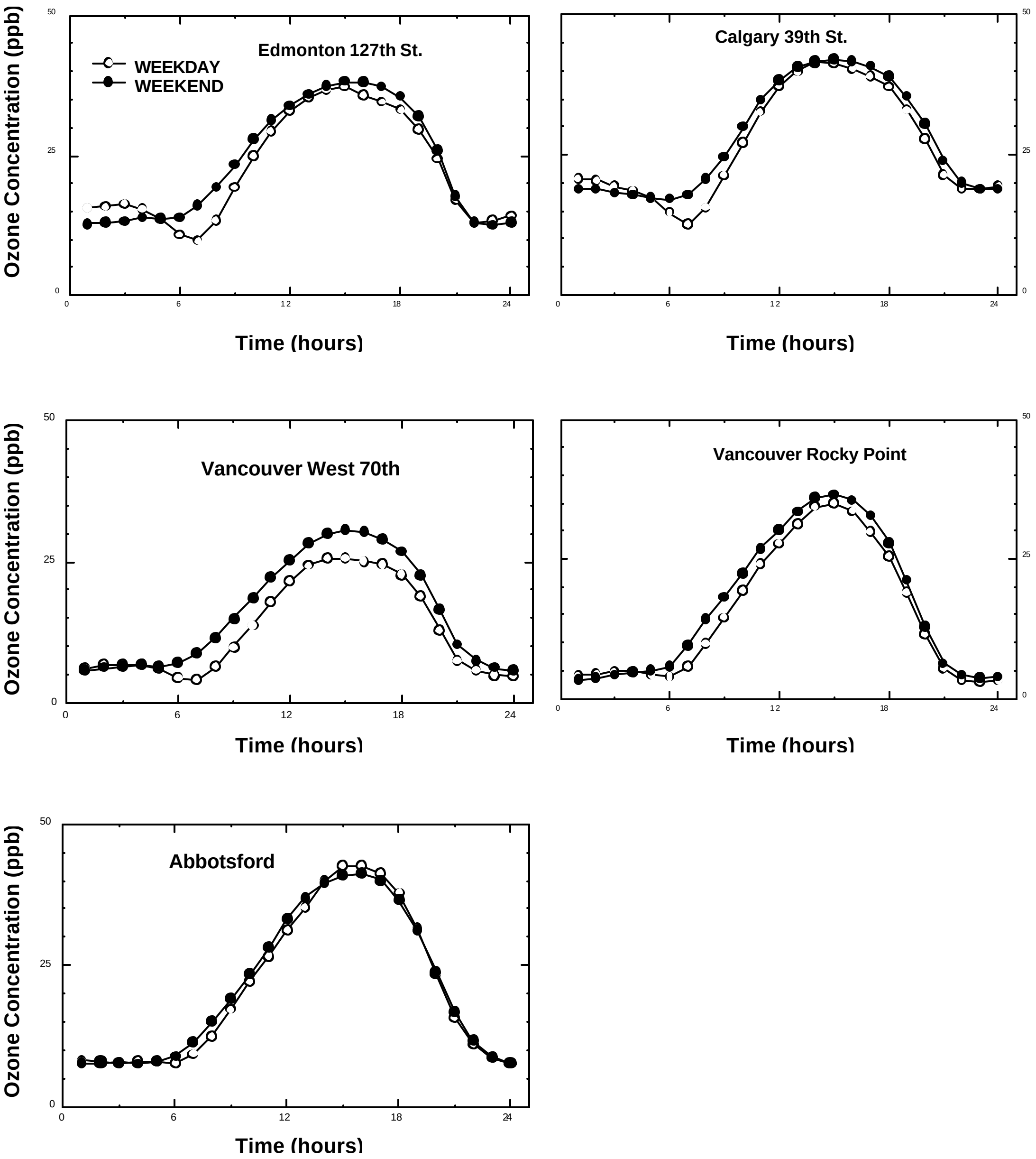


Figure 5.13 Hourly Average Ozone Concentrations (ppb) for Weekdays and Weekends (May to September, 1986 to 1993) – Saskatchewan, Manitoba and Northern Ontario

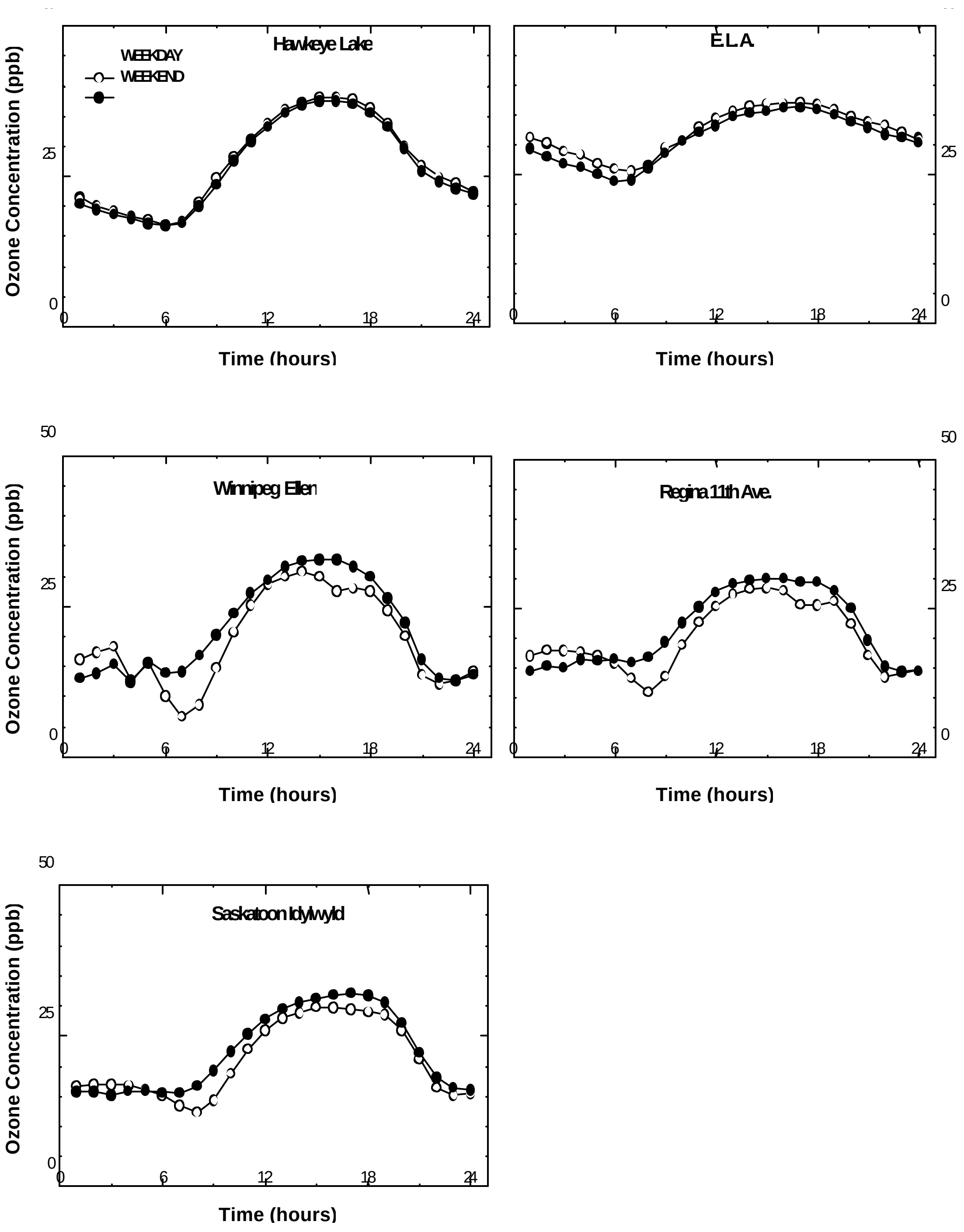


Figure 5.14 Hourly Average Ozone Concentrations (ppb) for Weekdays and Weekends (May to September, 1986 to 1993) - Toronto and Southern Ontario

