Fine Particles and Ozone in Canada A Canada-wide Standards Perspective 2003 National Summary

An Environment Canada Staff Report

in Support of the Canada-wide Standards for Particulate Matter and Ozone

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Executive Summary

The air that we breathe contains many substances, including microscopic particulate matter (PM) and ozone (O_3) , the two main components of summer smog. PM and ozone cause a number of health effects, including premature mortality, and they also adversely affect the environment. Recognizing the detrimental effects associated with PM and ozone, in June 2000 the Canadian Council of Ministers of the Environment (CCME) endorsed Canada-wide Standards (CWS) for PM and ozone which include ambient numerical targets to be achieved by 2010.

The ambient numerical targets (hereafter referred to as *standards*) are 30μ g/m³ for the fine size fraction of PM (i.e. PM_{2.5}) and 65 ppb for ozone. The levels to use for direct comparison to the standards (i.e. the *form* of the standards) are the 3-year average of the annual 98th percentile of the daily 24-hour average concentrations for PM_{2.5}, and the 3-year average of the annual 4th highest of the daily maximum 8-hour average concentrations for ozone. The forms of these standards are referred as the 3-year averages for short.

This report includes information on the national anthropogenic emissions of the sources of PM and its precursors (the gases sulphur dioxide (SO₂), oxides of nitrogen (NO_x), ammonia (NH₃) and volatile organic compounds (VOC)), and ozone precursors (NO_x and VOC). Its main objective, however, is to present information on the 2003 ambient monitoring results for PM_{2.5} and ozone based on the CWS numerics, including the 3-year averages for the period 2001-2003. Also included is an indication of how typical the PM_{2.5} and ozone levels were in 2003, and information on trends in ozone levels. Trends in PM_{2.5} levels could not be reported because of insufficient long-term data. The report also includes an Appendix that provides an update on the PM_{2.5} measurement method path forward, additional information on the nature of PM and ozone, information on some of the methods adopted for data analysis, and identification of the considered monitoring stations.

In 2000, 7700 kilotonnes (kt) of the aggregated emissions of SO₂, NO_x, VOC and primary PM_{2.5} were emitted in Canada from anthropogenic sources (excluding open sources). Industry was the largest emitter of the aggregated emissions followed by Transportation and Electricity Production. The Agriculture sector and the Pesticides and Fertilizer Applications sector were the two largest contributors to the national emissions of ammonia. Between 1990 and 2000, national NO_x emissions (excluding open sources) decreased by 6% and VOC emissions decreased by 15%. For both NO_x and VOC, reductions in emissions from On-road vehicles were partially offset by increases from the Upstream Oil and Gas Industry. National SO₂ emissions decreased by 27%, and National emissions of primary PM decreased by 30%.

The 3-year averages for 2001-2003 were computed for both $PM_{2.5}$ and ozone on a monitoring station basis for all stations that satisfied the applicable data completeness criterion. The Figure on the next page indicates whether these 3-year averages are below or above the standards. Because a number of these stations are within a rural setting, because not all stations in a given community are necessarily CWS reporting stations, and because CWS achievement reporting is on a community basis, the information in the Figure is not to be construed as being formally indicative of the achievement status of the standards for any of the communities in which the monitoring stations are located.

Saskatchewan-Manitoba and Newfoundland where the only two regions with 3-year averages below both standards at all considered stations. In British Columbia, only one station in the interior of the province recorded a 3-year average above the standard for $PM_{2.5}$, and in Alberta and Atlantic Canada only the ozone 3-year average was above the standard at some stations. In Ontario and Québec, most stations recorded an ozone 3-year average above the standard, and many stations (mostly in southern Ontario and Montréal) recorded 3-year averages above both standards.

Based on the population of the communities where the monitoring stations are located, 1/3 of Canadians (approximately) lived in communities with 3-year averages above the standard either for only PM_{2.5} or for both PM_{2.5} and ozone, and 1/2 lived in communities with 3-year averages above the standard for at least ozone.



How the PM_{2.5} and ozone 3-year averages (2001-2003) compare to the standards

The 2003 regional annual average and 98th percentile of the daily 24-hour average PM_{2.5} concentrations were compared to those over the previous four years (1999-2002) to obtain an indication of how typical the levels were in 2003. Nationally, 2003 was more or less typical of the previous 4-years with respect to the annual average, and a high year for the 98th percentile. Regionally, 2003 was a slightly low year in Saskatchewan-Manitoba, Ontario and Atlantic Canada, and



a high year in Québec. In Alberta and British Columbia, 2003 was a slightly high year with respect to the annual average, but a very high year for the 98th percentile.

For ozone, the 2003 regional annual average and annual 4th highest of the daily maximum 8-hour average concentrations (Dmax 8-hour O₃) were compared to levels over the previous ten years (1993-2002). 2003 was a slightly high year nationally and also regionally in Alberta, Ontario, Québec and Atlantic Canada. In BC, 2003 was a slightly high year for the 4th highest, and a high year for the annual average. In Saskatchewan-



Manitoba, 2003 was a high year for both the annual average and annual 4th highest.

Trends in ozone levels were evaluated for the regional (and national) annual average and the regional annual 4th highest of the Dmax 8-hour O_3 for (up to) the 15-year period from 1989 to 2003 based only on stations that satisfied stringent data completeness requirements.

The annual average Dmax 8-hour O₃ increased nationally and also in each of the six regions considered. The trends were statistically significant nationally and in **British Columbia** and Ontario, and nonsignificant in the other regions. The largest increases occurred in BC and in Ontario.



Nationally, the annual 4th highest Dmax 8-hour O₃ remained essentially unchanged over the 15 years. Regionally it increased in Québec, Ontario, Saskatchewan-Manitoba and Alberta, and it decreased in Atlantic Canada and BC. None of these trends, however, were statistically significant.



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All ambient PM_{2.5} and ozone data used to generate the information in this report were collected through the National Air Pollution Surveillance (NAPS) network and the Canadian Air and Precipitation Monitoring network (CAPMoN), with the data kindly provided by the Analysis and Air Quality Division of EC, the coordinating agency for NAPS. The pollutant emission data was provided by Pollution Data Branch, of EC, through the Emissions and Projections Working Group (EPWG).

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1. INTRODUCTION

The air that we breathe contains many substances, including microscopic particulate matter (PM) and ozone (O_3) , the two main components of summer smog. PM and ozone cause a number of health and environmental effects. Health effects may range from

PM and ozone cause a number of health and environmental effects.

subtle biochemical and physiological changes to difficulty breathing, wheezing, coughing and aggravation of existing respiratory and cardiac conditions. Because of the needed care, these effects may result in increased use of medication, increased number of visits to doctors or emergency units, and increased number of hospital admissions. In some cases they can also result in premature death. The segment of the population at greater risk of these effects include children, the elderly and individuals with existing respiratory and cardiac diseases. Effects on the environment include visibility impairment and ecosystem acidification in the case of PM, and crop damage and greater vulnerability to diseases in some tree species in the case of ozone.

Recognizing the detrimental effects associated with PM and ozone, in June 2000 the Canadian Council of Ministers of the Environment (CCME) endorsed (except Québec¹) *Canada-wide Standards for Particulate Matter and Ozone* (CWS). Under the CWS, federal, provincial and territorial jurisdictions committed to a number of actions including jurisdictional implementation plans to achieve the endorsed ambient numerical targets by 2010. For PM, an ambient target was endorsed for *fine* particles (PM_{2.5}). The CCME also recognized that the CWS numerical targets may not be fully protective, but they are an important first step towards the long-term goal of minimizing the risks that PM and ozone pose to health and the environment. The CWS represent a balance between achieving the best health and environmental protection possible and the feasibility and costs of reducing the pollutant emissions that contribute to PM and ozone in ambient air. Limited information on the CWS is provided in section 2, and detailed information is available at: http://www.ccme.ca/initiatives/standards.html?category_id=59

Objective of the report

This report includes information on the national anthropogenic emissions of PM and its precursors and ozone precursors. Its main objective, however, is to present information on the 2003 monitoring results for $PM_{2.5}$ and ozone based on the CWS numerics. Also included is an indication of how typical the $PM_{2.5}$ and ozone levels were in 2003, and information on trends in ozone levels. Trends in $PM_{2.5}$ levels could not be reported because of insufficient long-term data. It should be

All ambient data are from the NAPS and CAPMoN monitoring networks

All ambient data used to generate the information in this report are from the National Air Pollution Surveillance (NAPS) network and from the Canadian Air and Precipitation Monitoring network (CAPMoN). NAPS is operated cooperatively by federal, provincial, territorial and municipal monitoring agencies, and CAPMoN is operated by Environment Canada.

noted that it is not the intent of the report to account for the spatial and temporal variability in levels and trends in any lengthy analysis. The report also includes an Appendix that provides an update on the $PM_{2.5}$ measurement method path forward, additional information on the nature of PM and ozone, information on some of the methods adopted for data analysis, and the identification of the considered monitoring stations.

¹ Although Québec has not endorsed the CWS, it is committed to act in coherence with other jurisdictions in relation to the CWS.

2. THE PM AND OZONE CANADA-WIDE STANDARDS

The endorsed Canada-wide Standards (CWS) contain a number of provisions. This section presents information on the provisions relating to the ambient numerical targets that jurisdictions have committed to achieve by 2010, along with information on the requirements for reporting on achievement of the targets under the CWS.

The numerical targets (standards) to be achieved by 2010

Under the CWS, the $PM_{2.5}$ levels are characterized by the daily 24-hour average (midnight to midnight) concentrations (*daily 24-hour PM_{2.5}*), and ozone levels by the daily maximum of the running 8-hour average concentrations (*Dmax 8-hour O*₃). The ambient numerical targets to achieve under the CWS are based on these levels, and for reporting on achievement of the targets the CWS require that these levels be measured on a daily basis. The CWS ambient numerical targets, hereafter referred to as *standards*, have both a numerical level and a statistical form for evaluating their achievement. These are:

PM_{2.5} standard – 30 μg/m³, 24-hour average

The form of the standard is the 3-year average of the annual 98th percentile of the daily 24-hour PM_{2.5}

Ozone standard – 65 ppb, 8-hour average

The form of the standard is the 3-year average of the annual 4th highest Dmax 8-hour O₃

The forms of the standards simply mean that the $PM_{2.5}$ and ozone levels to be used for direct comparison to the standards are the values of the respective 3-year averages. The form of the standards are referred to in this report as the *3-year averages* for short. Jurisdictions have committed to achieve the standards by 2010. The 2010 achievement status will be evaluated from the values of the 3-year averages covering the years 2008, 2009 and 2010.

Reporting on achievement of the standards

Under the CWS, reporting on achievement of the standards is the responsibility of the jurisdictions. Reporting on achievement entails the designation by jurisdictions of CWS reporting communities and CWS monitoring stations within these communities. Reporting on achievement is to be conducted on a community oriented approach using Statistics Canada's Census Metropolitan Areas (CMA) and Census Agglomerations as guidance for identifying the communities for reporting. As a basic requirement, jurisdictions have to report on achievement for communities with a population of 100,000 or more. In large CMA, PM_{2.5} and ozone levels can differ quite substantially across the area because of their large land-area. Such larger CMA (with population over 500,000) can be sub-divided into reporting sub-areas (each with its own CWS monitoring stations) to better capture any spatial variation in PM_{2.5} and ozone levels across the CMA. Jurisdictions can also report on achievement for communities with population less than 100,000 based on such considerations as regional population density, proximity to sources, and local air quality.

Guidance Document on Achievement Determination (GDAD)



To ensure consistency of approaches and national comparability of data in evaluating achievement, a *Guidance Document on Achievement Determination for the PM and Ozone CWS* (GDAD) was developed as called for in the CWS. GDAD provides an outline of the procedures to establish CWS reporting areas, CWS reporting sites, and the PM and ozone data treatment and analysis procedures for evaluating achievement of the standards. A copy of GDAD is a available at:

http://www.ccme.ca/assets/pdf/gdad_eng_oct4.pdf.

