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AIR QUALITY TRENDS AND POLLUTION ROSES IN SELECTED CITIES OF
CANADA

By

Asfand Yar Said

A Thesis
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through the department of Civil and Environmental Engineering
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University of Windsor

Windsor, Ontario, Canada

2011

AIR QUALITY TRENDS AND POLLUTION ROSES IN SELECTED CITIES OF
CANADA

By

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ABSTRACT

Long term trend and pollution roses for selected pollutant were examined across major cities of Canada, include carbon monoxide(CO), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), nitric oxide (NO), nitrogen oxide (NO), ozone (O_3), and particulate matter (PM). Linear regression was used to obtain the annual mean trend from 1998-2007. There was a statistically significant downward trend for all pollutants studied except O_3 in most cities indicating effective regulatory provision and reduced emissions during the past decade. O_3 showed an upward trend and large year-to-year variation indicating strong influence of meteorological conditions and photochemical reactions. Wind rose and percentile pollution rose plots suggest that the higher concentration of SO_2 was associated with specific sources, while CO, PM, NO_x were associated with local production. O_3 was found to be regional with high concentrations mostly occurring in the direction of industrial cities of United States. Overall, the finding of the study indicates CO, SO_2, NO_X and PM as improved local pollutants. Future studies should take into consideration the effect of volatile organic compound levels on the long term trend of O_3.

DEDICATION

To my supervisor Dr. Xiaohong Iris Xu

ACKNOWLEDGEMENTS

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CHAPTER I

INTRODUCTION

1.1 Background

The state of air quality in a city is affected by different factors. These factors may vary in nature such as: 1) meteorological condition; 2) local emission sources; 3) trans-boundary movement of air pollutants; 4) emission control technologies; 5) activities leading to emissions. A short term variation in meteorology conditions may cause significant effect in air quality. However, the long term variation would not have significant effect. Local sources or the local production of pollutant from the sources which can be both mobile and stationary is another factor affecting air quality. Stationary sources are commonly referred to as point sources which include factories, industrial units and facilities. Mobile sources are normally associated with transportation including light duty, heavy duty and commercial vehicles. Air pollution can be transported from one region to another under the influence of trans-boundary movement of air mass. This effect can be observed both at regional, inter and intra provincial levels. The technological advancement have resulted in the cleaner state of vehicle, causing less pollution per unit activity, e.g. vehicle kilometer traveled (VKT). However, at the same time the ownership and usage of vehicle have increased which results in more vehicle kilometer traveled. Consequently, the net effect could be an increase in the level of air pollution.

This study primarily focuses on the seven key pollutants, carbon monoxide (CO), sulphur dioxide (SO_2), nitric oxide (NO), nitrogen dioxide (NO_2), nitrogen oxide (NO_x), ozone (O_3), and particulate matter (PM). Four of them i.e. carbon monoxide (CO),

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sulphur dioxide (SO_2), nitrogen oxide (NO_x), ozone (O_3), and particulate matter (PM) is the criteria pollutants (USEPA, 2009).

These pollutants are considered to be of major health concerns and financial impacts. For instance, the ground level ozone has been reported to cause several billion dollar damage in the human health and agricultural crop in each year in the province of Ontario (Geddes et al., 2009). Therefore, there continue to be a need to assess the air concentration levels. This could be done more effectively by examining the level of pollution in a relatively long period of time, such as 10 years. In each province, the Ministry of Environment operates in that region of Canada and releases annual reports summarizing the quality of air. However, there is no conclusive report describing the state of air quality in major cities across Canada.

1.2 Research Objectives

The overall objective of this thesis is to describe the state of air quality, including CO, SO_2, NO_x, NO_2, NO, O_3, and PM in the major cities of Canada. The results of this research work can be utilized by the policy maker to assess the overall state of air quality in Canada. The higher percentile concentration of the pollution rose plots provide an area for demarcation and can help in exposure assessment. The specific objectives of this research are as follows.

- To determine whether air pollution levels have changed during the past 10 years due to multiple factors, including pollution control programs, growth in cities, and increases in transportation and industrial activities.
- To find the factors responsible for the improvement and decline of air quality.