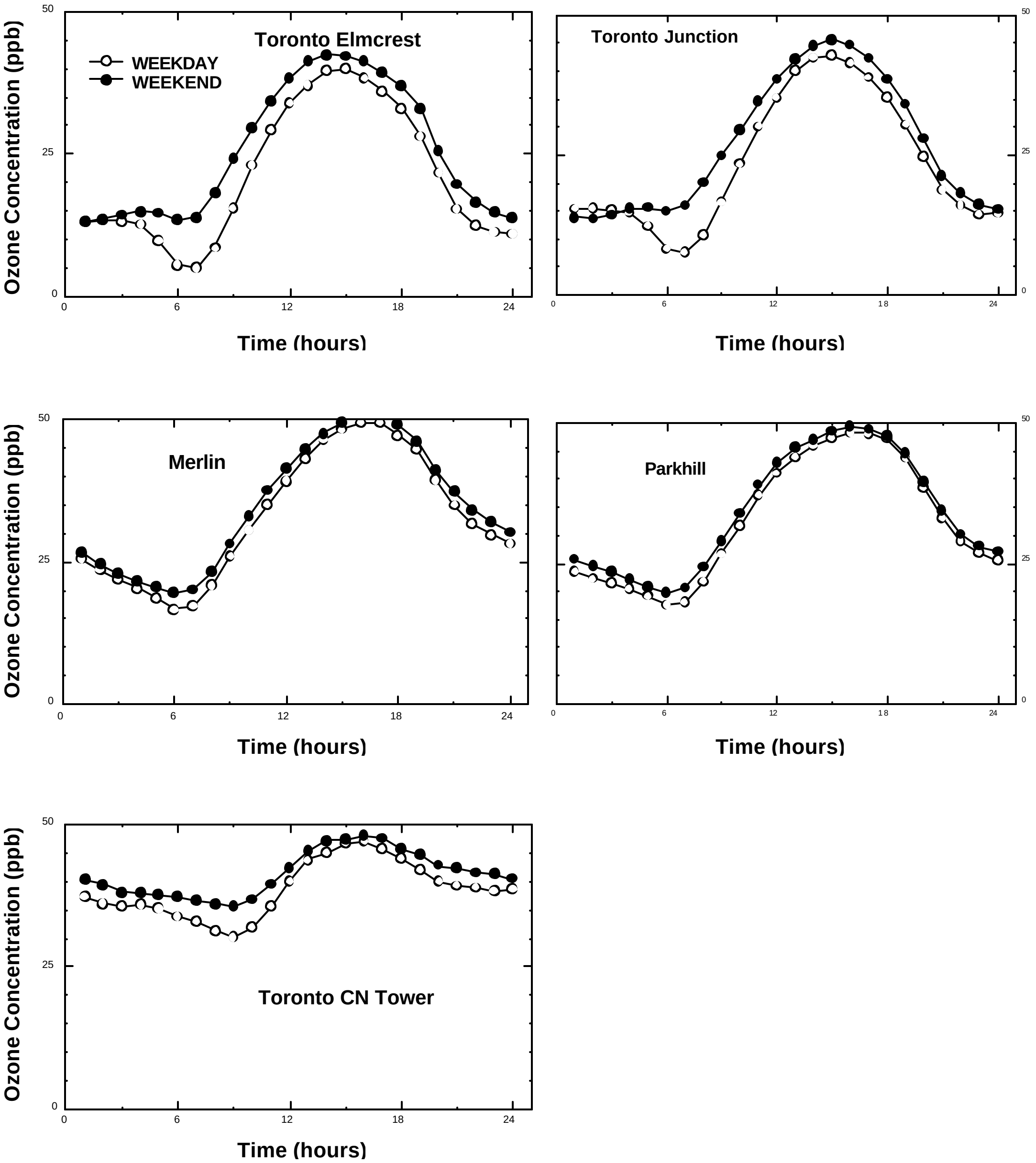
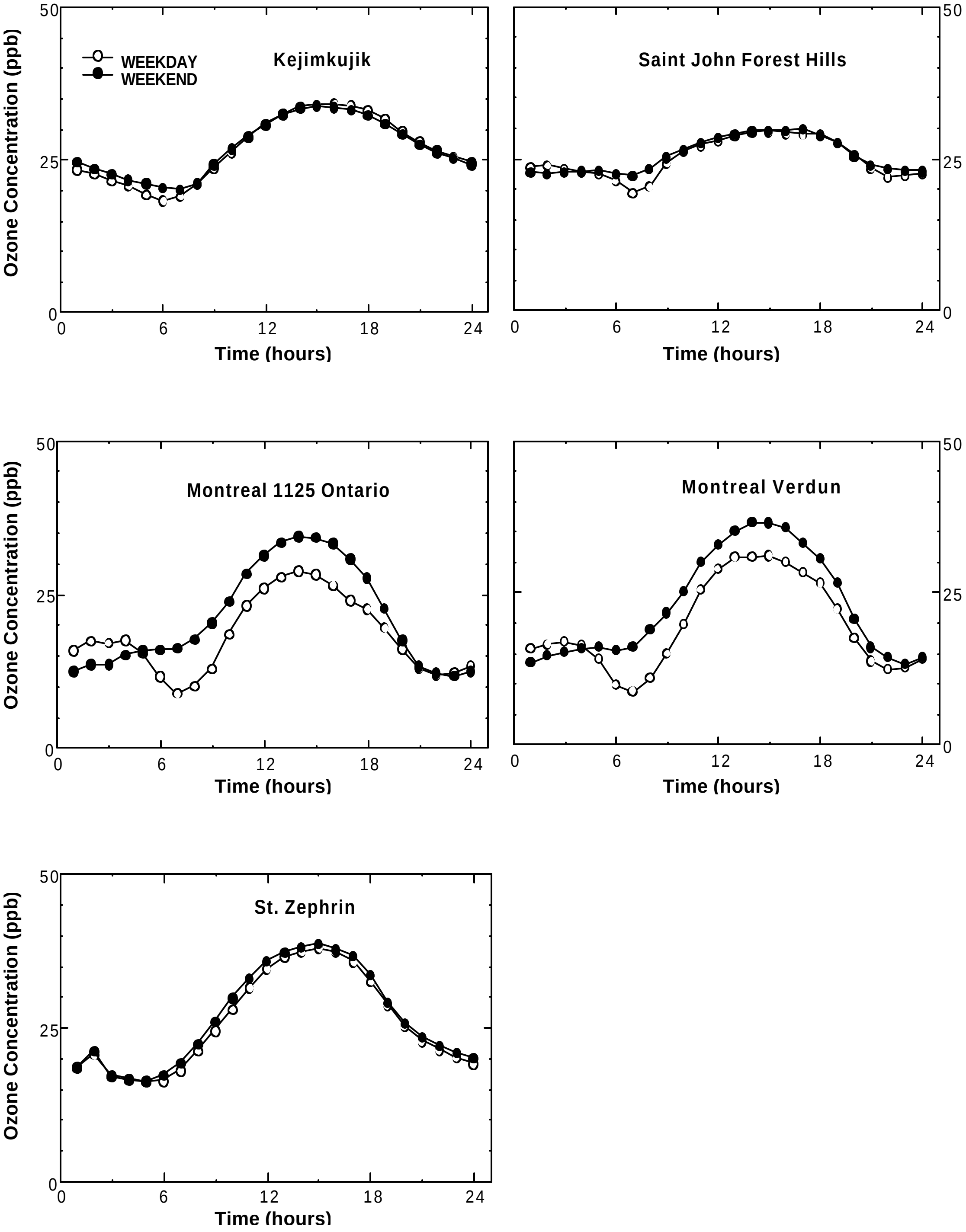


Figure 5.15 Hourly Average Ozone Concentrations (ppb) for Weekdays and Weekends (May to September, 1986 to 1993) - Montréal and Southern Atlantic



5.4 Trend Analysis

5.4.1 Principal Component Analysis and Trends in Mean and Daily Maximum Ozone

Most trend analyses for ozone have been carried out on single sites or for urban areas (Wakim, 1989; Jones et al., 1989; Curran & Frank, 1990; Dann, 1990; Fuentes & Dann, 1993). Since ozone episodes occur on a regional scale, this is a useful unit upon which to carry out the ozone trend analysis. As shown by Eder et al. (1993), principal component analysis (PCA) can be effectively used to study the regionality of ozone concentrations. In effect, PCA breaks apart regional concentrations of ozone levels by exploiting the correlation structure of the data. The analysis extended over the summer months (May to Sept.; 153 days) from 1985 to 1993.

Only Vancouver's Lower Fraser Valley (LFV), southern Ontario and southern Québec (mainly the Montréal area) have a sufficiently dense distribution of ozone monitoring stations to allow spatial analyses. The use of U.S. rural sites allows the spatial analysis to be extended to include most of northeastern North America. The PCA analysis therefore included both Canadian and U.S. monitoring sites. The PCA analysis did cluster sites within specific geographic sub-regions. These sub-regions were consistent with current knowledge of emission sources and of meteorological and topographical influences on ozone concentrations.

With only a few exceptions, the defined sub-regions incorporate the same set of stations whether the analysis is based on the daily mean or the daily maximum. Figure 5.16 shows the location of sites by sub-region for eastern North America and Figure 5.17 shows the location of sub-regions for the western sites (daily maxima analysis only).