3-year averages in this report and CWS achievement status – a caution

Section 8 of this report presents the levels of the 3-year averages for the period 2001 to 2003 on a monitoring station basis for all stations that satisfied the data completeness criteria specified in GDAD. Because a number of these stations are within a rural setting, because not all stations in a given community are necessarily CWS reporting stations, and because CWS achievement reporting is on a community basis, the station-specific 3-year averages presented in section 8 are not to be construed as being *formally* indicative of the achievement status of the standards for any of the communities in which the monitoring stations are located. Also, under the CWS the target date for achieving the standards is 2010.

3. NATURE OF PARTICULATE MATTER AND OZONE

Particulate matter and ozone are both pollutants that can be transported by the prevailing air flows (i.e. wind) over long distances. This means that they can affect air quality at locations close to their sources and also at locations within thousands of kilometres away, whether it be another community in the same province, another province, country or even continent. Because of their transport-potential, elevated levels of these pollutants in a given area do not necessarily imply that local emissions were the major or only contributors to the elevated levels. In some cases, transport plays a significant role. The remainder of this section provides separate information on each of PM and ozone.

Particulate Matter

Particulate matter represents the airborne microscopic liquid and solid substances that are present in the air either as single substances, or as a complex mixture of substances. These liquid and solid substances are also referred to as *particles*. On most smog days, what is perceived as "smog" is mostly the haze created by the particles. The haze reduces visibility and obscures what we see, as can be noticed in these two pictures of the federal Parliament Buildings on days with high and low levels of fine particles.

Particles come in a variety of sizes, shapes and compositions. Two important size fractions are the



inhalable (PM₁₀) and *fine* (PM_{2.5}) fractions. PM₁₀ consist of particles with diameter up to 10 μ m, and PM_{2.5} up to 2.5 μ m. Particles with diameter between 2.5 and 10 μ m are referred to as *coarse particles*. A size fraction that is considerably gaining attention is the *ultrafine* fraction, consisting of particles having a diameter up to 0.1 μ m.

Particles can be emitted directly to the air (primary particles) from varied sources, and they can also form in the air (secondary particles) from precursor gases. Primary PM includes soot (elemental carbon, EC) and fly ash; metals (like lead, mercury, cadmium, arsenic); re-suspended soil and road dust containing such crustal elements as iron, silicon, and calcium; fugitive emissions from the grinding and crushing of materials such as stones; sea-salt spray; and pollen. Precursors include the gases sulphur dioxide (SO₂), oxides of nitrogen (NO_x), ammonia (NH₃) and volatile organic compounds (VOC). SO₂, NO_x and NH₃ can lead to secondary PM such as ammonium sulphate and ammonium nitrate; VOC can lead to secondary PM containing various organic carbon (OC) substances. Many particles also contain water.





Ozone

Ozone is a gas that consists of three oxygen atoms, and it is present throughout the lower atmosphere. Ozone levels broadly increase with height to reach maximum levels at some 25 km above ground in the stratosphere in what is commonly known as the *ozone layer*. High up above ground ozone is beneficial because it absorbs the ultra-violet rays emitted by the sun, and in so doing it provides a layer of protection against the harmful effects of these rays. At ground-level, however, ozone is essentially a pollutant because it also causes health effects and it damages a variety of crops and materials.

Ozone is not emitted directly to the air in appreciable quantities. Instead, it forms in the air from precursor substances. In the stratosphere it forms from the naturally occurring oxygen under sunlight. In the troposphere (layer of air from the ground up to ~ 10 kilometres), ozone mostly forms following the dissociation of nitrogen dioxide (NO₂) under sunlight, and it can also form from the naturally occurring nitrogen and oxygen during lightning discharges.

 NO_2 is emitted directly to the air together with nitric oxide (NO) during the burning of fossil fuels – NO_2 and NO are collectively known as nitrogen

Ground-level ozone concentrations exhibit typical diurnal and seasonal patterns

Ozone formation from NO_x and VOC occurs only during daylight hours, with the formation being higher during sunny days than cloudy days. Diurnally, hourly ozone levels typically peak in the afternoon to early evening as ozone gradually accumulates throughout the day. In areas affected by transported ozone, however, hourly levels can peak at different times, including night time. Typically, ozone levels decrease during the night to reach minimum levels early in the morning because it is no longer formed and its deposition and reaction with other substances remove it from the air.

Seasonally, *hourly* ozone levels are typically the highest during the summer because ozone formation is higher under intense sunlight and high air temperature. In many parts of Canada, however, *monthly* average ozone levels are typically the highest in spring.

oxides (NO_x). However, most of the ambient NO₂ follows from the conversion of the emitted NO since only a small portion of the emitted NO_x is NO₂. The conversion of NO to NO₂ occurs as NO reacts with other substances, such as ozone itself. The reaction of ozone with NO, known as ozone scavenging, consumes ozone since in the process ozone converts to oxygen, and this effectively reduces the ambient ozone levels.

The formation of ozone from NO_x is significantly enhanced if other pollutants such as volatile organic compounds (VOC) are also present in the air. VOC allow the conversion of NO to NO_2 without consuming ozone in the process, thereby allowing ozone to accumulate to much higher levels than would otherwise occur from NO_x alone. As such, NO_x and VOC are known as the main ozone precursors, and these are emitted by both anthropogenic (human-related) and natural sources.

Ozone levels may be higher in rural areas in some regions of Canada

High ozone levels are not only a concern in large urban centres, but they can also be of concern in rural areas, and in some regions of Canada ozone levels are commonly higher in rural areas than in urban centres. Part of this may be associated with less ozone scavenging in the rural areas because of the generally lower ambient NO levels there.

Part of it may be associated with the delay between the time that the precursors are emitted and the time that ozone starts to form and accumulate. During this time, the precursors and the ozone being formed are transported by the wind out of the urban centres and into the surrounding downwind rural areas.

4. SOURCES OF PARTICULATE MATTER AND OZONE

PM is emitted directly to the air and it also forms in the air from precursor gases such as SO_2 , NO_x , VOC and ammonia. Ozone is formed in the air from precursors consisting mostly of NO_x and VOC. During hot and sunny weather conditions these pollutants interact to form what is commonly known as smog, with PM and ozone being its two main components. This section provides an indication of some of the sources of these pollutants, followed by quantitative estimates of their emissions from major anthropogenic sources in Canada.

Many sources of air pollutants are related to our activities (*anthropogenic* sources), whether by necessity or recreation. In addition to contributing to the formation of smog, many of these sources also emit the greenhouse gases that contribute to global warming in particular and climate change in general.

Anthropogenic sources include all the motorised vehicles that use fossil-fuels (such as cars, trucks, marine vessels, tractors, recreational vehicles, etc); the industries and factories; the power plants; the agricultural activities; the industrial use of solvents (such as cleaners and degreasers); the construction and demolition of houses and



buildings; and the burning of wood (such as in woodstoves and fireplaces). Other more personal sources which collectively are quite substantial include the motorised lawn and snow-removal equipment; the residential use of solvents (such cleaners, paints and cosmetics); and the cooking of food especially on a grill.



Pollutants are also released by natural sources. Whether alone or in combination with anthropogenic emissions, natural sources can at times significantly degrade the air quality. Trees and vegetation release very substantial quantities of VOC during the growing season, which can contribute to ozone formation. Forest fires release very large quantities of particles and precursors of both PM_{2.5} and ozone as seen in the picture. Volcanic eruptions release massive quantities of particles, and high winds can lift the soil in the air causing dust storms.

4.1 National Aggregated Anthropogenic Emissions

Figure 1 presents the sector contribution to the 2000 aggregated national emissions of SO_2 , NO_x , VOC and primary $PM_{2.5}$ from anthropogenic sources in Canada, excluding *open sources*. Open sources include a number of different sources with the common element that the emitted air pollutants are too dispersed to be captured and released from emissions systems such as stacks, chimneys, vents and tailpipes. Instead, the pollutants are emitted directly in the *open* air, and typically over a large area. Open sources include, for example, emissions of dust from paved and unpaved road, wind-blown soil dust and dust from land tilling, construction and demolition activities, forest fires and land fill sites. These sources were excluded primarily because of the larger uncertainty associated with their emissions.

Figure 1: Sector contribution to the 2000 aggregated national emissions of SO₂, NO_x, VOC and primary PM_{2.5} from anthropogenic sources (excluding open sources).



In 2000, about 7700 kilotonnes (kt) of these four pollutants were released to the air. Industry was the largest emitter of the aggregated emissions followed by Transportation (includes vehicles that are driven On-road and Off-road) and the Electricity Production sector. Regarding ammonia (not included in Figure 1), the Agriculture sector contributed 56% of the total national emissions of 569 kt, and the Pesticides and Fertilizer Applications sector contributed another 35%.

The aggregated anthropogenic emissions of SO₂, NO_x, VOC and PM_{2.5} released in Canada in 2000 correspond to the weight of 100 million adults. Figure 2 presents the 2000 emissions density by census subdivision of the aggregated emissions of SO₂, NO_x, VOC and primary PM_{2.5} from anthropogenic sources (excluding open sources). The emission densities are obtained by dividing the aggregated emissions in a given CSD by the area of the CSD. It should be noted that this procedure distributes the aggregated emissions uniformly within a CSD. In reality, however, emissions are not uniformly distributed as they may be high in some part of the CSD, and low in another. Also, a low emission density for a given CSD does not imply that the actual aggregated emissions in the CSD are lower than those in a CSD with a higher emission density.

In most of Canada the emissions density was less than 2.5 tonnes per square kilometre (t/km²). Most major urban centres such as Montreal, the Hamilton-Toronto-Oshawa corridor, Edmonton and Vancouver have among the highest emission densities, and many small area CSD also have similarly high emissions densities. For many of these smaller CSD this is likely due to the presence within the CSD of a single or few large industrial sources.



Figure 2: Emissions density of the aggregated anthropogenic emissions in 2000.

4.2 1990 versus 2000 Anthropogenic Emissions by Pollutant

Figure 3 presents the sector contributions to the national anthropogenic emissions (excluding open sources) of NO_x for 1990 and 2000. Between 1990 and 2000 national emissions of NO_x decreased slightly by about 6%. On-road vehicles were the largest emitters of NO_x in both 1990 and 2000, but their contribution to the national total decreased from about 44% (1207 kt) in 1990 to 33% (850 kt) in 2000. As the contribution from On-road vehicles emissions decreased, the contribution from the Upstream Oil and Gas Industry sector increased from 7% in 1990 to 13% in 2000.

Figure 3: Sector contribution to the 1990 and 2000 national emissions of NO_x from anthropogenic sources (excluding open sources).



From 2005 UNECE Annual Emission Data, Feb 2005, EC.

The sector contribution to the national anthropogenic emissions of VOC (excluding open sources) for 1990 and 2000 is presented in Figure 4. Between 1990 and 2000 national VOC emissions decreased by about 15%. In 1990 On-road vehicles were the largest emitters of VOC with a contribution of 27% to the national total followed by the Upstream Oil and Gas Industry sector at 19% and Solvent Use at 17%. In 2000 the largest emitter was Upstream Oil and Gas Industry with a 31% contribution to the national total. The contribution from On-road vehicles decreased to 17%, and the contribution from Solvent Use remained more or less unchanged at 19%.

Figure 4: Sector contribution to the 1990 and 2000 national emissions of VOC from anthropogenic sources (excluding open sources).



From 2005 UNECE Annual Emission Data, Feb 2005, EC.

Figure 5 presents the sector contributions to the national anthropogenic emissions (excluding open sources) of SO₂ for 1990 and 2000. Between 1990 and 2000 national emissions of SO₂ decreased 27%. The Base Metal Industry sector was the largest emitter in both 1990 and 2000 but its contribution to the national total decreased from 43% in 1990 to 32% in 2000. During this period, SO₂ emissions from the Upstream Oil and Gas Industry increased from 7% in 1990 to 15% in 2000.





From 2005 UNECE Annual Emission Data, Feb 2005, EC.