- To determine whether the major sources are local or regional, the wind directional concentration levels were investigated by generating pollution roses.

CHAPTER II

REVIEW OF LITERATURE

2.1 Selected Pollutants

The pollutants investigated in this study are CO, SO_2, O_3, NO_x, NO_2, NO, PM2.5 and PM10. A brief review of pollutant with negative health effect is discussed one by one below.

2.1.1 Carbon Monoxide (CO)

CO is a colorless, odorless, and tasteless gas. It is lighter than air and only slightly soluble in water. CO is produced from natural processes and human activities. The major sources of CO that have been identified as natural include; volcanic, marsh and natural gases, oceans, fires, and electrical storms (Health Canada, 1998). CO is also formed by the combustion of substances that are carbonaceous in nature. Estimated total CO emissions in Canada in year 2005 were 9,538,301 tonnes (excluding open sources e.g. forest fires, prescribed burning) (EC, 2005a).

In Fig 2-1 the man-made emission source categories of CO have been defined by sectors. They are: 1) on-road vehicles; 2) other transportation sources; 3) residential; 4) other industrial processes; 5) smelters/primary metals. Overall, transportation sector accounted for the largest contribution of CO, i.e. 85%. The *road vehicle* includes passenger cars, trucks, buses and motorcycles. Whereas the *other transportation* comprising of off-road vehicles may include aircraft, locomotives, vessels and miscellaneous engines such as farm equipment, industrial and construction machinery, lawnmowers and snowmobiles.

(Emissions from Point/Area/Transportation Sources, 2006 Estimates)		
Pie Chart	**Category**	**Percent**
	Road Vehicles	45%
	Other Transportation	40%
	Residential/Miscellaneous	7%
	Other Industrial Processes	5%
	Smelters/Primary Metals	3%
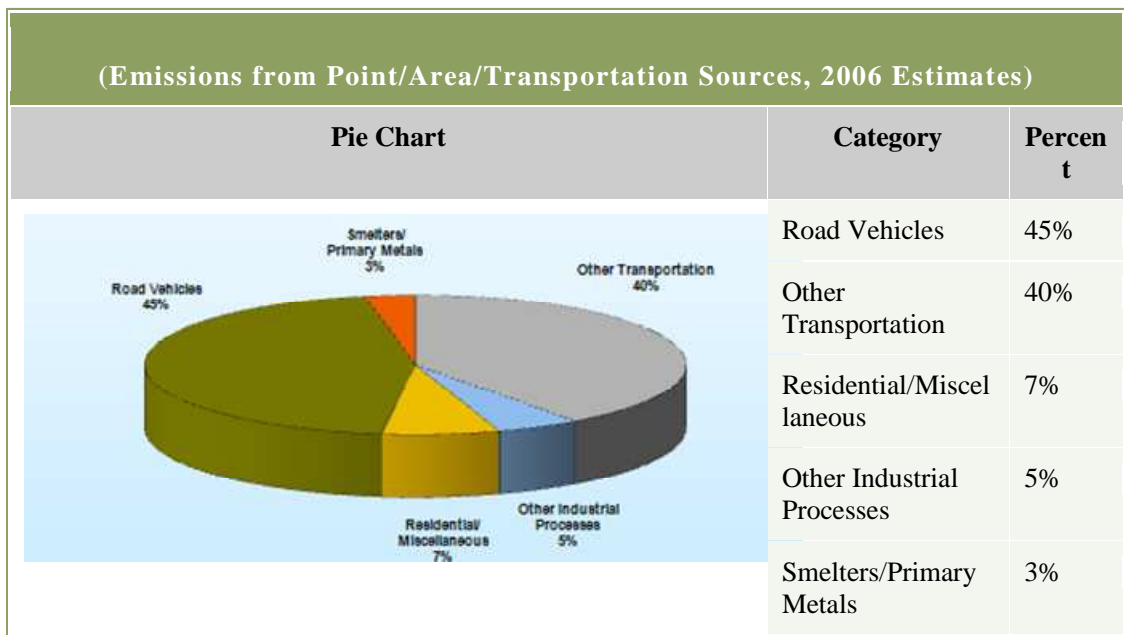
Fig 2-1: Ontario CO Emissions by Sectors (MOE, 2007)