Figure 5.16 Site Clusters Based on Daily Maximum Ozone for May-Sept. 1986 to 1993 - Eastern North America

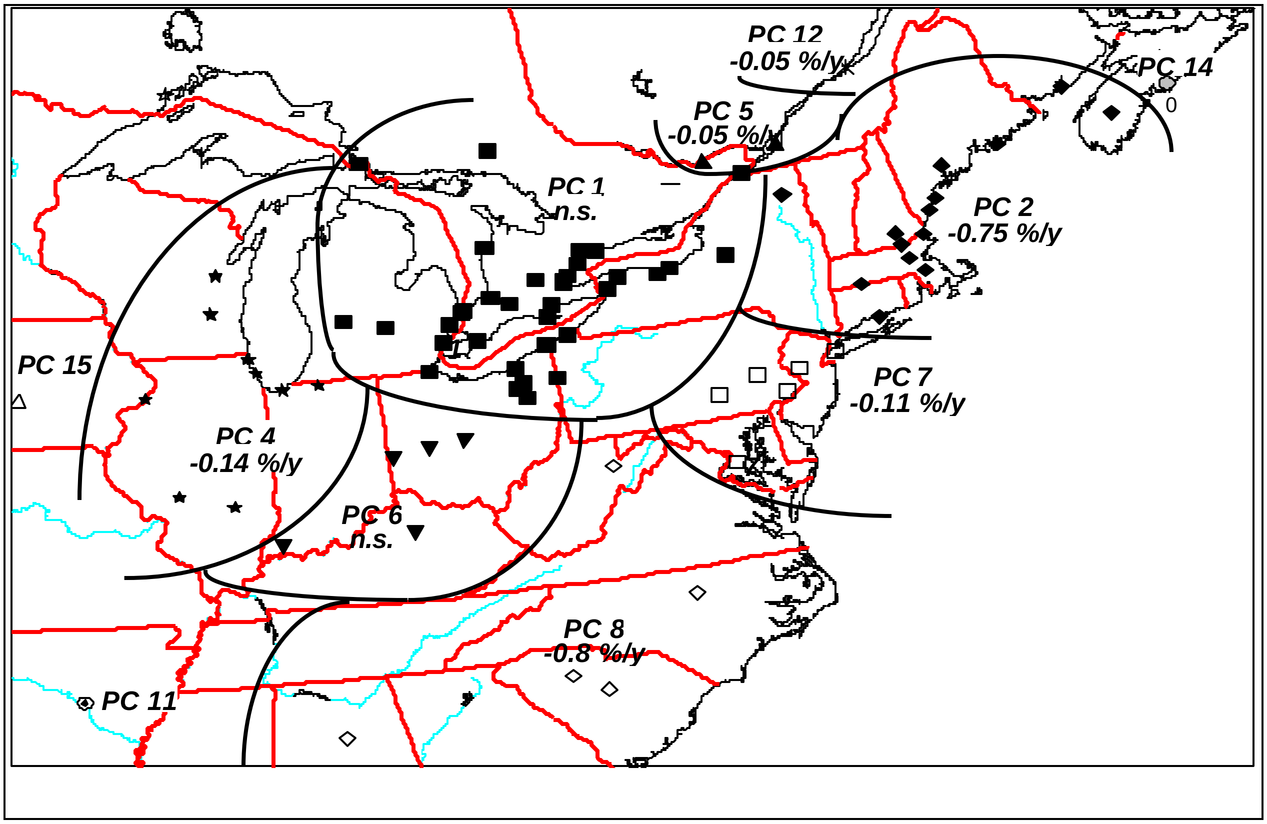
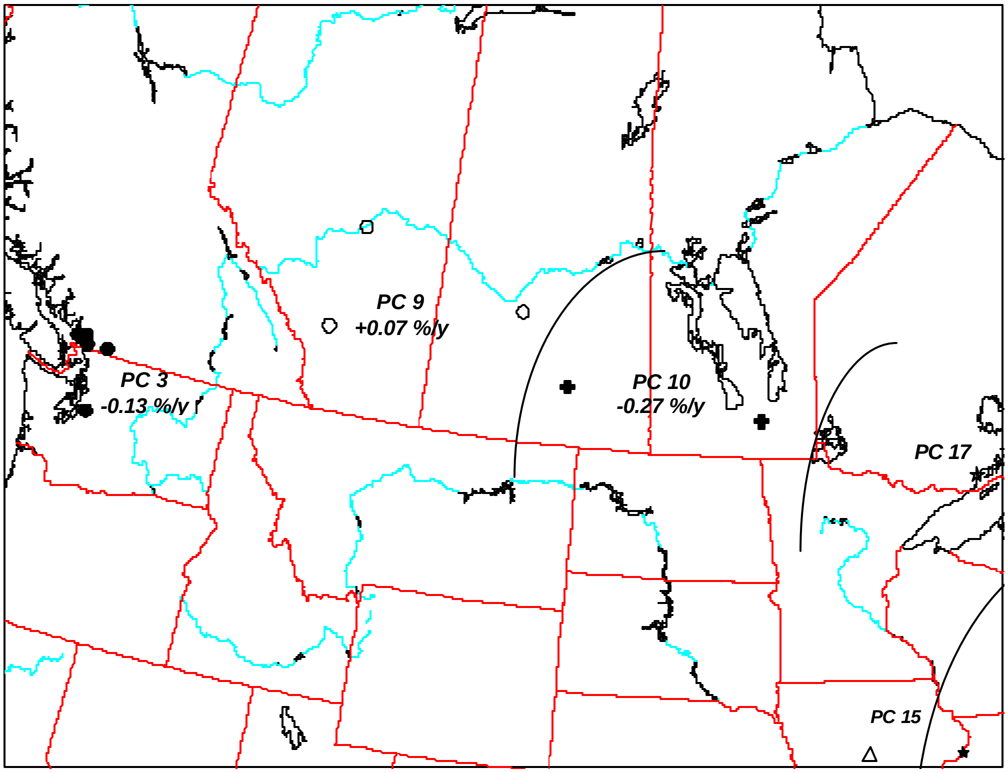


Figure 5.17 Site Clusters Based on Daily Maximum Ozone for May-Sept. 1986 to 1993 - Western North America



Most sub-regions showed a declining trend in daily maximum ozone ranging from 0.05%/yr. to 0.80%/yr. (significant at the 95% confidence level). PC1 (Southern Ontario/Great Lakes) showed no significant trend and one sub-region, PC9 (Saskatchewan/Alberta), showed an increasing trend of 0.07%/yr. The Iowa site also showed an increasing trend of 0.59%/yr. For the daily mean analysis, three sub-regions showed an increasing trend, ten a declining trend and one region no significant trend (no data shown here; refer to Report of the Data Analysis Working Group (Multistakeholder NO_x/VOC Science Program, 1997). An earlier analysis (Kim & Fuentes, 1995, 1996) for the 1982-93 time period (all months included) had indicated increasing trends in daily mean ozone in five out of ten regions. Eder et al. (1993) found no significant trend in mean or daily maximum ozone in identified sub-regions (U.S. data only) between 1985 and 1990.

5.4.2 Trends in Daily Maximum Ozone—Meteorologically Adjusted

The number, duration and intensity of summer ozone episodes at a given site are related in a complex manner to a variety of factors. These include precursor emission levels, solar radiation intensity, temperature and synoptic variables controlling air mass transport over medium and long-range spatial scales. Due to the strong correlation between meteorology and ozone concentrations, variations in meteorological conditions (on all time scales) not only have substantial impacts on ozone concentrations, but they are likely to mask any long-term trends in ozone that may be due to changes in emissions of NO_x and VOC (U.S. National Research Council (NRC), 1991). Accordingly, temporal changes in meteorological conditions need to be considered when assessing ozone trends and relating them to changes in precursor emissions.

Xu et al. (1995) have determined meteorologically adjusted trends for daily maximum ozone for the period 1980 to 1990 for a number of sites in southern Ontario and in Montréal. The trend analysis was recently extended to include sites in the Lower Fraser Valley and in the Southern Atlantic region for the period 1985 to 1992. Two regression modelling approaches were applied: Model 1 (with no meteorological parameters) took into account only a linear trend and seasonal variations; while Model 2 included the meteorological adjustment.

Windsor–Québec City Corridor

The results for locations in Ontario for the years 1980 to 1990 are presented in Table 5.4. The meteorologically adjusted trends for each site are given in column 2. The last column indicates the difference between Models 1 and 2 in terms of the yearly percentage change in ozone. On average, the use of a meteorological adjustment added a negative change of 0.3%/yr. to the base ozone trends. The adjusted trends show that annual change in daily maximum ozone varies from -0.7%/yr. (Ottawa) to +2.9%/yr. (Sudbury). While the overall trend appears to be that the ozone concentrations are increasing at a rate of 1.2%/yr., three sites show weak declining trends and a fourth site indicates no significant trend.

The results for three Québec sites are also shown in Table 5.4 for the years 1981 to 1993. Two sites have a declining trend of 1.5 and 1.1%/yr., while the third site indicates no significant change over the period. The use of a meteorological adjustment added a negative change of 0.4%/yr. to the base ozone trends. This was essentially the same effect found for the Ontario sites.