The sector contribution to the national anthropogenic emissions of primary $PM_{2.5}$ for 1990 and 2000 is presented in Figure 6. Between 1990 and 2000 national primary emissions decreased by about 30%. The Industry sector was the largest emitter in both 1990 and 2000, with contributions of about 44% in 1990 and 39% in 2000. The burning of wood for house heating purposes such in as woodstoves were the second largest emitters with contributions of about 26% in 1990 and 29% in 2000.

Figure 6: Sector contribution to the 1990 and 2000 national emissions of primary PM_{2.5} from anthropogenic sources (excluding open sources).



From 2005 UNECE Annual Emission Data, Feb 2005, EC.

5. MONITORING STATIONS CONSIDERED

Figures 7 and 8 indicate the location of the stations considered for this report (as specified by the jurisdictions) at which continuous PM_{2.5} and ozone monitors were either or both operated for some time during 2003. Most of these stations are part of the National Air Pollution Surveillance (NAPS) network and a few are from the Canadian Air and Precipitation Monitoring network (CAPMoN). NAPS is operated cooperatively by federal, provincial, territorial and municipal monitoring agencies, and CAPMoN is operated by Environment Canada. NAPS stations are mostly in urban areas, and the CAPMoN stations are all in rural areas. Section 1 of the Appendix contains a list of the station considered.

Figures 7 and 8 also indicate the boundaries of the CMA and CA (section 2), and the type of monitoring stations. For the purpose of this report, stations are classified in three broad types as large urban, small urban and rural. Large urban stations are located in communities with population over 100,000 (these are all CMA and a few CA). Small urban stations are located in communities with population less then 100,000 (these are most of the CA). Rural stations are located in areas where the land-use is predominantly rural although some of these stations, especially some of those in eastern Canada, may be downwind or close to urban centres. As such, these stations may not be truly representative of remote areas unaffected by nearby sources.

This report includes data maps showing information on various $PM_{2.5}$ and ozone levels. Because of stringent quality assurance and quality control procedures used to validate the $PM_{2.5}$ and ozone measurements, a given $PM_{2.5}$ or ozone level was not assessed for stations (monitors) that did not satisfy the stated data completeness criteria (indicated in the applicable sections of the report). These stations were also not included in the applicable data maps and, as such, the various data maps do not necessarily show all the stations that were in operation in 2003 (Figures 7 and 8). Figure 7: The 2003 continuous $PM_{2.5}$ monitoring stations considered in the report.



2003 Continuous PM_{2.5} Monitoring Stations (NAPS & CAPMoN)



Figure 8: The 2003 ozone monitoring stations considered in the report.

6. FINE PARTICLES LEVELS

For CWS reporting, the CWS require that the 24-hour average concentration of $PM_{2.5}$ be measured on a daily basis (the *daily 24-hour PM_{2.5}*). In Canada, the *daily 24-hour PM_{2.5}* is determined by continuous methods that provide hourly concentrations in real-time. As such, this report presents some 2003 monitoring results based on the CWS numerics from continuous monitors only.

The continuous monitoring method most widely-used in Canada is the Tapered Element Oscillating Micro-balance monitor (TEOM[®]). Another method that is increasingly being deployed, especially in eastern Canada, is the Beta Attenuation Monitor (BAM). Please refer to section 4 of the Appendix for a brief discussion on the potential implications on CWS reporting of using different methods for measuring the daily 24-hour PM_{2.5}, and for an update on the PM_{2.5} measurement method path forward.

6.1 Number of Days Above 30 μg/m³

The number of days with daily 24-hour $PM_{2.5}$ above 30 µg/m³ in 2003 (*exceedance days*) are indicated in Figure 9 by ranges of days (arbitrarily set). Exceedance days are displayed only for those monitors where measurements of the daily 24-hour $PM_{2.5}$ were available for at least 75% of the days in 2003 (this is the *data completeness criteria* referred to in the last paragraph of section 5 for reporting the exceedance days). Of the operated BAM, only two BAM in Québec satisfied this criterion, the first was at a large urban station located in Montréal, and the second at a rural station located just south of Montréal. A TEOM was also operated concurrently at each of these two stations.

Exceedance days occurred in each region except Whitehorse and Saskatchewan-Manitoba. Most TEOM exceedances were in the range of 1 to 5 days and 6 to 10 days. TEOM exceedances in the highest range of 11 to 15 days were limited to Montréal, Calgary, southern Ontario and in the interior of British Columbia.

At the two Québec stations where the TEOM and BAM were concurrently operated, the number of exceedance days were 15 from the TEOM and 41 from the BAM at the Montréal station, and 8 and 17 days respectively at the rural station.

At the Montréal station with both TEOM and BAM, the reported number of exceedances were 15 from the TEOM and 41 from the BAM.



Figure 9: The 2003 number of days with daily 24-hour $PM_{2.5}$ above 30 μ g/m³.

6.2 98th Percentiles

The 98th percentiles of the daily 24-hour $PM_{2.5}$ for 2003 are indicated in Figure 10 for those monitors with a data completeness of at least 75% in each calendar quarter, or for those monitors having a 98th percentile greater than 30 μ g/m³ for the available daily 24-hour $PM_{2.5}$. Of the operated BAM, five satisfied either of these criteria, four in Québec and one in Nova Scotia (Sable Island).

The TEOM 98th percentiles were mostly in the range of 11 to 20 μ g/m³ and 21 to 30 μ g/m³. The lowest 98th percentiles in the range of 1 to 5 μ g/m³ were recorded at stations in coastal locations of British Columbia (BC), at Whitehorse and at one small urban station in Alberta. TEOM 98th percentiles in the highest range of 31 to 50 μ g/m³ were recorded at stations in southern Québec, southern Ontario, Calgary and in the interior of BC.

At the four BAM stations in Québec the 98th percentiles ranged from 30.2 to 64.3 μ g/m³, and at the Sable Island BAM the 98th percentile was 32.5 μ g/m³. At the two stations in Québec with collocated TEOM and BAM (see section 4.2), the 98th percentiles from the TEOM and BAM were 40.1 and 64.3 μ g/m³ respectively at the Montréal station, and 30.6 and 42.6 μ g/m³ at the rural station.

At the Montréal station with both TEOM and BAM, the reported 98th percentiles were 40.1 from the TEOM and 64.3 μg/m³ from the BAM.



Figure 10: The 2003 98th percentiles of the daily 24-hour $\mathsf{PM}_{2.5}$.

6.3 Annual averages

The annual averages of the daily 24-hour $PM_{2.5}$ measured in 2003 are indicated in Figure 11. The annual averages are displayed only for those monitors where the daily 24-hour $PM_{2.5}$ could be reported for at least 75% of the days in 2003, and of the operated BAM only two satisfied this criterion, the same two already mentioned in section 6.1. Annual averages are not part of the CWS, but they are included here mostly because they are one of the metrics that can be used in relation to the Continuous Improvement (CI) and Keeping Clean Areas Clean (KCAC) provisions of the CWS. For one perspective on the magnitude of the 2003 annual averages, the United States annual standard is 15 μ g/m³ as a 3-year average.

The TEOM annual averages were mostly in the range of 6 to 9 μ g/m³. Few sites had 3-year averages in the lowest range of 2 to 5 μ g/m³, and fewer still in the highest range of 10 to 13 μ g/m³. Sites in this latter range were mostly in Montréal, Calgary, southern Ontario and in the Interior of British Columbia (BC). Of interest to note is that in BC, interior communities typically recorded higher annual averages than coastal communities. At the two stations in Québec with collocated TEOM and BAM, annual averages from the TEOM and BAM were respectively 9.9 and 17.0 μ g/m³ at the Montréal station, and 7.4 and 11.8 μ g/m³ at the rural station.



Figure 11: The 2003 daily 24-hour PM_{2.5} annual averages.

7. OZONE LEVELS

This section presents a summary of the 2003 ozone monitoring results based on some of the CWS numerics.

7.1 Number of Days Above 65 ppb

The number of days with the daily maximum 8-hour average ozone (Dmax 8-hour O_3) above 65 ppb (*exceedance days*) in 2003 are presented in Figure 12. The exceedance days are reported only for those stations with a data completeness of the Dmax 8-hour O_3 of at least 75% in each of the 2nd and 3rd calendar quarters. In 2003 ozone exceedance days were recorded across Canada with the number of days ranging mostly from zero to 10 in western Canada, and 4-20 in eastern Canada. A number of monitoring stations in southern Ontario recorded 21 to 45 exceedance days.



Figure 12: The 2003 number of days with Dmax 8-hour O_3 above 65 ppb.

7.2 4th Highest Dmax 8-hour O₃

Figure 13 presents the 4th highest Dmax 8-hour O_3 for 2003 for those monitors with a data completeness of at least 75% in the 2nd and 3rd calendar quarters, or if the 4th highest for the available Dmax 8-hour O_3 data was above 65 ppb.

The 4th highest was above 65 ppb at one or more station in each province except Manitoba. In Ontario, all but two stations recorded a 4th highest in the range of 66 to 110 ppb. Most stations in Québec recorded a 4th highest in the range of 66 to 85 ppb, and with the exception of Manitoba the other provinces recorded a 4th highest that ranged from 35 to 75 ppb. In the Lower Fraser Valley (LFV) the 4th highest was generally higher in the more rural eastern segment of the LFV than the more urbanised western segment.





8. THREE YEAR AVERAGES

This section presents the 3-year averages of the annual 98th percentiles of the daily 24-hour $PM_{2.5}$ and the annual 4th highest Dmax 8-hour O_3 for the years 2001, 2002 and 2003. While these 3-year averages are in the form of the standards, they are not to be construed as being *formally* indicative of the achievement status of standards as discussed in section 2.

Consistent with the Guidance Document on Achievement Determination, 3-year averages for $PM_{2.5}$ are presented only for those monitors where the annual 98th percentile could be reported for at least two of the years in the 3-year period. For a given year, the 98th percentile was reported if either the data completeness of the daily 24-hour $PM_{2.5}$ was at least 75% in each calendar quarter, or if the 98th percentile was greater than 30 μ g/m³ irrespective of the data completeness. Of the operated BAM, only two in Québec satisfied these reporting criteria, the same two mentioned in section 4.2.

Similarly, the ozone 3-year averages are indicated only for those monitors where the annual 4th highest Dmax 8-hour O_3 could be reported for at least two of the years in the 3-year period. For a given year, the 4th highest was reported if either the data completeness for Dmax 8-hour O_3 was at least 75% during the 2nd and 3rd calendar quarters, or if the 4th highest was above 65 ppb irrespective of the data completeness.

8.1 PM_{2.5}

The 3-year averages of the annual 98th percentiles for 2001-2003 are indicated in Figure 14. TEOM 3-year averages were mostly in the range 11-20 μ g/m³ and 21-30 μ g/m³. Only three stations recorded 3-year average in the lowest range of 7-10 μ g/m³. Three year averages above 30 μ g/m³ were mostly recorded at stations in southern Ontario and Québec, and at few stations in Atlantic Canada. In British Columbia, only one station in the interior of the province recorded a 3-year average above 30 μ g/m³.

At the two stations in Québec with collocated TEOM and BAM, the 3-year averages were 34 μ g/m³ from the TEOM and 57 μ g/m³ from the BAM at the Montréal station, and 27 and 43 μ g/m³ respectively at the rural station.

At the Montréal station with both TEOM and BAM, the 3-year averages were 34 and 57 μg/m³ respectively.



Figure 14: The PM_{2.5} 98th percentiles 3-year averages (2001 – 2003).

8.2 Ozone

The 3-year averages of the annual 4th highest Dmax 8-hour O_3 for 2001-2003 are indicated in Figure 15. Most monitoring stations outside of Ontario and Québec recorded 3-year averages either in the range 32-55 ppb or 56-65 ppb. British Columbia, Saskatchewan and Manitoba were the three provinces where the 3-year averages were all less than or equal to 65 ppb. The other provinces contained at least one station with a 3-year average above 65 ppb. In Ontario, all but three stations recorded 3-year averages either in the range 76-85 ppb or 86-108 ppb, and in Québec the 3-year averages were mostly in the range 66-75 ppb.