A substantial number of studies have been carried out in urban areas to determine the concentrations of CO in the ambient air (NAPS, 2004a). The large temporal and spatial variability of CO and the limited number of monitoring stations in the urban areas make it difficult to assess the overall human exposure. However, the patterns of trends of urban CO have been observed in some studies. One such study is conducted by NAPS (2004a) which showed pronounced bimodal diurnal pattern for CO in urban areas. The peak concentrations of CO were found to occur in the morning and late afternoon. These time periods correspond with the traffic activity, which shows that besides other factors such as meteorology and location the concentration of CO depends on the emissions by vehicles. Furthermore the concentration of CO was found to be lower in weekends than on weekdays.

CO reacts with the haemoglobin component of the blood to form carboxyhaemoglobin. The presence of *Carboxyhaemoglobin*impedes the oxygen carrying capacity of the blood. As a result tissues which require higher intake of oxygen (heart, brain and exercising skeletal muscles) are adversely affected by carboxyhaemoglobin. It has been indicated that people spend about 90% of the time at indoors. Therefore, the time spent at indoors is an important pathway of exposure to CO (Monette et al., 2004).

The indoor levels of CO can also be influenced by outdoor levels. High level of CO at indoors can result in headache, drowsiness and cardiac arrhythmias. The sufficient high levels may lead to coma and death. Studies have shown that healthy adults exposed to increased levels of CO can exhibit decreased aerobic capacity, impaired work capacity, and reduced visual perception, manual dexterity, and performance of complex sensory-motor tasks (Health Canada, 1998). The short term exposure of CO results in decreased physical performance and heart symptoms. Small increases in CO exposure could adversely affect myocardial function and produce ischemia (a local loss of blood flow), and these effects may lack a safe threshold (Environment Canada & Health Canada, 1994).

2.1.2 Sulphur Dioxide (SO_2)

SO_2 is a colourless and tasteless gas with pungent odour. It combines with water to form sulphurous acid (H_2SO_4). A number of oxides are formed by sulphur but two of them,SO_2 and SO_3 (sulphur trioxide), are of prime importance. SO_2 and SO_3 are treated as sulphur oxides. In the year 2005 the estimated emission of SO_2 in Canada were reported as 2 057 997 tonnes (EC, 2005b), these figures excluded the open sources.

Atmospheric SO_2 is produced from the natural and manmade processes. Naturally the compounds of sulphur (SO_2 and H_2S) are produced by the volcanoes and anaerobic decay of bacteria in soil marshed and tidal flats. Man made processes responsible for the production of SO_2 includes combustion of fuel for heating and energy production. The manmade sources have been divided into three broader categories of: 1) industrial; 2) domestic; and 3) vehicular activities. Fig 2-2 presents a summary of break down for these categories in the province of Ontario. The highest SO_x emissions of 69% were produced from industrial activities (smelter and utilities). The downstream petroleum industry and the transportation sector accounted for 9% and 4% of SO_x emissions respectively.