Lower Fraser Valley

Meteorologically adjusted trends for ten sites in Vancouver and the Lower Fraser Valley were computed for the period 1985 to 1992, as shown in Table 5.5. Seven sites indicated an increasing trend, while a declining trend is noted for the remaining three sites. The adjusted rates range from -1.3 to +1.7%/yr. For all sites, ozone is increasing at an average of 0.5%/yr. Differences in trends between Model 1 and 2 range from 0.2 to 0.2%/yr., with an average of 0.1%/yr.

Table 5.4 Trends in Daily Maximum Ozone for Ontario and Québec Sites with Meteorological Adjustment

Site	Trend from Model 2 %/yr.	Standard Error	T test value for slope = 0	Sign.	Db %/yr.
Ontario (1980-90)					
Burlington	1.1	0.0017	6.58	0.0001	0.2
Etobicoke	2.3	0.0020	11.27	0.0001	0.5
Kitchener	0.0	0.0020	0.20	0.8448	0.5
London	0.8	0.0015	5.11	0.0001	0.3
Ottawa	-0.7	0.0018	-3.69	0.0002	0.0
Sarnia	-0.1	0.0016	-0.77	0.4426	0.1
Stouffville	2.5	0.0016	15.49	0.0001	0.3
Sudbury	2.9	0.0029	10.08	0.0001	0.4
Tiverton	2.3	0.0018	13.11	0.0001	0.4
Toronto	2.5	0.0021	12.03	0.0001	0.5
Windsor	-0.6	0.0018	-3.55	0.0004	0.5
Region	**1.2**				**0.34**
Montréal (1981-93)					
Dorval	-1.5	0.0024	-6.37	0.0001	0.5
Pte. aux Trembles	0.0	0.0027	0.064	0.9491	0.4
Peel St.	-1.1	0.0037	-2.97	0.0030	0.2
Region	**-0.87**				**0.37**

$\Delta\beta = \beta 1 - \beta 2$ is the difference of trend between model 1 (no meteorological parameters) and 2 (meteorological parameters added).

Southern Atlantic Region

Similar variability is noted in the adjusted trends for the Southern Atlantic region based on the results from three sites (Table 5.5). The results show strong increasing trends at two sites and a strong declining trend at the third site. Values range from -3.7 to +7.5%/yr., while the composite trend averages 2.2%/yr. Differences in trends between Models 1 and 2 range from 0.3 to 0.4%/yr., with an average of 0.33%/yr.

Table 5.5 Trends in Daily Maximum Ozone for LFV and S. Atlantic Sites with Meteorological Adjustment

Site	Trend from Model 2 %/yr.	Standard Error	T test value for slope = 0	Sign.	Δβ %/yr.
LFV (1985-92)					
70th Ave.	1.3	0.0039	3.30	0.0010	-0.1
Hastings	1.1	0.0035	3.17	0.0015	0.1
Rocky Pt. Park	-0.7	0.0036	-2.05	0.0406	-0.1
Willingdon	-1.0	0.0033	-3.01	0.0027	0.0
Riverside Dr.	1.1	0.0041	2.72	0.0064	0.0
Sunnyside Rd.	1.5	0.0034	4.40	0.0001	-0.2
Welsh Rd.	0.2	0.0050	0.46	0.6427	0.2
Ring Rd.	1.7	0.0031	5.66	0.0001	-0.1
72nd Ave.	-1.3	0.0034	-4.13	0.0001	-0.2
Abbotsford	0.6	0.0031	1.93	0.0540	-0.2
Region	**0.45**				**-0.06**
Atlantic (1985-92)					
Shearwater	7.5	0.0036	21.225	0.0001	0.3
Saint John (P.O.)	2.8	0.0040	6.866	0.0001	0.4
Saint John (FH)	-3.7	0.0038	-9.853	0.0001	0.3
Region	**2.2**				**0.33**

Δβ=β1–β2 is the difference of trend between models 1 (no meteorological parameters) and 2 (meteorological parameters added).

5.4.3 Summary

The application of the regression model to daily maximum ozone levels at selected urban sites in the three regions revealed strong inconsistencies in the trends within each region. The aggregate values suggest an increasing trend for urban areas within each of the regions. The decrease of NO levels at many urban sites with a resulting decrease in ozone scavenging is the most apparent reason for the increase in average daily maximum ozone concentrations.

5.5 OZONE ANALYSIS FOR AN 8 HOUR AVERAGING PERIOD

The analysis presented in this section is based upon the Report to the Health Objective Working Group - Ozone Data Analysis for Six and Eight Hour Averages (1980 - 1992) (Dann, 1994). Only the 8 hour data are discussed here. Ozone data were extracted from the NAPS database for the period 1980 to 1992, and results are reported for 35 sites in five regions most impacted by ozone - Southern Atlantic, Montréal, Toronto/Hamilton/Niagara, Southwestern Ontario and Vancouver and for six remote (background) sites (first 6 sites in Table 5.6). Sites were chosen based on completeness of data record and representativeness of the site within the region (Fuentes and Dann, 1993). The remote sites had a much shorter data record than the other sites but are useful for comparison purposes. Running averages were based on end time (i.e. the running eight hour average for 01:00 on day 2 represents the period 17:00 on day 1 to 01:00 on day 2). A seventy-five percent data completeness requirement was used to calculate a valid eight hour running average.

5.5.1 Frequency of Daily Maximum 8 Hour Ozone Concentrations

The percentile distributions for daily maximum eight-hour ozone concentrations at 41 Canadian sites are provided in Table 5.6 for the period 1980 to 1992. The percentiles show the percentage of days with daily maxima equal to or less than the indicated value.

Table 5.6: Frequency distribution of daily maximum 8 hour running averages - 1980 - 1992

8 hr Running Average																			
							Percentiles												
Station	City	Address	Start	Stop	Days	Min	5	10	25	50	75	90	95	98	99	99.9	Max.	Mean	Std. Dev.
10201	CORMACK, NFLD.	CORMACK	4/19/1989	12/21/1992	862	7	19	21	25	31	38	45	49	51	55	61	61	32.1	9.3
54001	MONTMORENCY, QUÉBEC		5/31/1988	12/30/1992	1558	7	21	25	29	34	40	49	54	63	71	89	91	35.7	10.5
54101	SUTTON, QUÉBEC		12/6/1988	5/31/1990	366	9	19	23	28	34	44	53	59	66	73	77	77	36.2	12.0
54201	CHAPAIS, QUÉBEC		6/10/1988	5/31/1990	685	9	20	24	28	34	42	50	56	63	67	87	87	35.4	11.0
64001	ELA, ONT.	EXPERIMENTAL LAKES AREA	5/9/1988	12/30/1992	1419	14	23	26	30	36	44	51	56	61	64	75	76	37.3	10.1
102001	SATURNA, B.C.		5/28/1991	12/30/1992	579	6	19	22	27	32	38	45	48	52	57	66	66	32.8	9.1
30501	KEJIMKUJIK, N.S.	NATIONAL PARK	4/16/1985	12/31/1991	2311	9	20	22	27	32	39	47	55	65	73	97	103	34.0	11.3
40202	SAINT JOHN, N.B.	POST OFFICE	1/1/1980	10/15/1991	3778	1	13	17	23	30	39	48	57	68	75	121	135	31.5	13.8
40203	SAINT JOHN, N.B.	FOREST HILLS	1/1/1980	12/31/1992	4247	2	14	18	24	31	41	50	59	73	86	134	146	34.0	15.0
40501	POINT LEPREAU, N.B.	MAIN GATE	7/15/1986	11/29/1992	1005	1	10	20	27	34	43	58	71	88	95	120	135	36.9	17.6
50102	MONTRÉAL, QUÉBEC	JARDIN BOTANIQUE	1/1/1980	10/17/1992	3829	1	6	9	14	23	33	44	54	64	73	99	106	25.0	14.8
50103	MONTRÉAL, QUÉBEC	POINTE-AUX-TREMBLES	1/1/1980	10/31/1992	3868	1	8	10	17	25	34	45	54	63	71	94	146	26.6	14.3
50104	MONTRÉAL, QUÉBEC	1125 ONTARIO EST	1/1/1980	12/31/1992	4215	1	5	8	13	20	30	44	54	66	75	98	106	23.6	15.1
50110	MONTRÉAL, QUÉBEC	PARC PILON, MTL.-NORD	3/7/1980	12/31/1992	3765	1	5	9	15	23	33	46	58	71	80	114	121	25.6	16.3
50112	MONTRÉAL, QUÉBEC	BOUL. LAURENTIDES	1/1/1980	9/30/1992	3793	1	8	10	18	26	36	48	59	71	80	108	125	28.1	15.9
50113	MONTRÉAL, QUÉBEC	PIE X & CARDINAL	1/1/1980	9/30/1992	3961	1	9	11	20	29	39	50	61	75	85	115	123	30.3	16.4
60204	WINDSOR, ONT.	467 UNIVERSITY AVE. WEST	1/1/1980	12/31/1992	4653	0	6	9	15	26	43	61	72	83	90	109	135	30.9	20.6
61004	SARNIA, ONT.	FRONT ST. AT C.N. TRACKS	1/1/1980	12/31/1992	4712	1	10	15	23	31	42	57	68	79	87	103	128	33.6	17.1
61005	SARNIA, ONT.	MTC SHED	1/1/1980	12/31/1992	4433	1	14	17	24	32	44	60	71	83	92	111	130	35.6	17.5
62101	HURON PARK, ONT.	COLLEGE OF AGRICULTURE	1/1/1980	11/9/1991	3981	3	15	19	25	33	45	61	71	82	88	109	116	36.5	17.1
62201	MERLIN, ONT.	MOE WATER PUMP STN.	1/1/1980	12/31/1992	4561	0	14	18	24	32	45	61	72	83	92	115	125	36.2	17.7
62401	PARKHILL, ONT.	PUC BLDG.	7/22/1983	12/31/1992	3246	1	15	18	26	34	47	64	74	87	94	115	120	38.1	18.1