Figure 15: The 4th highest Dmax 8-hour O₃ 3-year averages (2001 – 2003).
8.3 PM_{2.5} and Ozone

Figure 16 indicates where the stations fall with respect to both the $PM_{2.5}$ and ozone standards based on the information provided in the previous two sections. It indicates the stations with 3-year (2001-2003) averages below both standards, stations with either the $PM_{2.5}$ or the ozone 3-year average above the standard, and stations with the $PM_{2.5}$ and ozone 3-year averages both above the standards.

Saskatchewan-Manitoba and Newfoundland where the only two regions with 3-year averages below both standards at all considered stations. In British Columbia, only one station in the interior of the province recorded a 3-year average above the standard for PM_{2.5}, and in Alberta and Atlantic Canada only the ozone 3-year average was above the standard at some stations. In Ontario and Québec, most stations recorded an ozone 3-year average above the standard, and many stations (mostly in southern Ontario and Montréal) recorded 3-year averages above both standards.

Based on the population of the communities where the monitoring stations are located, 1/3 of Canadians (approximately) lived in communities with 3-year averages above the standard either for only $PM_{2.5}$ or for both $PM_{2.5}$ and ozone, and 1/2 lived in communities with 3-year averages above the standard for at least ozone.



Figure 16: Stations below and above the $PM_{2.5}$ and ozone standards.

9. 2003 COMPARED TO PREVIOUS YEARS

To obtain an indication of how low or how high the $PM_{2.5}$ and ozone levels were in 2003, this section compares the 2003 regional $PM_{2.5}$ levels to those over the previous four years (1999 to 2002), and to those over the previous ten years (1993 to 2002) for ozone. For $PM_{2.5}$, only measurements from the TEOM are considered, and the comparison period is the previous four years because this is the longest period with available data for a majority of the TEOM monitors. The method used and the sites considered are indicated in section 4 of the Appendix.

9.1 PM_{2.5}

Nationally, 2003 was more or less typical of the previous four years with respect to the annual average, but a high year (by 15%) for the 98th percentile (Figure 17). Regionally, 2003 was a slightly low year in Saskatchewan-Manitoba, Ontario and Atlantic Canada for both the annual average and the 98th percentile, and a high year for both in Québec (by 25% and 13% respectively). In Alberta and British Columbia, 2003 was a slightly high year with respect to the annual average, but a very high year for the 98th percentile (by 38% and 29% respectively). A cursory examination of available information suggests that *some* stations in some regions like British Columbia and Alberta, and possibly Québec, might have been influenced by smoke from forest fires.

Figure 17: Percentage difference between the 2003 PM_{2.5} levels and those over the previous four years.



9.2 Ozone

Nationally, 2003 was a slightly high year for both the annual average (higher by 7%) and the annual 4th highest (by 4%) compared to the previous ten years (Figure 18). Similarly, 2003 was a slightly high year in Alberta, Ontario, Québec and Atlantic Canada. In British Columbia, 2003 was a slightly high year for the 4th highest, and a high year (higher by 11%) for the annual average. For Saskatchewan-Manitoba, 2003 was a high year for both the annual average (higher by 14%) and the annual 4th highest (by 15%).





10. OZONE TRENDS

This section presents the trends in the annual average Dmax 8-hour O_3 and the annual 4th highest Dmax 8-hour O_3 for (up to) the 15-year period from 1989 to 2003. The trends are evaluated on a monitoring station basis for all three types of stations discussed in section 5, and also on a regional basis. The method used and the sites considered for the regional trends are indicated in section 5 of the Appendix.

10.1 Station Trends

The annual average Dmax 8-hour O_3 experienced an increasing trend at most stations (Figure 19) and, except for some urban stations, most of these trends were not (statistically) significant (95% confidence level). Of interest to note are the trends in the Lower Fraser Valley (LFV) where, although the annual average increased at all stations, the trends were significant mostly at stations in the more urbanised western segment of the valley. Likewise, in Ontario and Québec although the annual average increased at both urban and rural stations, the trends were significant mostly at urban stations, and few rural stations experienced a decreasing trend.





The annual 4th highest decreased at some stations and increased at others, with the trends (whether increasing or decreasing) being mostly non-significant (Figure 20). Of interest to note again are the trends in the LFV. In this case the annual 4th highest mostly decreased, but the decreasing trends were significant mostly again at stations in the more urbanised western segment of the LFV. Also of interest is that in Québec and Ontario the annual 4th highest decreased (although not significant) at a greater number of rural stations.





10.2 Regional and National Trends

Nationally, the national annual average Dmax 8-hour O_3 increased on average by 4.5% during the considered period (1990 – 2003), with the trend being statistically significant (Figure 21). Regionally, it increased in all six regions, but the trend is significant only in Ontario and British Columbia (all but one of the considered stations for BC are in the Lower Fraser Valley). The regional average increased the most in British Columbia and Ontario, with average increases of 6.2 and 5.1% respectively.





The national annual 4th highest Dmax 8-hour O_3 remained essentially unchanged over the considered period given the slight average increase of only 1.1% (Figure 22). Regionally, it increased slightly in Alberta, Saskatchewan-Manitoba, Ontario and Québec but the trends were all non-significant. The regional average decreased in British Columbia (all considered stations are in the Lower Fraser Valley) and Atlantic Canada but the trends were also non-significant. For both regions, it is likely that the large drop in levels at the beginning of the period had a large influence on the reported average decreases.



Figure 22: Trends in the regional annual 4th highest Dmax 8-hour O₃.

10.3 Discussion

A robust evaluation of any trend in ozone levels requires first the identification of the factors influencing the ozone levels, followed by analyses of the changes in these factors over time. Although such work is beyond the scope of this report, some preliminary inferences may be possible based on what is known of the nature of ozone.

It is very likely that ambient NO levels decreased in urban centres given the 30% reduction in NO_x emissions from On-road vehicles between 1990 and 2000 (section 4.2). This is also confirmed in Appendix 1 of the 2002 National Summary which reported that ambient NO levels decreased in urban centres between 1991 and 2002. As discussed in section 2 of the Appendix, ozone levels can increase in some cases following a reduction in NO_x emissions because the ensuing lower ambient NO scavenges a comparable smaller amount of ozone. The increasing ozone trends at urban stations are therefore consistent, at first glance, with what could be expected if ozone scavenging by NO was reduced.

Ozone levels increasing in urban centres as NO_x emissions are reduced is also consistent with the results of some air quality modelling studies conducted in Canada and the United States which indicate that insufficient reductions in NO_x emissions can lead to higher ozone levels in some urban centres. These modelling studies also indicate that more aggressive reductions eventually lead to a decrease in ozone levels.

Because most rural sites are at some distances from major NO_x sources, the ozone at these sites should not be significantly affected by NO scavenging effects. As such, these sites may better reflect the ozone contributions from the various origins. It has been suggested that background ozone levels may be increasing, and this may be contributing to the increasing ozone trends at some stations in Canada. While this is possible, the reported non-significant increasing trends in the annual average Dmax 8-hour O_3 at rural stations and the (non-significant) decreasing trends in the annual 4th highest Dmax 8-hour O_3 at some of these stations, appear to suggest that any potential contribution from the increasing background ozone levels may have been offset at rural stations by a decrease in the ozone from other origins.

That NO_x emission reductions may be contributing to the increasing ozone trends is one possible explanation for the increasing ozone trends at urban stations, however, further detailed analysis should be conducted. Similarly, the mostly non-significant trends at the rural stations suggest that more analyses are needed to verify the extent of any potential contribution from increasing background ozone levels to the reported increasing trends in ozone at stations across Canada.

11. SUMMARY

This report presented information on the national anthropogenic emissions of the sources of PM and its precursors. It's main objective, however, was to present information on the 2003 ambient monitoring results for $PM_{2.5}$ and ozone based on the CWS numerics. It also included an indication of how typical the $PM_{2.5}$ and ozone levels were in 2003, and information on trends in ozone levels. Trends in $PM_{2.5}$ levels could not be reported because of insufficient long-term data.

In 2000, 7700 kilotonnes (kt) of the aggregated emissions of SO₂, NO_x, VOC and primary PM_{2.5} were emitted in Canada from anthropogenic sources (excluding open sources). Industry was the largest emitter of the aggregated emissions followed by Transportation and Electricity Production. The Agriculture sector and the Pesticides and Fertilizer Applications sector were the two largest contributors to the national emissions of ammonia. Between 1990 and 2000, national NO_x emissions (excluding open sources) decreased by 6% and VOC emissions decreased by 15%. For both NO_x and VOC, reductions in emissions from On-road vehicles were partially offset by increases from the Upstream Oil and Gas Industry. National SO₂ emissions decreased by 27%, and National emissions of primary PM decreased by 30%.

Saskatchewan-Manitoba and Newfoundland where the only two regions with 3-year averages below both standards at all considered stations. In British Columbia, only one station in the interior of the province recorded a 3-year average above the standard for PM_{2.5}, and in Alberta and Atlantic Canada only the ozone 3-year average was above the standard at some stations. In Ontario and Québec, most stations recorded an ozone 3-year average above the standard, and many stations in southern Ontario and Montréal recorded 3-year averages above both standards.

Nationally, 2003 was more or less typical of the previous 4-years with respect to the annual average of the daily 24-hour $PM_{2.5}$ and a high year for the 98th percentile. Regionally, 2003 was a slightly low year in Saskatchewan-Manitoba, Ontario and in Atlantic Canada for both the annual average and 98th percentile, and a high year for both in Québec. In Alberta and British Columbia, 2003 was a slightly high year with respect to the annual average, but a very high year for the 98th percentile.

For ozone, 2003 was a slightly high year nationally for both the annual average of the Dmax 8hour O_3 and the annual 4th highest relative to the previous ten years. Likewise, 2003 was a slightly high year in Alberta, Ontario, Québec and Atlantic Canada. In British Columbia, 2003 was a slightly high year for the 4th highest, and a high year for the annual average. For Saskatchewan-Manitoba, 2003 was a high year for both the annual average and the annual 4th highest.

Over the 15-year period from 1989 to 2003 the annual average of the Dmax 8-hour O_3 increased nationally and also in each of the six considered regions, with the trends being statistically significant in two regions. The largest increases occurred in BC (mostly stations in the Lower Fraser valley) and Ontario. Corresponding trends in the annual 4th highest Dmax 8-hour O_3 indicate that the 4th highest remained essentially unchanged nationally. Regionally it increased in Québec, Ontario, Saskatchewan-Manitoba and Alberta, and it decreased in Atlantic Canada and BC (the Lower Fraser Valley only), but none of these trends were statistically significant.

Fine Particles and Ozone in Canada A Canada-wide Standards Perspective 2003 National Summary

Appendix

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1. MONITORING STATIONS

Tables 1-5 indicate the monitoring stations considered for the 2003 National Summary. Most of these stations are part of the National Air Pollution Surveillance (NAPS) Network, and a few are from the Canadian Air and Precipitation Monitoring Network (CAPMoN). NAPS is operated cooperatively by federal, provincial, territorial and municipal monitoring agencies and CAPMoN is operated by Environment Canada. The NAPS stations are mostly in urban areas, and the few CAPMoN stations are all in rural areas. CAPMoN stations are given a NAPS station identifier and their data is integrated within the NAPS database.

For the purpose of this report, stations are classified in three broad types as large urban (located in communities with population over 100,000), small urban (located in communities with population less then 100,000) and rural (located in areas where the land-use is predominantly rural). The stations are also arbitrarily grouped according to the Census Metropolitan Areas (CMA) or Census Agglomerations (CA) in which the stations are located.