8 hr Running Average

Station	City	Address	Start	Stop	Days	Min	Percentiles										Max.	Mean	Std. Dev.
							5	10	25	50	75	90	95	98	99	99.9			
62501	TIVERTON, ONT.	CON. RD. 2 LOT A	1/1/1980	12/31/1992	4538	1	20	24	30	36	47	64	76	90	98	121	139	40.4	17.0
62601	SIMCOE, ONT.	EXPERIMENTAL FARM	1/1/1980	12/31/1992	4524	1	17	21	27	36	49	65	76	86	93	110	172	39.7	18.1
60413	TORONTO, ONT.	ELMCREST ROAD	1/1/1980	12/31/1992	4506	0	6	10	17	25	38	53	66	80	88	110	117	28.9	18.1
60415	TORONTO, ONT.	QUEENSWAY W & HURONTARIO	1/1/1980	12/31/1992	4567	0	7	10	16	24	35	49	60	73	82	113	138	27.2	16.6
60418	TORONTO, ONT.	JUNCTION TRIANGLE	3/20/1981	12/31/1992	4167	0	6	10	17	26	38	53	66	79	86	110	134	29.5	17.9
60513	HAMILTON, ONT.	VICKERS RD. & EAST 18TH ST.	10/10/1985	12/31/1992	2569	0	8	11	18	27	41	59	69	80	87	107	115	31.4	18.6
61302	ST. CATHARINES, ONT.	ARGYLE CRESCENT	1/5/1988	12/31/1992	1737	1	12	15	21	30	43	59	69	78	83	102	125	33.8	17.4
61602	OAKVILLE, ONT.	BRONTE RD. & WOBURN CRES.	4/9/1980	12/31/1992	4531	0	10	14	20	29	41	54	65	76	84	108	140	32.0	16.8
61701	OSHAWA, ONT.	RITSON RD. & OLIVE AVE.	1/1/1980	12/31/1992	4595	0	9	13	19	27	36	48	60	76	86	103	140	29.2	15.6
62901	NIAGARA FALLS, ONT.	ALLENDALE AVE.	5/18/1988	12/31/1991	1285	1	13	17	24	34	50	68	78	90	96	127	127	38.4	20.2
100108	VANCOUVER, B.C.	250 WEST 70TH AVENUE	1/1/1980	12/31/1992	4094	0	2	4	10	19	28	34	39	43	48	65	92	19.4	11.6
100111	VANCOUVER, B.C.	ROCKY PT. PARK	1/1/1980	12/31/1992	4337	0	2	5	12	24	35	46	55	68	77	121	159	25.2	17.1
100122	VANCOUVER, B.C.	SUNNYSIDE ROAD ANMORE	5/1/1982	12/31/1992	3594	0	7	11	18	26	34	43	50	62	71	111	140	26.9	13.8
100124	VANCOUVER, B.C.	475 GUILDFORD WAY PORT MOODY	5/1/1982	12/31/1992	2893	0	2	4	12	21	31	40	46	57	67	87	109	22.4	14.2
100126	VANCOUVER, B.C.	RING ROAD BURNABY	6/1/1984	12/31/1992	2770	2	12	15	20	25	32	39	45	54	60	88	124	26.6	10.6
100127	VANCOUVER, B.C.	19000 & 72ND AVE. SURREY	12/22/1983	12/31/1992	3105	0	6	10	19	28	36	44	50	58	66	90	100	28.1	13.6
100129	VANCOUVER, B.C.	HAMILTON & PAISLEY	6/8/1987	12/31/1992	1577	0	5	10	18	26	35	43	49	58	70	102	119	26.7	13.6
101001	ABBOTSFORD, B.C.	AIRPORT	8/1/1982	1/3/1992	3008	0	7	12	22	31	39	47	54	62	70	88	107	30.5	14.0
101201	PITT MEADOWS, B.C.	AIRPORT	5/21/1985	12/31/1992	2166	0	4	8	18	26	35	44	50	58	66	80	99	26.8	13.8

5.5.2 Partitioning of Hourly Data for Selected Daily 8 Hour Maxima

Counts of hourly averages within 10 ppb concentration classes from 0-200 ppb were determined for daily maximum 8 h concentrations over the range of 50 to 200 ppb. The results of this analysis for 41 sites are provided in detail in Dann, 1994. Figures 5.18 to 5.23 show the frequency distribution of hourly concentrations when eight hour daily maxima were in the range of 50 to 90 pbb for selected sites. These plots are provided by region for the year 1988 (a high ozone year). The x-axis numbers represent the start values of the 10 ppb ranges (i.e. 50 represents 50-60 ppb). For any given 8 hour daily maximum concentration there is a very low probability of occurrence of hourly maxima that are 20 ppb or more greater than the 8 hour daily maximum concentration. This is also illustrated in Figure 5.24 which shows the relationship between daily maximum one hour concentrations and daily maximum eight hour concentrations for 1992. Analyses of data from other years show similar regressions to that in Figure 5.24. The graphs were constructed using all days with one hour ozone maximum > 50 ppb for all 41 sites.

Figure 5.18: Frequency of hourly averages for selected daily 8 hr maximum ozone concentrations (ppb) - Remote sites 1988. X-axis values represent the starting value for each 10 ppb range.

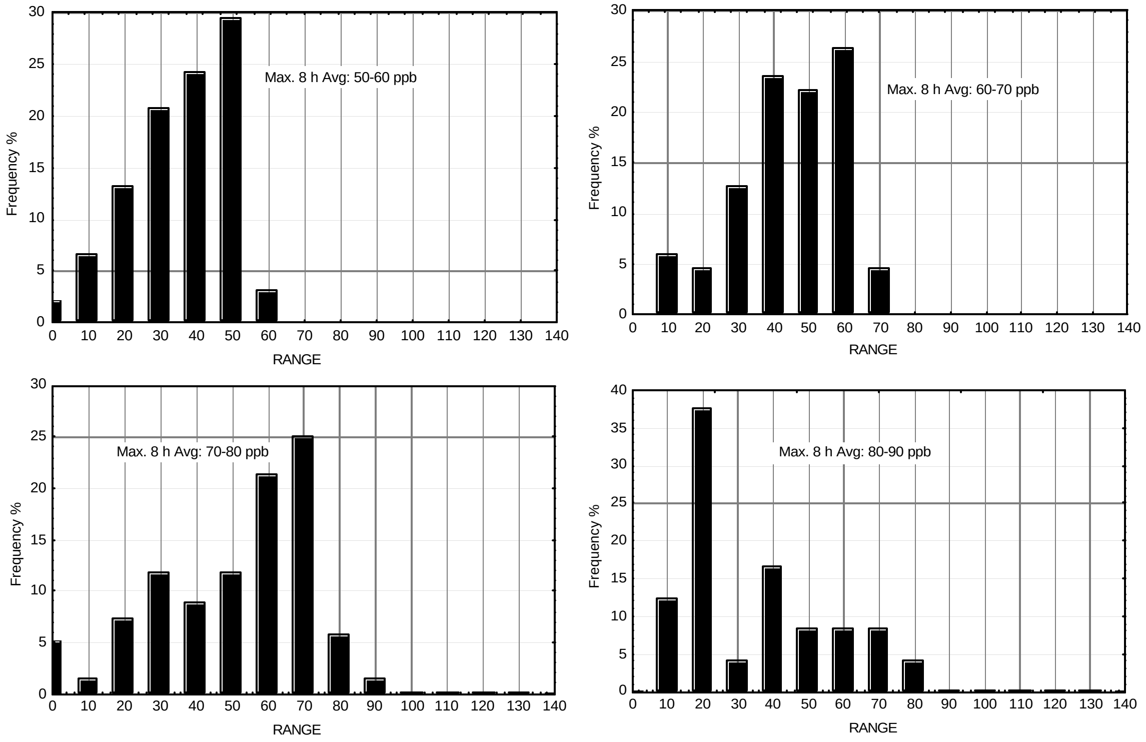


Figure 5.19: Frequency of hourly averages for selected daily 8 hr maximum ozone concentrations (ppb) - Southern Atlantic Region 1988. X-axis values represent the starting value for each 10 ppb range.