	NIADO		Otatian		
CMA/CA/Area	NAPS Station ID	Station Location	Station	Ozone	PM _{2.5}
	Station ID		туре		
Newfoundland and Labrador					
St. John's (CMA)	10102	Water Street	LU	×	Т
Corner Brook	10301	Brook Street	SU	×	Т
St. John's - Mount Pearl	10401	Old Placentia Road	LU	Х	Т
Nova Scotia					
Halifax (CMA)	30118	Barrington Street	LU	X	
	30120	Darthmouth	LU		Т
Cape Breton (CA)	30310	Welton Street	LU	X	Т
Kejimkujik	30501	Kejimkujik National Park	R	X	Т
Aylesford	30701	Mountain Brow Road	R	X	
Yarmouth	30801	Yarmouth Weather Office	R	×	
Pictou	30901	Beaches Road	SU	X	в
Sable Island	31001	Sable Island	R	×	В
Kentville	31101	Main Street	R	Х	
New Brunswick					
The Dranomork	40203	Forest Hills	111	×	т
Saint John (CMA)	40206	Customs Building	111	×	
	40207	Westside (Hillcrest)	10	X	
Eredericton (CA)	40103	Aberdeen Street	10	X	т
Moncton (CA)	40302	Thanet Street	10	X	T
Fundy National Park	40401	Hastings Tower	R	X	
Point Lepreau	40501	Recreation Area	R	X	
Central Blissville	40601	Airport Road	R	X	
Norton	40701	Hwy 124	R	X	
Dow Settlement	40801	Route 122	R	X	
St. Andrews	40901	Brandy Cove Road	R	X	т
Campobello Island	41001	Campobello Island	R	X	
St. Leonard	41101	Chemin de l'Aéroport	R	X	
Lower Newcastle	41201	Route 11 Hwy	R	X	
LU = Large Urban station. SU = Small Urba	an station. R = R	ural station. X= ozone monitor was	s operated.		
T = TEOM monitor was operated. B = BAM n	nonitor was oper	rated. T/B = TEOM and BAM monito	rs both operated		

Table 1: Stations considered for Atlantic Canada.

CMA/CA/Area	NAPS Station ID	Station Location	Station Type	Ozone	PM _{2.5}	
	50102	Jardin Botanique	LU	Х		
	50103	Montreal-Est	LU	×		
	50104	Rue Ontario	LU	×		
	50105	Rue Drummond	LU		Т	
	50109	Rue Duncan (Échangeur Décarie)	LU	×	Т	
	50110	Parc Pilon	LU	×	т	
	50113	Laval (Chomedey)	LU	×	т	
Montreal (CMA)	50115	Downtown	LU	×		
	50116	Verdun	LU	×		
	50119	Rue Victoria	LU	×		
	50121	Brossard (Parc Océanie)	LU	×	т	
	50126	Sainte-Anne-de-Bellevue	LU	X	т	
	50128	Aéroport Dorval	LU	X	т	
	50129	Rivière des Prairies	LU	X	T/B	
	50131	Hochelaga-Maisonneuve	LU		Т	
	52601	Varennes	LU	Х		
	54501	L'Assomption	LU	Х	т	
	50308	Rue des Sables	LU	Х	т	
Québec (CMA)	50309	Rang St. Ange - Sainte-Foy	LU	X		
	50310	Blvd. René-Lévesque	LU	Х	т	
Trois - Rivières (CMA)	50801	Rue Hart	LU	Х	т	
Trois - Rivieres (CMA)	54703	Bécancour	LU		т	
Sherbrooke (CMA)	50404	Rue Papineau	LU	Х	т	
Gatineau (CMA)	50204	Secteur Hull	LU	X	т	
Chicoutimi - Jonquière (CMA)	50504	Blvd. des Étudiants (Chicoutimi)	LU	Х	т	
Rouyn-Noranda (CA)	50604	Rue Paradis	SU	Х	в	
Saint-Jean-sur-Richelieu (CA)	55301	Route 219	SU	Х	T/B	
St. Zéphirin-de-Courval	51501	Rang Saint-Michel	R	Х		
Charette	52001	Au nord du 170 2e Rang	R	Х	т	
Saint-Simon	52201	4e Rang Est	R	Х	в	
Saint-Faustin-Lac-Carré	52301	Chemin du Lac (Caribou)	R	Х	в	
La Pêche	52401	Lac Philippe - Masham	R	Х	в	
La Doré	53201	Route 167	R	Х	в	
Deschambault	53301	3e Rang - Deschambault	R	Х	в	
Ste-Cathde-JCartier	53401	Rue Laurier	R	Х		
Saint-François	53501	Rue Royale Île D'Orléans	R	Х		
Notre-Dame-du-Rosaire	53601	Rang St-Louis	R	Х	B	
St-Hilaire-de-Dorset	53701	Rang Dorset	R	X	B	
Tingwick	53801	Chemin Radar et Warwick	R	X	B	
Lac-Édouard	53901	Derrière L'Hôpital Village	R	X		
Saint-Anicet	54401	Rue de La Guerre	R	Х	т	
Stukely-Sud	54801	Chemin Montbel	R	Х	в	
La Patrie	54901	Rang Petit Canada Ouest	R	Х		
Ferme-Neuve	55001	Rang Gravel	R	Х		
Lemieux	55201	Cranberry Farm	R	Х		
LU = Large Urban station. SU = Small Urba	LU = Large Urban station. SU = Small Urban station. R = Rural station. X = ozone monitor was operated.					
T = TEOM monitor was operated. B = BAM m						

Table 2: Stations considered for Québec.

CMA/CA/Area	NAPS Station ID	Station Location	Station Type	Ozone	PM _{2.5}
Mindeor (CMA)	60204	Windsor University	LU	Х	Т
Windson (CMA)	60211	Windsor College	LU	X	Т
	60410	Toronto-East	LU	X	Т
	60415	Mississauga	LU	×	Т
	60421	Toronto-North	LU	×	Т
	60424	Toronto-Downtown	LU	Х	т
Toronto (CMA)	60428	Brampton	LU	X	т
	60429	Etobicoke South	LU	Х	т
	65101	Newmarket	LU	Х	т
	61603	Oakville - Halton Reserve	LU	Х	т
	63201	Stouffville	LU	Х	
	60512	Hamilton-Downtown	LU	Х	Т
Hamilton (CMA)	60513	Hamilton-Mountain	LU	Х	т
	63001	Burlington	LU	X	Т
Ottawa (CMA)	60104	Rideau & Wurtemburg	LU	X	Т
Kingston (CMA)	60302	Dalton Avenue	LU	X	Т
Oshawa (CMA)	61701	Ritson Rd. & Olive Ave.	LU	X	Т
Sudbury (CMA)	60607	Ramsey Lake Rd.	LU	X	
St. Catharines - Niagara (CMA)	61302	St. Catharines	LU	X	Т
Kitchener (CMA)	61502	West Ave. & Homewood	LU	X	т
Peterborough (CMA)	61104	Hospital Drive	LU	X	т
Thunder Bay (CMA)	60807	James Street South	LU	X	т
London (CMA)	60903	Highbury Avenue	LU	X	т
Sault Sainte Marie (CA)	60707	Patrick St.	SU	X	т
Sarnia (CA)	61004	Front St.	SU	X	т
Cornwall (CA	61201	Bedford & Third St.	SU	X	Т
Guelph (CA)	61802	Exhibition Park	LU	X	Т
North Bay (CA)	62001	Chippewa St.	SU	X	Т
Barrie (CA)	65001	Perry Street	LU	X	Т
Belleville (CA)	65401	Sidney Street	SU	X	Т
Merlin	62201	MOE Water Pump Stn.	R	X	т
Tiverton	62501	Bruce Nuclear Visitor Center	R	X	Т
Norfork (CA)	62601	Experimental Farm (Simcoe)	R	X	Т
Dorset	63301	Hwy 117 & Paint Lake Road	R	X	т
Grand Bend	63701	Hwy 21 & County Rd 83	R	X	Т
Experimental Lakes Area	64001		R	X	
Algoma	64101		R	Х	
Egbert	64401		R	Х	
Parry Sound	65201	Bay Street	SU	X	Т
Port Stanley	65301	Dexter Line	SU	X	Т
LU = Large Urban station. SU = Small Urba	n station. R = R	ural station. X= ozone monitor was o	operated.		
T = TEOM monitor was operated. B = BAM m					

Table 3: Stations considered for Ontario.

Table 4: Stations considered for Manitoba, Saskatchewan, Alberta and the Yukon and Northwest Territories.

CMA/CA/Area	NAPS Station ID	Station Location	Station Type	Ozone	PM _{2.5}
Manitoba					
Minnings (CMII)	70118	Jefferson & Scotia	LU	Х	Т
winnipeg (CiwA)	70119	Ellen Street	LU	Х	Т
Brandon (CA)	70203	Victoria Avenue East	SU	Х	Т
Flin Flon	70301	Main Street - Provincial building	SU		Т
Saskatchewan					
Regina (CMA)	80110	Brent building, 11th Avenue	LU	Х	Т
Saskatoon (CMA)	80211	Corman Park	LU	X	т
Bratt's Lake	80901	Radiation Observatory	R	Х	
Alberta					
	90121	Edmonton East	LU	Х	Т
Edmonton (CMA)	90122	Edmonton NW	LU	Х	Т
	90130	Edmonton Central	LU	Х	Т
	90601	Fort Saskatchewan	LU	Х	Т
Calgary (CMA)	90218	Calgary East	LU	Х	Т
	90222	Calgary - Northwest	LU	×	Т
	90227	Calgary Central	LU	×	Т
	90702	Fort Mcmurray - Timberlea	SU	×	Т
Wood Buffalo (CA)	90801	Fort Mackay	SU	×	Т
	91801	Fort Chipewyan	R	Х	Т
Red Deer (CA)	90302	73 Street & Riverside Drive	SU	×	Т
Esther	91001	Esther	R	X	
Hightower Ridge	91201		R	Х	Т
Tomahawk	91301		R	X	Т
Violet Grove	91401		R	X	
Beaverlodge	91501	Beaverlodge Research Farm	R	X	
Carrot Creek	91601		R	X	
Steeper	91701		R	X	
Caroline	91901		R	X	
Yukon					
Whitehorse (CA)	119003	1 st Avenue	SU	Х	Т
Northwest Territories					
Yellowknife (CA)	129002	52nd Street	SU	Х	В
LU = Large Urban station. SU = Smal	I Urban station. R = R	ural station. X= ozone monitor was	operated.		
T = TEOM monitor was operated. $B = B$	BAM monitor was oper	rated. T/B = TEOM and BAM monitor	rs both operated		

CMA/CA/Area	NAPS Station ID	Station Location	Station Type	Ozone	PM _{2.5}
Victoria (CMA)	100304	Тораz	LU	Х	Т
	100307	Sooke Road	LU	×	Т
	100110	Burnaby - Kensington Park	LU	X	Т
	100111	Port - Moody Rocky Point Park	LU	×	Т
	100112	Vancouver - Downtown	LU	×	
	100118	Vancouver - Kitsilano	LU	×	
	100119	Burnaby South	LU	×	Т
	100121	North Vancouver - Second Narrows	LU	X	
	100125	North Delta	LU	X	
Veneruser (CMI)	100126	Burnaby - Mountain	LU	Х	
Vancouver (CMA)	100127	Surrey East	LU	Х	
	100128	Richmond South	LU	Х	
	100131	North Vancouver - Seymour	LU	Х	
	100132	North Vancouver - Mahon Park	LU	X	
	100134	Vancouver - Airport	LU	×	Т
	100135	Coquitlam	LU	X	
	101202	Pitt Meadows	LU	X	т
	101301	Langley	LU	X	т
	101501	Maple Ridge	LU	X	
	101003	Bevan Ave.	LU	X	
Abbotsford (CMA)	101004	Abbotsford Airport	LU		т
Chilliwack (CA)	101101	Airport Road	SU	X	Т
Норе	101401	Airport Road	SU	х	
Kelowna (CMA)	100701	College Way	LU	х	т
	101701	Callanan Street	SU		т
	101702	Mountain Ash Road	SU		т
Quesnel (CA)	101703	Pinecrest Road	SU		т
	101704	Correlieu School	SU		т
	102701	1045 Western Avenue	SU	X	т
Williams Lake (CA)	102702	Skyline School	SU	х	т
	102706	CRD Library	SU		т
Prince George (CA)	100202	4th Avenue	SU	X	т
Kamloops (CA)	100402	Mavfair Street	SU	X	Т
Squamish (CA)	101601	2nd Avenue	SU	×	
Nanaimo (CA)	102102	Labieux Road	SU	X	т
Powel River (CA)	102301	Cranberry Lake	SU		т
Bulkley - Nechalko Regional District (CA)	102401	Smithers	SU	X	
Terrace (CA)	102501		SU		т
Campbell River (CA)	102801	Adjacent to 660 Westmere	SU	X	
Vernon (CA)	104003	Highway 6	SU	X	т
Kitimat (CA)	103901	Riverlodge	SU		Т
Fort St. John (CA)	105501	NP Cultural Centre	SU		Т
Golden	103202	Hospital	SU		Т
Whistler	105001	Meadow Park	SU	X	
Houston	105101	Firehall	SU		т
Saturna Island	102001		R	×	
U = Large Urban station SU = Small Urb	an station R = R	⊥ Rural station X = ozone monitor was o	nerated		
T = TEOM monitor was operated $B = DAM$	nonitor was one	rated T(B - TEOM and BAM monitors	hoth onerated		
I - TEOM monitor was operated. B = BAM I	normor was oper	rated. TVD - TEOW and DAW MUNITURS	pour operated		

Table 5: Stations considered for British Columbia.