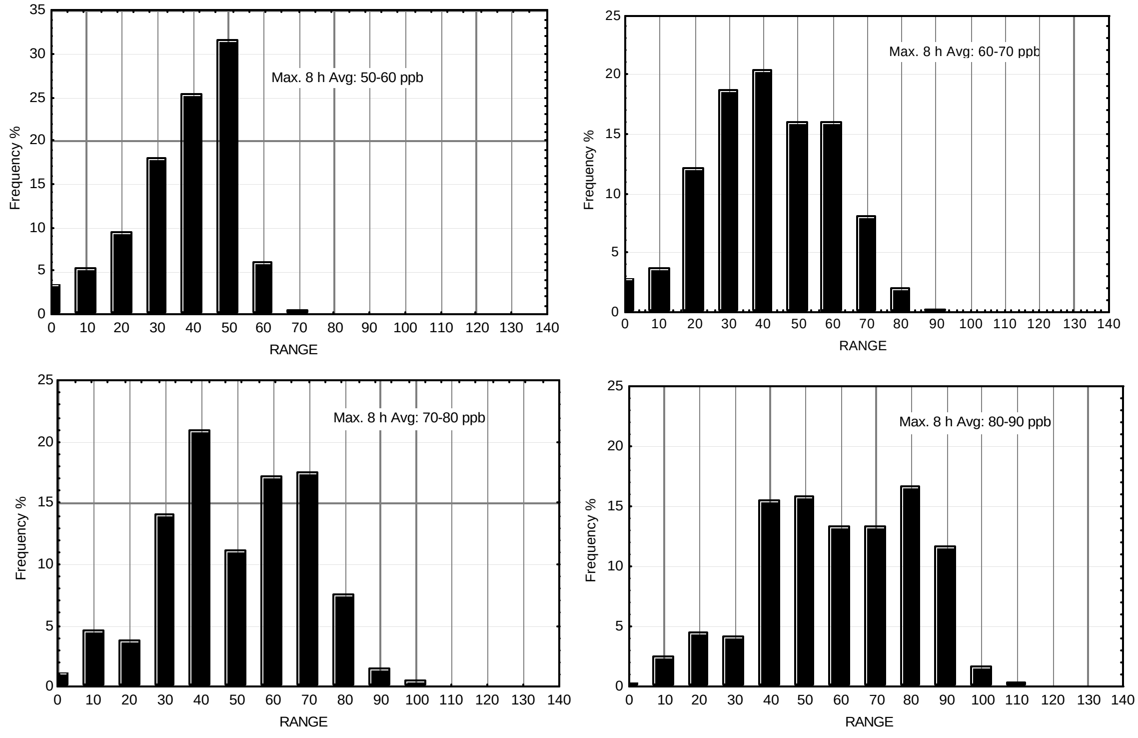


Figure 5.20: Frequency of Hourly Averages for Selected Daily 8 h Maximum Ozone Concentrations. (ppb) - Montréal 1988. . X-axis values represent the starting value for each 10 ppb range.

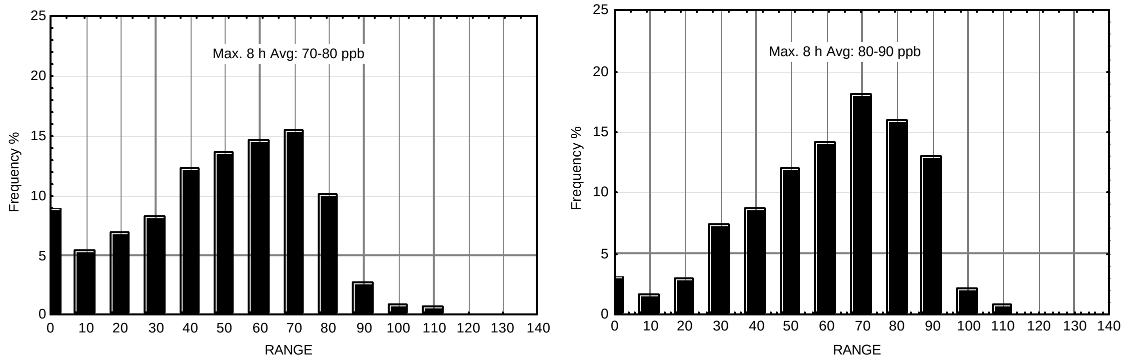


Figure 5.21: Frequency of hourly averages for selected daily 8 hour maximum ozone concentrations (ppb) - Southwestern Ontario 1988. X-axis values represent the starting value for each 10 ppb range.

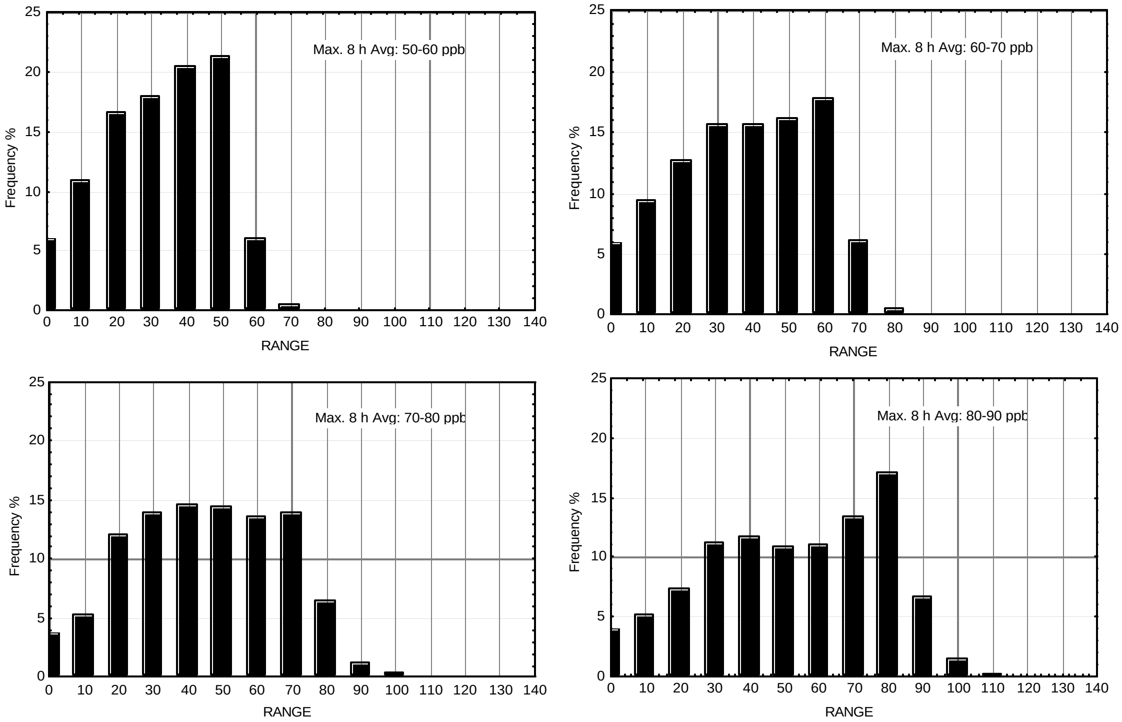


Figure 5.22: Frequency of hourly averages for selected daily 8 hr maximum ozone concentrations (ppb) - Toronto/Hamilton/Niagara 1988. X-axis values represent the starting value for each 10 ppb range.

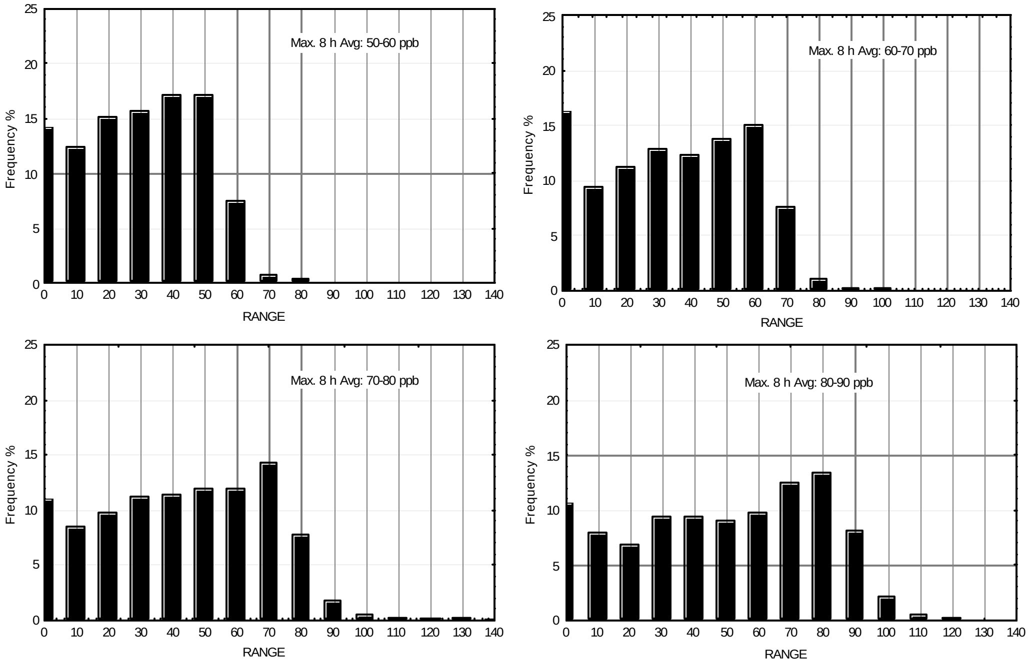


Figure 5.23: Frequency of hourly averages for selected daily 8 hour maximum ozone concentrations (ppb) - Vancouver / Lower Fraser Valley 1988. X-axis values represent the starting value for each 10 ppb range.

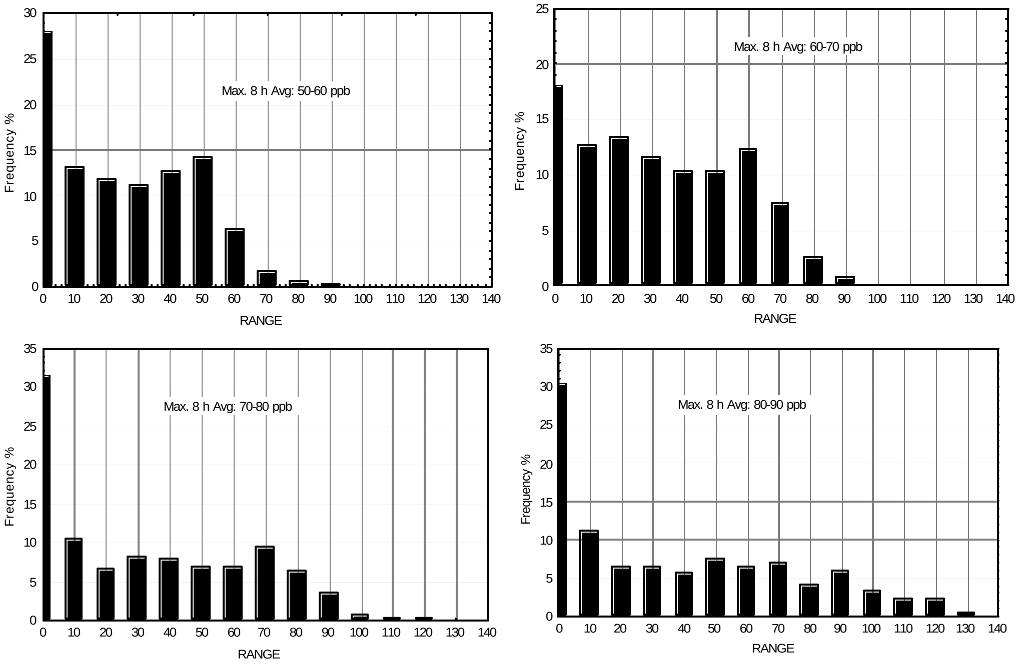
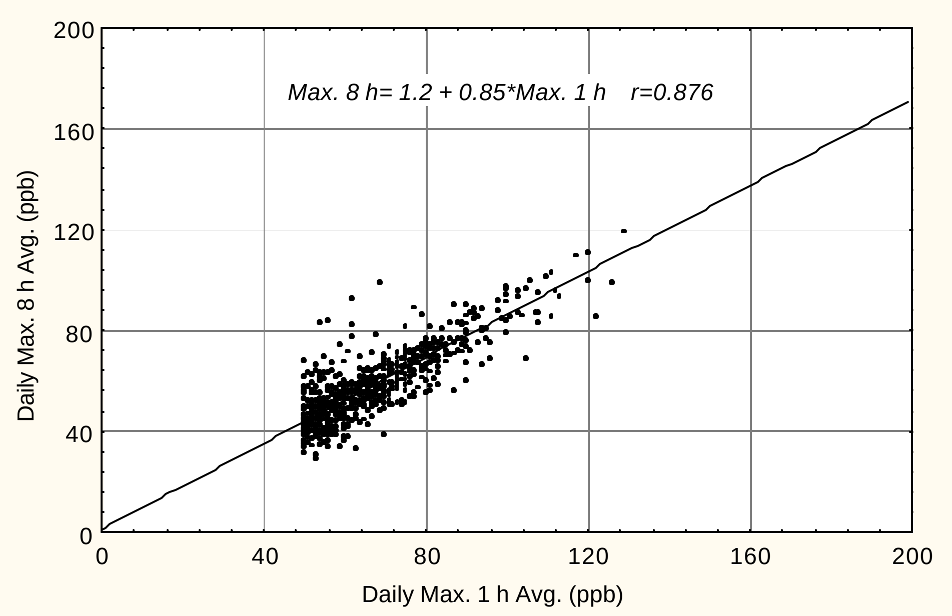


Figure 5.24: Relationship Between Daily Maximum 8 hour Average and Daily Maximum 1 hr. Avg. for 1992 – All Sites (n=1541)



5.5.3 Diurnal Patterns of 8 hour Average Ozone

An analysis of the time of day occurrence of running 8 hour average ozone concentration greater than selected values was also carried out (Dann, 1994). Sample outputs shown in Figures 5.25 to 5.27 are for counts of 8 hour running averages greater than 70 ppb by end time for each site group for the years 1988, 1990 and 1992 (high, moderate and low ozone years respectively). Running averages were based on end time (i.e.; the running eight-hour average for 01:00 on day 2 represents the period 17:00 on day 1 to 01:00 on day 2). The order of plotting has been changed on some of the graphs to improve legibility. Figures 5.28 and 5.29 show mean concentrations of 8 hour running average ozone by end time for periods greater than 70 ppb (remote sites not included because of very few occurrences of 8 hour ozone > 70 ppb). These figures display data for the year 1988 only.

At most sites the highest number of 8 hour averages greater than 70 ppb occurred somewhere between the 1000-1800 and 1300-2100 time periods (endtimes 18 to 21, Figures 5.25 – 5.27). The Montréal and southern Atlantic sites showed less diurnal variation in counts of running 8 hour averages greater than 70 ppb than the other non-remote sites. Remote sites, not surprisingly, had the fewest counts of running 8 hour averages greater than 70 ppb. Mean eight hour concentrations by end time (for 8 hour periods > 70 ppb) were very similar for all site groupings except southern Atlantic for end times between 1500 and 1900 (Figures 5.28 and 5.29). For other periods of the day there were large differences between regions.

Figure 5.25: Site average count of 8 hour running average ozone >70 ppb by end time - 1988.

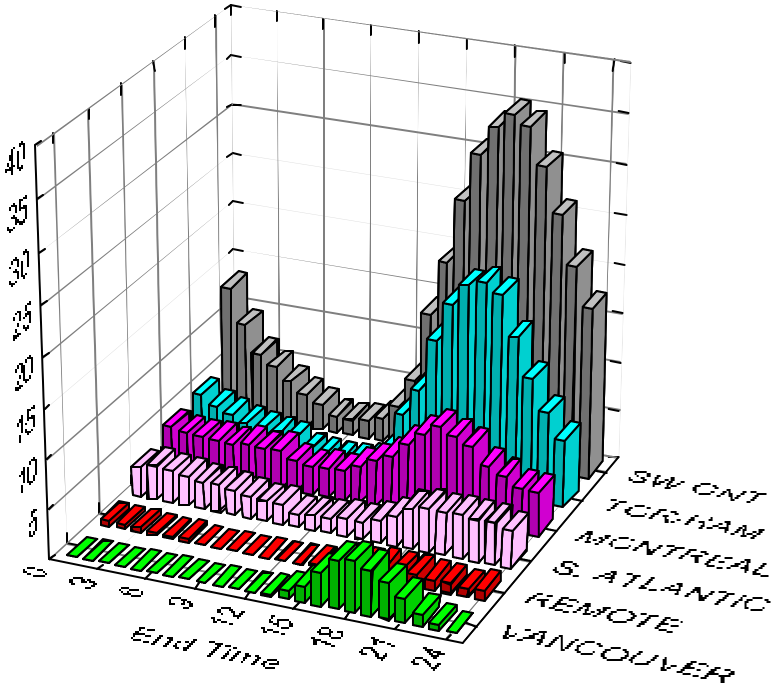


Figure 5.26: Site average count of 8 hr running average ozone >70 ppb by end time - 1990.