2. NATURE OF PARTICULATE MATTER AND OZONE

Particulate matter and ozone have a number of common features. One of these is that they both are pollutants that can be transported by the prevailing air flows (i.e. wind) over long distances. This means that they can affect air quality at locations close to their sources and also at locations within thousands of kilometres away, whether it be another community in the same province, another province, country or even continent. Because of their transport-potential, elevated levels of these pollutants in a given area does not necessarily imply that local emissions were the major or only contributors to the elevated levels. In some cases, transport plays a significant role. In eastern Canada, for example, air flows from the south coming from the United States are typically associated with higher ozone and PM levels than air flows from the north coming from Canada, especially in the summer.

The remainder of this section provides separate information on the nature of each of PM and ozone.

2.1 Particulate Matter

Particulate matter (PM) is a general term that is used to represent the airborne microscopic liquid and solid substances that are present in the air either as single substances, or as a mixture of substances. These liquid and solid substances are also referred to as *particles*.

Most particles are too small to be seen individually, but collectively they can be seen as plumes of smoke such as those from industrial stacks and residential chimneys, or as haze when their levels are high over a large area. On most smog days, what is perceived as "smog" is mostly the haze created by the particles. The haze reduces visibility and obscures what we see, as can be noticed in these two pictures of the federal Parliament Buildings on days with high and low levels of fine particles.



PM is both a primary and secondary pollutant

PM is a primary pollutant in that it is emitted directly to the air, and a secondary pollutant in that it also forms in the air from precursor gases. Primary PM includes soot (elemental carbon (EC)) and fly ash; metals like lead, mercury, cadmium, arsenic; re-suspended soil and road dust containing such crustal elements as iron, silicon, and calcium; fugitive emissions from the grinding and crushing of materials such as stones; sea-salt spray (near ocean areas); and pollen. Precursors include the gases sulphur dioxide (SO₂), oxides of nitrogen (NO_x), ammonia (NH₃) and volatile organic compounds (VOC). SO₂, NO_x and NH₃ can lead to secondary PM such as ammonium sulphate and ammonium nitrate; VOC can lead to secondary PM containing various organic carbon (OC) substances. Many particles also contain water in hydrated form (chemically-bound) and non-hydrated form (particle-bound) as a layer around the particle.

PM is among the most complex pollutants

PM is complex because individual particles typically consist of mixtures of both primary and secondary PM, causing most particles to differ in type and fraction of PM content, shape, size, and physical and chemical properties. Many particles also have a solid core surrounded by a liquid layer. It is complex also because some substances are semivolatile. Semi-volatile substances can exist in the air both as PM and as gases, and the mass of the semi-volatile PM (e.g. ammonium nitrate and some organic compounds) is not static but can instead change frequently. Particles may loose mass as some of the semi-volatile PM volatilises (i.e. convert into their gaseous forms), and they may gain mass (or new particles are created) as some semi-volatile gases convert into their (secondary) PM forms. Particles can also be carriers of known toxic substances, such as some polycyclic aromatic hydrocarbons.



Schematic of a particle

The size of particles and its role on health and transport distance

Particles are present in the air in a variety of sizes. Particles that can remain airborne for some time are typically smaller than 40 micrometers (μ m), although some are as large as 100 μ m (for comparison, a table-salt grain is about 500 μ m). A common property used to identify the particles is their aerodynamic diameter size. Two important size fractions are the *inhalable* (PM₁₀) and *fine* (PM_{2.5}) fractions. PM₁₀ consist of particles with diameter up to 10 μ m, and PM_{2.5} up to 2.5 μ m. Particles with diameter between 2.5 and 10 μ m are referred to as *coarse particles*. A size fraction that is considerably gaining attention is the *ultrafine* fraction, consisting of particles having a diameter up to 0.1 μ m.

The size of the particles also provides an indication of their origin, how long they can remain airborne, and how deep they can penetrate into the respiratory system. Coarse particles are composed mostly of primary PM of crustal origin, while fine particles are dominated by secondary PM and primary elemental and organic carbon. Fine particles pose the greatest risk to health because they are small enough to penetrate to the finer structure of the lungs. They can also remain airborne for longer periods (up to one to two weeks) and this allows them to be transported over long distances. This

The PM in a community may have different origins, and levels can be elevated year-round

The PM in a community may have a number of origins, including primary PM emitted by sources in the community; primary PM emitted by distant (e.g. another community, province, country or continent) sources and transported into the community; secondary PM formed from precursors emitted in the community; and secondary PM formed from precursors emitted by distant sources and transported into the community.

Elevated levels of fine particles can occur year-round, with levels usually being higher in areas with major emissions of primary PM.

makes $PM_{2.5}$ a local, regional and even global pollutant because it can affect air quality at locations close to the sources and also at thousands of kilometres away.

For more information http://www.msc-smc.ec.gc.ca/saib/smog/docs/PRECURSOR_e.PDF

2.2 Ozone

Ozone (O_3) is a gas that consists of three oxygen atoms, and it is present throughout the lower atmosphere. The lower atmosphere consists of the two (distinct) layers of air closest to the earth's surface – the *troposphere* and the *stratosphere*. The lower portion of the troposphere contains the layer of air that we breathe. Ozone levels broadly increase with height to reach maximum levels at some 25 km above ground in the stratosphere in what is commonly known as the *ozone layer*.

High up above ground ozone is beneficial because it absorbs the ultraviolet rays emitted by the sun, and in so doing it provides a layer of protection to all life forms (including humans) against

Ground-level ozone concentrations exhibit typical diurnal and seasonal patterns

Ozone formation from NOx and VOC occurs only during daylight hours, with the formation being higher during sunny days than cloudy days. Diurnally, hourly ozone levels typically peak in the afternoon to early evening as ozone gradually accumulates throughout the day. In areas affected by transported ozone, however, hourly levels can peak at different times, including night time. Typically, ozone levels decrease during the night to reach minimum levels early in the morning because it is no longer formed and its deposition and reaction with other substances remove it from the air.

Seasonally, *hourly* ozone levels are typically the highest during the summer because ozone formation is higher under intense sunlight and high air temperature. In many parts of Canada, however, *monthly* average ozone levels are typically the highest in spring.

the harmful effects of these rays. At ground-level, however, ozone is essentially a pollutant because it also causes health effects and it damages a variety of crops and materials.

Ozone is not emitted directly to the air in appreciable quantities. Instead, it *forms* in the air from precursor substances. In the stratosphere it forms from the naturally occurring oxygen under sunlight. In the troposphere (layer of air from the ground up to \sim 10 kilometres), ozone mostly forms following the dissociation of nitrogen dioxide (NO₂) under sunlight, and it can also form from the naturally occurring nitrogen and oxygen during lightning discharges. The remainder of this section discusses ground-level ozone, hereafter referred simply as *ozone*.

Ozone is a secondary pollutant, with NO_2 being its direct precursor

Ozone is a secondary pollutant in that it *forms* in the air. In the air that we breathe it forms following the (photo) dissociation of nitrogen dioxide (NO₂) gas. As NO₂ absorbs sunlight, it dissociates into nitric oxide (NO) and an oxygen atom (O). This oxygen atom very rapidly combines with an oxygen molecule (O₂) to form ozone (O₃). NO₂ is thus the direct precursor of ozone.



Most of the ambient NO₂ results from the conversion of NO in the air. NO_2 is both a primary and a secondary pollutant. It is a primary pollutant in that it is emitted directly to the air during the burning of fossil fuels. The burning of fossil fuels releases oxides of nitrogen (NO_x), which consists of approximately 10% NO_2 and 90% NO. NO_2 is also a secondary pollutant since, like ozone, it also forms in the air from the conversion of NO. In fact,

most of the ambient NO₂ follows from this conversion.

The role of NO_x (the NO_x – ozone cycle)

The conversion of NO to NO_2 occurs as NO gains an oxygen atom by chemically reacting with specific substances that are in the air. One such substance is ozone itself. As ozone reacts with NO to form NO_2 it is in fact being removed from the air (known as ozone scavenging or titration by NO) since through the reaction ozone looses an oxygen atom and in so doing it becomes an oxygen molecule (O_2).

NO, therefore, plays two opposing roles. On the one hand it is the precursor of NO_2 , and on the other it scavenges ozone from the air. Because of this opposing roles, if the air contained only NO_x a



cycle would form (the NO_x – *ozone cycle*) where NO and NO₂ would be recycled into each other through the ozone formed. This cycle would then lead to a constant ozone concentration that would be proportional to the ratio of the initial ambient levels of NO₂ to NO.

The Role of VOC

The formation of ozone from NO_x is significantly enhanced if other pollutants such as volatile organic compounds (VOC) are also present in the air. VOC allow the conversion of NO to NO_2 without consuming ozone in the process, thereby allowing ozone to accumulate to much higher levels than would otherwise occur from the NO_x – ozone cycle alone. As such, NO_x and VOC are known as the main ozone precursors, and these are emitted by both anthropogenic (humanrelated) and natural sources.



The combined role of NO_x and VOC

The amount of NO that can be converted to NO_2 (and hence ozone) through the VOC is commensurate with the ambient levels of VOC. For areas where ambient NO_x levels are much lower than those of VOC (as is often the case in rural areas), this means that the VOC will allow the conversion of most, if not all, of the NO to NO_2 . In these latter areas, the amount of ozone that *forms* can be higher than what would be expected based on the ambient levels of NO_x alone since, as indicated in the schematic above on ozone formation, the dissociation of NO_2 returns the original NO that produced it. If there are VOC, this recycled NO would then be converted back again to NO_2 , leading to the formation of an additional ozone molecule. The implication of the recycling of NO to NO_2 through the VOC is that even low ambient NO_x levels can lead to high ozone levels as long as there are sufficient VOC to allow the conversion of the recycled NO to NO_2 .

For areas where ambient NO_x levels are higher than the VOC levels (as is the case in many urban centres), there aren't sufficient VOC to allow the conversion of all NO to NO_2 . There will therefore remain some excess NO that hasn't been converted to NO_2 through the VOC.

The non-linearities of ambient ozone

In areas where ambient NO_x is higher than ambient VOC, the excess NO that is not converted to NO2 will be available to scavenge the ozone that is forming and also any ozone already in the air or being transported into the area. This scavenging leads to lower ozone levels than would otherwise occur in its absence. As such, any reduction in the amount of excess NO could lead to higher ozone levels simply because of the ensuing reduction in the amount of ozone scavenged. Therefore, reductions in NO_x emissions may not necessarily lead to lower ozone levels because any ensuing reductions in the amount of ozone formed can be partially or fully offset by a reduction in the amount of ozone scavenged.

Reductions in NO_x emissions can in some cases lead to an *increase* in ozone levels

This may happen, for example, for the case where NO_x emission reductions do lower the ambient NO_x levels but these newer lower NO_x levels are still higher than the ambient VOC levels. In this case the same amount of NO will be converted to NO₂ (and hence ozone) by the VOC as occurred before the NO_x reductions. However, because ambient NO_x levels have been reduced, there now is less excess NO to scavenge the same amount of ozone formed, thereby leading to higher actual ozone levels.