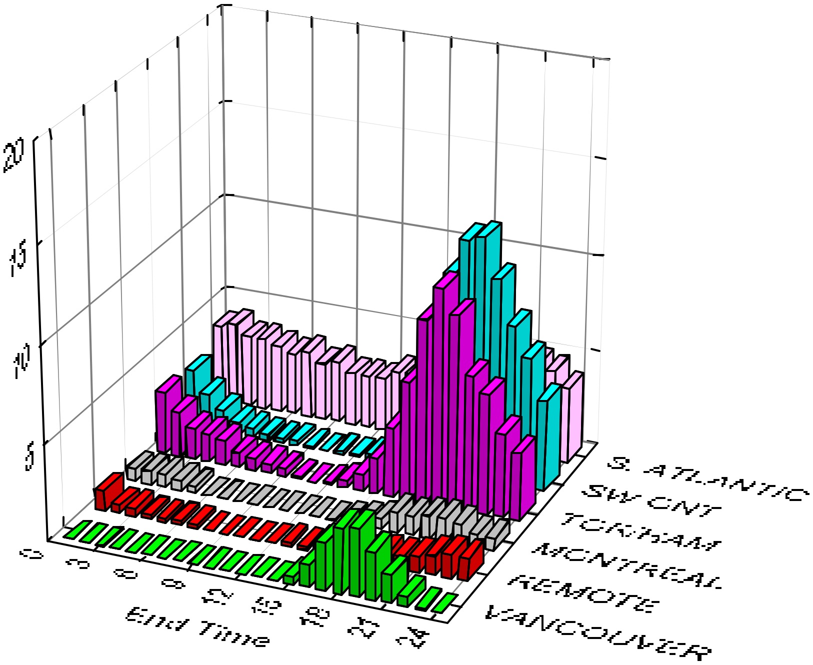


Figure 5.27: Site average count of 8 hr running average ozone >70 ppb by end time - 1992.

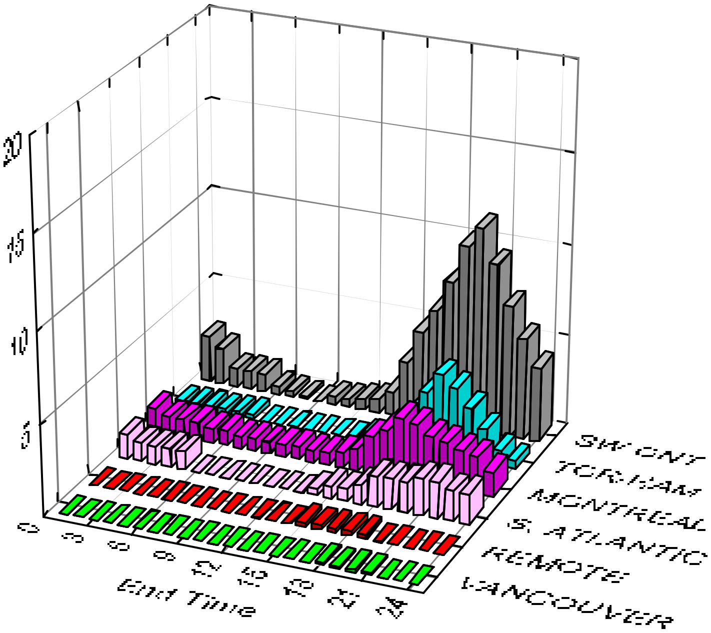


Figure 5.28: Mean 8 hr ozone concentration (ppb) by end time, 1988 (for 8 hr periods >70 ppb only) - Windsor / Québec City Corridor.

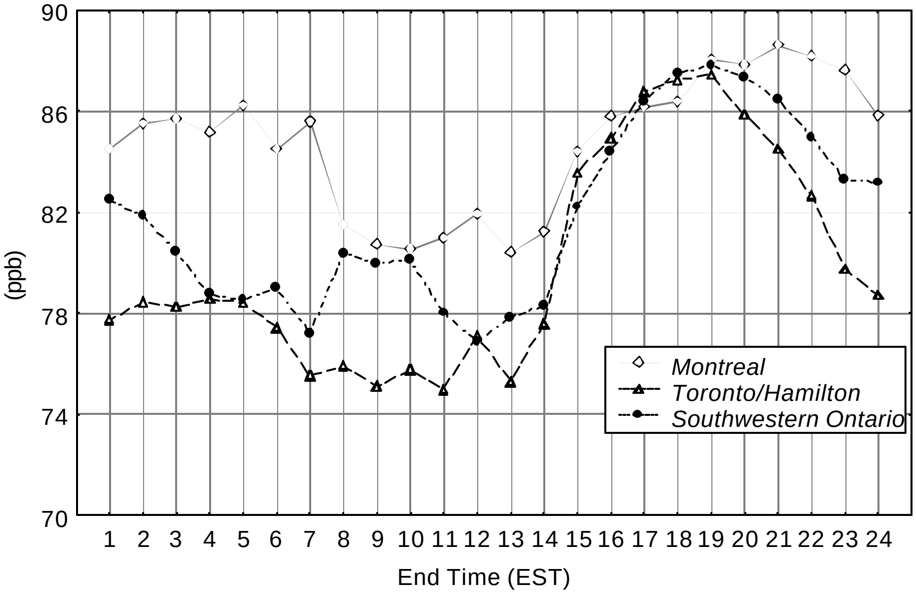
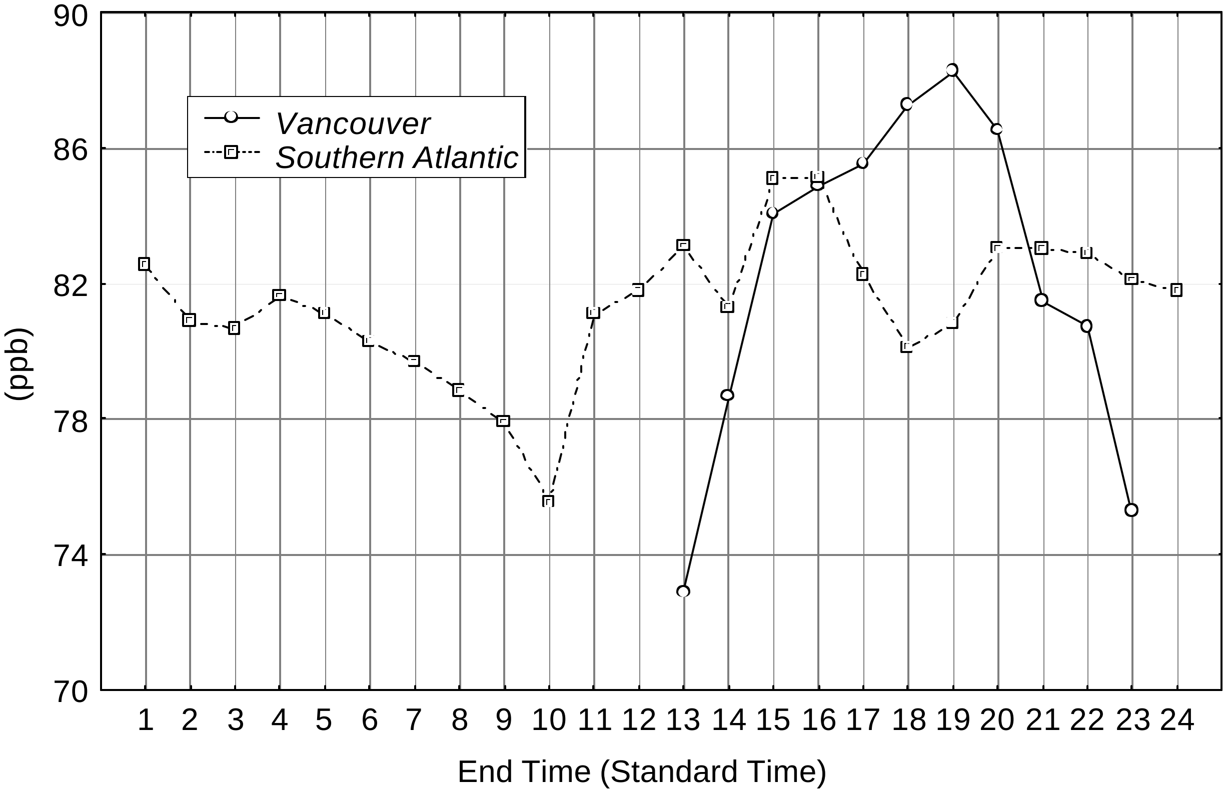


Figure 5.29: Mean 8 hour ozone concentrations (ppb) by end time, 1988 (for 8 hr periods >70 ppb only) - Vancouver and Southern Atlantic Region.



5.5.4 Summary of 8 hour ozone data

As described in Chapter 3 of this document, measurements of ambient ozone with modern continuous analyzers store ozone readings each minute. Data are generally reported over a 1 hour averaging time. The database of hourly ozone values at each site can, however, be easily converted to other ozone metrics. This section has presented an overview of ozone values for an 8 hour averaging period for different regions of Canada. The analysis has shown that for any given 8 hour daily maximum concentration, there is a very low probability that hourly maxima, 20 ppb or more greater than the 8 hour daily maximum concentration, will occur. Analyses of the time-of-day occurrence of high 8 hour values (> 70ppb) showed that these tended to occur between the 1000-1800 and 1300-2100 time periods.

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