In areas affected by transported ozone, local reductions in NO_x emissions can decrease the amount of NO that scavenges the transported ozone, thereby leading to a possible increase in ozone levels. The production of more than one NO_2 molecule (and hence ozone) from the same NO as discussed previously, and the offset in the reduction of the amount of ozone formed, are examples of non-linearities between ozone and its precursors. That is to say, for example, that a given percentage reduction in NO_x emissions may not produce the same percentage reductions in ozone levels.

The ozone in a community can be of various origins

The ozone present in a given community may have many origins. Two broad origins are the ozone formed from precursors emitted by anthropogenic and natural sources in the community, and the ozone (and precursors) that is transported in the community. The transported ozone includes the ozone formed from NO_x and VOC (and other precursors) emitted by distant anthropogenic and natural sources in another community, province, country and continent. Other origins of ground-level ozone may be the ozone formed higher up above ground in the troposphere and the ozone formed in the stratosphere which, under certain meteorological conditions, can both be transported downward to the surface.

Ozone levels may be higher in rural areas in some regions of Canada

High ozone levels are not only a concern in large urban centres, but they can also be of concern in rural areas, and in some regions of Canada ozone levels are commonly higher in rural areas than in urban centres. Part of this may be associated with less ozone scavenging in the rural areas because of the generally lower ambient NO levels there.

Part of it may be associated with the delay between the time that the precursors are emitted and the time that ozone starts to form and accumulate. During this time, the precursors and the ozone being formed are transported by the wind out of the urban centres and into the surrounding downwind rural areas.

The eventual blending of the ozone from various origins where any one origin is no longer discernible could be viewed as forming what is referred to as *background ozone*. For policy purposes, the Environmental Protection Agency of the United States (US) defines background ozone in the US as the ozone formed from natural sources anywhere on earth, and from anthropogenic sources outside North America.

All of this means that ...

Explaining trends in ozone levels is not a simple task. The many factors that can influence ambient ozone levels indicate that a rigorous evaluation of the reasons behind any trend in ozone levels is necessary. This evaluation should also include the identification of the factors that affect the ozone levels in a given community, and an evaluation of the trends in all of these factors.

The non-linear interactions also mean that stateof-the art meteorological and chemical transport models that are capable of simulating the many atmospheric processes that affect ozone are needed to quantitatively evaluate the effects that given emission reduction measures will have on ozone (and PM), and to assist in the assessment of trends.

Ozone levels can vary significantly between years

Ozone levels can vary significantly between years, especially the higher levels. Most of any annual variability between *consecutive* years is likely to be due to differences in weather conditions between the years since year to year changes in emissions of precursors are generally small. Over the long-term, however, changes in weather conditions tend to even out, and in such cases any significant trend in levels (whether upward or downward) could likely be a reflection of systematic changes in other factors that affect the ozone levels, such as changes in emissions of precursors or changes in any transported ozone.

3. UPDATE ON THE PM_{2.5} MEASUREMENT METHOD PATH FORWARD

PM_{2.5} concentrations have traditionally been measured by the (manual) filter-based sampler method. These samplers provide a single 24-hour average concentration, and they are routinely operated once every sixth day (or once every third day). Because filter-based samplers are resource-intensive (both human and financial), in Canada and other countries PM_{2.5} levels are now mostly measured by continuous monitors that provide hourly concentrations in real-time. The real-time capacity of these monitors also allows PM_{2.5} to be included in programs that inform the public on the status of air quality in real-time such as air quality indices and smog advisories. The continuous monitoring method most widely-used in Canada is the Tapered Element Oscillating Micro-balance monitor (TEOM[®]), and another method that is increasingly being deployed, especially in eastern Canada, is the Beta Attenuation Monitor (BAM).

Because of the complexities of PM, there is no reference PM mass and composition that can be used to test the performance of a measurement method as there is for ozone. Instead, the concentration of PM can only be defined by the design and configuration of the measurement method, and by the conditions (e.g. temperature and relative humidity) under which the measurements are made. All of this means that the various methods

that are used in Canada and elsewhere may report concentrations that may differ to some extent because of differences in methoddesign, method-configuration and conditions under which the measurement is made. This can be a concern for CWS achievement evaluation if the differences in concentration reported by the various methods used are unacceptably large.

The use of various methods to measure the levels of PM_{2.5} can be of concern for CWS achievement evaluation.

The US designated a reference method for evaluating achievement of their standards. To address this concern, the United States designated a reference method for the purpose of evaluating achievement of their standards, and this method is a filter-based sampler type. In Canada, the $PM_{2.5}$ CWS was developed from filter-based samplers data, but when the CWS were endorsed in June 2000

there was no Canadian reference method. The endorsed CWS did not, therefore, specify the method to use to evaluate achievement. The only specified requirement at that time was the need to evaluate achievement based on *daily* measurements of the 24-hour average concentration (daily 24-hour $PM_{2.5}$), with the intent that the method(s) to use for evaluating achievement would be addressed by the *Monitoring Protocol* that is called for under the CWS. This Protocol is currently under development.

As mentioned above, in Canada the TEOM and BAM are used to obtain the daily 24-hour PM_{2.5}. Preliminary studies conducted in Canada indicate that the concentrations reported by the TEOM are typically lower than those reported by filter-based samplers, especially in winter, while the concentrations from the BAM are typically higher year-round. These studies also suggested that lower TEOM concentrations may be due in part to the greater volatilization of semi-volatile PM (such as ammonium nitrate and organics) in the TEOM, and in some cases the differences between the TEOM and BAM concentrations can be significantly large to be of concern for CWS reporting.

Given this concern, the National Air Pollution Surveillance (NAPS) Network agencies tabled a proposal to the former Joint Action Implementation Coordinating Committee (JAICC) of the PM and Ozone CWS for addressing the methods issue. Two key recommendations in the proposal are the development of a NAPS Reference Method (NRM) for measuring the mass concentration of $PM_{2.5}$, and the deployment of a national inter-comparison monitoring network where measurements from the NRM will be used to develop performance criteria for determining equivalency with the NRM.

A PM_{2.5} NAPS Reference Method (NRM) is being developed and a national intercomparison monitoring network is being deployed.

Performance equivalency criteria will be developed by 2007 to give agencies sufficient time to implement any necessary adjustments to their $PM_{2.5}$ monitoring network by the start of 2008, the first year of the three year period (2008 to 2010) for evaluating achievement of the CWS. In the mean time, all available $PM_{2.5}$ levels will continue to be reported irrespective of the method, and because the equivalency status of the methods are uncertain at this time, any information on $PM_{2.5}$ levels should also specify the method used to measure the levels. As such in this report the TEOM and BAM $PM_{2.5}$ levels are accordingly distinguished. It should also be noted that, because of the current uncertainty in the equivalency status of these methods, and as already mentioned in section 2 of the report, the 3-year averages of the 98th percentiles are not to be construed as being formally indicative of the achievement status of the $PM_{2.5}$ standard.

4. METHODS AND STATIONS FOR 2003 COMPARISON TO PREVIOUS YEARS

This section describes the methods used for comparing the 2003 regional levels to those over the previous years as discussed in section 9 of the report, and it also indicates the stations included.

The annual levels considered for $PM_{2.5}$ are the annual average of all daily 24-hour $PM_{2.5}$ and the corresponding annual 98th percentile. For ozone the annual levels considered are the annual average of all Dmax 8-hour O₃ and the corresponding annual 4th highest. The 2003 regional levels were compared to those over the previous four years (1999-2002) for $PM_{2.5}$ (TEOM only) and to those over the previous ten years (1993-2002) for ozone.

A given 2003 regional level is defined as being the average of the (considered) station-specific 2003 levels, and the corresponding previous years' regional level is defined as being the average of the station-specific previous years average levels. For example, the regional previous 10-year 4th highest Dmax 8-hour O_3 is the average of the previous 10-year average of the annual 4th highest from each station.

Stations were included only if their annual levels were available in 2003 and in three of the previous four years for $PM_{2.5}$, and in seven of the previous ten years for ozone. The regional levels are based on all three type of stations (large urban, small urban and rural) mentioned in section 1, and the stations included in the regional levels are indicated in Tables 6-8.

CMA/CA/Area	NAPS Station ID	Station Location	Station Type	Ozone	PM _{2.5}			
St. John's (CMA)	10102	Water Street	LU	X	Х			
Kejimkujik	30501	Kejimkujik National Park	R	X				
Yarmouth	30801	Yarmouth Weather Office	R	X				
Halifax (CMA)	30118	Barrington Street	LU	X				
Saint John (CMA)	40203	Forest Hills	LU	X	Х			
	40206	Customs Building	LU	X				
Moncton (CA)	40302	Thanet Street	LU		Х			
Fundy National Park	40401	Hastings Tower	R	X				
Point Lepreau	40501	Recreation Area	R	X				
Central Blissville	40601	Airport Road	R	X				
Norton	40701	Hwy 124	R	X				
St. Andrews	40901	Brandy Cove Road	R		X			
Campobello Island	41001	Campobello Island	R	X				
	50102	Jardin Botanique	LU	X				
	50103	Montréal-Est	LU	X				
	50104	Rue Ontario	LU	X				
	50105	Rue Drummond	LU		X			
	50109	Rue Duncan (Échangeur Décarie)	LU	X				
	50110	Parc Pilon	LU	X				
	50113	Laval (Chomedey)	LU	X				
	50115	Downtown	LU	X				
Montréal (CMA)	50116	Verdun	LU	X				
	50119	Rue Victoria	LU	X				
	50121	Brossard (Parc Océanie)	LU	X				
	50126	Sainte-Anne-de-Bellevue	LU		Х			
	50128	Aéroport Dorval	LU					
	50129	Rivière-des-Prairies	LU		Х			
	50131	Hochelaga-Maisonneuve	LU					
	52601	Varennes	LU	X				
	54501	L'Assomption	LU	X	X			
	50308	Rue des Sables	LU		X			
Québec (CMA)	50309	Rang St. Ange - Sainte-Foy	LU	X				
	50310	Blvd. René-Lévesque	LU					
Trois - Rivières (CMA)	50801	Rue Hart	LU		Х			
Saint-Jean-sur-Richelieu (CA)	55301	Route 219	SU		X			
St. Zéphirin-de-Courval	51501	Rang Saint-Michel	R	X				
Charette	52001	Au nord du 170 2e Rang	R	X				
Saint-Simon	52201	4e Rang Est	R	X				
Saint-Faustin-Lac-Carré	52301	Chemin du Lac (Caribou)	R	X				
La Pêche	52401	Lac Philippe - Masham	R	X				
La Doré	53201	Route 167	R	X				
Deschambault	53301	3e Rang - Deschambault	R	X				
Ste-Cathde-JCartier	53401	Rue Laurier	R	X				
Saint-François	53501	Rue Royale Île D'Orléans	R	X				
Notre-Dame-du-Rosaire	53601	Rang St-Louis	R	X				
St-Hilaire-de-Dorset	53701	Rang Dorset	R	X				
Tingwick	53801	Chemin Radar et Warwick	R	X				
Lac-Édouard	53901	Derrière L'Hôpital Village	R	X				
Saint-Anicet	54401	Rue de La Guerre	R	X	X			
Stukely-Sud	54801	Chemin Montbel	R	X				
La Patrie	54901	Rang Petit Canada Ouest	R	X				
Ferme-Neuve	55001	Rang Gravel	R	X				
LU = Large Urban station. SU = Small Urban station. R = Rural station. X = data from station included for regional averages.								

Table 6: Atla	antic Canada and	Québec stations	considered for	comparison to	previous years.
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CMA/CA/Area	NAPS Station ID	Station Location	Station Type	Ozone	PM _{2.5}
(05mdaar (OM0)	60204	Windsor University	LU	х	
	60211	Windsor College	LU	х	
	60410	Toronto-East	LU	Х	
Toronto (CMA)	60415	Mississauga	LU	Х	Х
	60421	Toronto-North	LU	Х	Х
	60424	Toronto-Downtown	LU	Х	
	63201	Stouffville	LU	Х	
	60512	Hamilton-Downtown	LU	Х	Х
Hamilton (CMA)	60513	Hamilton-Mountain	LU	Х	X
	63001	Burlington	LU	Х	
)shawa (CMA)	61701	Ritson Rd. & Olive Ave.	LU	Х	Х
Ottawa (CMA)	60104	Rideau & Wurtemburg	LU	Х	Х
Kingston (CMA)	60302	Dalton Avenue	LU	Х	
Sudbury (CMA)	60607	Ramsey Lake Rd.	LU	х	
St. Catharines - Niagara (CMA)	61302	St. Catharines	LU	х	Х
Kitchener (CMA)	61502	West Ave. & Homewood	LU	Х	X
'hunder Bay (CMA)	60807	James Street South	LU	х	
ondon (CMA)	60903	Highbury Avenue	LU	х	
Sault Sainte Marie (CA)	60707	Patrick St.	SU	Х	
Sarnia (CA)	61004	Front St.	SU	Х	
ornwall (CA	61201	Bedford & Third St.	SU	X	
Guelph (CA)	61802	Exhibition Park	LU	X	
North Bay (CA)	62001	Chippewa St.	SU	Х	
Aerlin	62201	MOE Water Pump Stn.	R	Х	
Tiverton	62501	Bruce Nuclear Visitor Center	R	x	
Norfork (CA)	62601	Experimental Farm (Simcoe)	R	Х	X
)orset	63301	Hwy 117 & Paint Lake Road	R	х	
Frand Bend	63701	Hwy 21 & County Rd 83	R	х	
Experimental Lakes Area	64001		R	х	
Igoma	64101		R	x	
Egbert	64401		R	X	

Table 7: Ontario stations considered for comparison to previous years.

CMA/CA/Area	NAPS Station ID	Station Location	Station Type	Ozone	PM _{2.5}			
Minnings (CMA)	70118	Jefferson & Scotia	LU	Х	Х			
winnipeg (CiwA)	70119	Ellen Street	LU	X				
Brandon (CA)	70203	Victoria Avenue East	SU	Х				
Regina (CMA)	80110	Brent building, 11th Avenue	LU	X				
Saskatoon (CMA)	80211	Corman Park	LU	X				
	90121	Edmonton East	LU	X				
Edmonton (OM8)	90122	Edmonton NW	LU	X	X			
Edmonton (CIMA)	90130	Edmonton Central	LU	X				
	90601	Fort Saskatchewan	LU	X				
	90218	Calgary East	LU	Х				
Calgary (CMA)	90222	Calgary - Northwest	LU	X				
	90227	Calgary Central	LU	X	Х			
Ward Duffele (C.0)	90702	Fort Mcmurray - Timberlea	SU		Х			
WOOD Bullalo (CA)	90801	Fort Mackay	SU		X			
Esther	91001	Esther	R	Х				
Victoria (CMA)	100304	Topaz	LU		Х			
	100110	Burnaby - Kensington Park	LU	Х				
	100111	Port - Moody Rocky Point Park	LU	Х				
	100112	Vancouver - Downtown	LU	X				
	100118	Vancouver - Kitsilano	LU	X				
	100119	Burnaby South	LU	X				
	100121	North Vancouver - Second Narrows	LU	X				
Vancouver (CMA)	100125	North Delta	LU	X				
	100127	Surrey East	LU	Х				
	100128	Richmond South	LU	Х				
	100132	North Vancouver - Mahon Park	LU	Х				
	100134	Vancouver - Airport	LU		Х			
	101202	Pitt Meadows	LU		Х			
	101301	Langley	LU	X				
Abbeteferd (CMA)	101003	Bevan Ave.	LU	Х				
Appolisiona (CIMA)	101004	Abbotsford Airport	LU					
Chilliwack (CA)	101101	Airport Road	SU	Х	Х			
Kelowna (CMA)	100701	College Way	LU	Х	Х			
Prince George (CA)	100202	4th Avenue	SU	Х	Х			
Kamloops (CA)	100402	Mayfair Street	SU		Х			
Squamish (CA)	101601	2nd Avenue	SU	X				
Nanaimo (CA)	102102	Labieux Road	SU		Х			
Powel River (CA)	102301	Cranberry Lake	SU		Х			
Saturna Island	102001		R	X				
LU = Large Urban station. SU = Small Urban station. R = Rural station. X = data from station included for regional averages.								

Table 8: Manitoba, Saskatchewan, Alberta and British Columbia stations considered for comparison to previous years.

5. METHODS AND STATIONS FOR OZONE TRENDS

This section describes the methods used for evaluating the trends in ozone levels as presented in section 10 of the report, and it also indicates the stations included for the regional trends.

The trends are evaluated for the annual average of all Dmax 8-hour O_3 and the corresponding annual 4th highest. For the regional trends, the trends are evaluated for the corresponding regional levels. A regional annual level for a given year is defined as being the average of the (considered) station-specific 2003 levels. For example, the 2003 regional annual 4th highest is the average of the 4th highest from each station in 2003.

For the station-specific trends, only stations with annual levels available in eleven of the 15-year period were considered. In addition to this criteria, for the regional trends a visual screening of the station-specific annual levels was also performed. This was done to ensure that stations believed to have a relatively large influence (based on the available annual levels) on the regional average were not included if their missing annual levels might have affected the trend. The stations included for the regional trends are indicated Tables 9 -11.

A *trend* can be thought of as the *predominant* tendency (increasing or decreasing) in levels over the considered period. The trends and their statistical significance are evaluated based on the non-parametric Sen method at the 95% confidence level. A *statistically non-significant* trend implies that random variations were likely (95% confident) responsible for the trend, and as such the actual levels may have in fact remained more or less unchanged over the period. A *statistically significant* trend means that random variations were likely not the cause of the trend, and this implies in turn that *some* underlying cause or causes *may* have been responsible for the trend, and the trends – which cause(s), however, is unknown.

Table 9: Atlantic Canada and Québec stations considered for regional ozone trends.

CMA/CA/Area	NAPS Station ID	Station Location	Station Type	Annual Average	4th Highest			
Kejimkujik	30501	Kejimkujik National Park	R	×	X			
Saint John (CMA)	40203	Forest Hills		Х				
Fundy National Park	40401	Hastings Tower	R		X			
Point Lepreau	40501	Recreation Area	R		X			
Central Blissville	40601	Airport Road	R		X			
Norton	40701	Hwy 124	R		X			
	50102	Jardin Botanique	LU	х	X			
Montreal (CMA)	50103	Montréal-Est	LU		X			
	50104	Rue Ontario	LU	x	X			
	50110	Parc Pilon	LU		X			
Montreal (CMA)	50113	Laval (Chomedey)	LU	x	X			
	50115	Downtown	LU	х	Х			
	50116	Verdun	LU	x	X			
	50119	Rue Victoria	LU	х	X			
	50121	Brossard (Parc Océanie)	LU		Х			
Québec (CMA)	50309	Rang St. Ange - Sainte-Foy	LU	х	Х			
St. Zéphirin-De-Courval	51501	Rang Saint-Michel	R	×	X			
Charette	52001	Au nord du 170 2e Rang	R	×	X			
Saint-Simon	52201	4e Rang Est	R	×	X			
Saint-Faustin-Lac-Carré	52301	Chemin du Lac (Caribou)	R	X	X			
La Pêche	52401	Lac Philippe - Masham	R	x	X			
La Doré	53201	Route 167	R	x	X			
Deschambault	53301	3e Rang - Deschambault	R	x	X			
Saint-François	53501	Rue Royale Île D'Orléans	R	×	X			
Notre-Dame-du-Rosaire	53601	Rang St-Louis	R	×	X			
St-Hilaire-de-Dorset	53701	Rang Dorset	R	x	X			
Tingwick	53801	Chemin Radar et Warwick	R	x	X			
Lac-Édouard	53901	Derrière L'Hôpital Village	R	x	X			
Stukely-Sud	54801	Chemin Montbel	R	x	X			
La Patrie	54901	Rang Petit Canada Ouest	R	х	X			
Ferme-Neuve	55001	Rang Gravel	R	х	Х			
LU = Large Urban station. SU = Small Urban station. R = Rural station. X = data from station included for regional trends.								

CMA/CA/Area	NAPS Station ID	Station Location	Station Type	Annual Average	4th Highest
Windsor (CMA)	60204	Windsor University	LU	X	X
	60211	Windsor College	LU		X
Toronto (CMA)	60410	Toronto-East	LU	X	X
	60413	Toronto-West	LU	Х	X
	60415	Mississauga	LU	Х	X
	60421	Toronto-North	LU	X	X
	60424	Toronto-Downtown	LU		X
	61602	Oakville - Bronte Road	LU	Х	X
	63201	Stouffville	LU	х	X
Hamilton (CMA)	60512	Hamilton-Downtown	LU	Х	Х
	60513	Hamilton-Mountain	LU	X	X
	63001	Burlington	LU	Х	X
Ottawa (CMA)	60104	Rideau & Wurtemburg	LU	х	Х
Kingston (CMA)	60302	Dalton Avenue	LU	×	X
Oshawa (CMA)	61701	Ritson Rd. & Olive Ave.	LU	х	X
Sudbury (CMA)	60607	Ramsey Lake Rd.	LU	x	X
St. Catharines - Niagara (CMA)	61302	St. Catharines	LU	x	X
Kitchener (CMA)	61502	West Ave. & Homewood	LU	x	X
Thunder Bay (CMA)	60807	James Street South	LU	x	X
Sault Sainte Marie (CA)	60707	Patrick St.	SU	x	X
Sarnia (CA)	61004	Front St.	SU	x	X
Cornwall (CA	61201	Bedford & Third St.	SU	X	X
Guelph (CA)	61802	Exhibition Park	LU		X
North Bay (CA)	62001	Chippewa St.	SU	x	X
Merlin	62201	MOE Water Pump Stn.	R	x	X
Tiverton	62501	Bruce Nuclear Visitor Center	R	×	X
Norfork (CA)	62601	Experimental Farm (Simcoe)	R	×	X
Dorset	63301	Hwy 117 & Paint Lake Road	R		X
Grand Bend	63701	Hwy 21 & County Rd 83	R		X
Experimental Lakes Area	64001		R	×	X
Algoma	64101		R	×	X
Eabert	64401		R	x	X
 III= Large Urban station _ SII= Small	Ulrhan station R = R	ural station. X = data from station i	ncluded for region	al trends	~ ~ ~

Table 10: Ontario stations considered for regional ozone trends.

Table 11: Manitoba, Saskatchewan, Alberta and British Columbia stations considered for regional ozone trends.

CMA/CA/Area	NAPS Station	Station Location	Station Type	Annual Average	4th Highest
Regina (CMA)	80110	Brent building, 11th Avenue	LU	×	X
Winnipeg (CMA)	70118	Jefferson & Scotia	LU	1	X
	70119	Ellen Street	LU	×	X
Brandon (CA)	70203	Victoria Avenue East	SU	×	X
Edmonton (CMA)	90121	Edmonton East	LU	×	X
	90122	Edmonton N/V	LU	×	X
	90130	Edmonton Central	LU	×	×
	90601	Fort Saskatchewan	LU	×	X
Calgary (CMV)	90218	Calgary East	LU	×	×
	90222	Calgary - Northwest	LU	×	X
	90227	Calgary Central	LU	×	X
Vancouver (CMA)	100110	Burnaby - Kensington Park	LU	×	X
	100111	Port - Moody Rocky Point Park	LU	×	X
	100112	Vancouver - Downtown	LU	×	×
	100118	Vancouver - Kitsilano	LU	×	×
	100121	North Vancouver - Second Narrows	LU	×	X
	100125	North Delta	LU	×	X
	100126	Burnaby - Mountain	LU	×	X
	100127	Surrey East	LU	×	X
	100128	Richmond South	LU	×	×
	100132	North Vancouver - Mahon Park	LU		×
	101301	Langley	LU		X
Abbotsford (CMA)	101003	Bevan Ave.	LU		×
Chillwack (CA)	101101	Airport Road	SU	×	X
Kelowna (CMA)	100701	College Way	LU	×	
Saturna Island	102001		R	×	X
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