Pie Chart	Category	Percent
	Smelters	50%
	Utilities	19%
	Downstream Petroleum Industry	9%
	Other Processes	9%
	Cement and Concrete	6%
	Transportation	4%
	Miscellaneous	3%
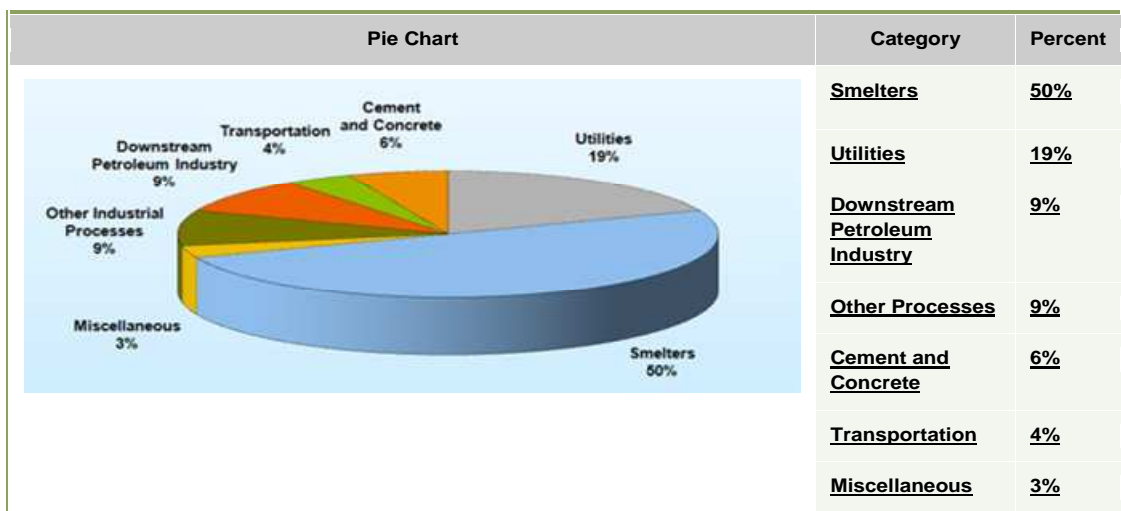
Fig 2-2: Ontario SO_2 Emissions by Sectors (MOE, 2007)

The dispersion of SO_2 from elevated combustion sources such as power plant stacks is dependent upon several factors including: a) temperature and efflux velocity of the gasses: b) stack height: c) topographical features: d) meteorology. *Temperature* and the exit velocity play a key role in case of small sources of emissions such as domestic

fires and incinerators. For these sources the buoyancy of pollutant is less due to lower temperature difference from surrounding air. Therefore, the greatest impact is observed in the near vicinity. Contrarily, for large installation the impact at immediate vicinity is less and weaker effects are produced over a wide area. The use of *tall stack* aids in the dispersion and dilution of SO_2. One such example is the use of tall stacks in case of chimneys. Various models have also been developed to predict the concentration of SO_2 on the basis of emission from multiple sources. In case of closely packed building the effect of SO_2 concentration in the near vicinity is more than high raise apartment buildings (WHO, 1979a). This is due to the functional relationship between the height of SO_2 emission and the building. *Topographical features* including hills, tall buildings and landscape feature have an important effect on the dispersion of plume. The dispersion of pollutant is more observed in case of exposed locations. *Meteorology* plays a vital role in the dispersion of SO_2 pollutants. The phenomena of inversion can trap SO_2 thereby increasing the concentration to hundreds of times (Waller &Commins, 1967).

The health effects of SO_2 are observed both at the level of living organism and structures. In case of human the higher levels of exposure to SO_2 can lead to breathing problem, respiratory illness and can affect the lung defensive mechanism. Individuals who suffer from asthma, lung or heart diseases are at higher risk of getting affected by SO_2. Study conducted by Health Canada (2001) showed that increased level of SO_2 may lead to premature death. SO_2 react with air to form airborne PM that too affects human health. Furthermore, they play a role in the formation of urban smog which is a significant health hazard.

Long term SO_2 exposure affects the photosynthesis action of the plant by bleaching the chlorophyll. The most significant damage is caused by the acid rain. Provinces such as Ontario, Quebec, New Brunswick, and Nova Scotia are found to be most affected because there water and soil system cannot fight against damaging consequences of acid rain (EC, 2005b). SO_2 and acid rain may cause damage to building outdoors due to highly corrosive property.

2.1.3 Ozone (O_3)

O_3 is a colourless and odourless gas which consists of three atoms of oxygen that are bounded together. O_3 at tropospheric level is not emitted directly but is formed by a series of complex reaction. That reaction involves oxides of nitrogen (NO_x) and volatile organic compounds (VOC) in the presence of sunlight. O_3 is a major component of smog. Smog is the term given to a noxious mixture of air pollutants, including gases and fine particles that can often be seen as a brownish-yellow or greyish-white haze. Study indicates that 90% of all smog found in urban areas is made up of ground level O_3 (MOE, 2007).

O_3 can be generated from NO_x and VOCs. However, the production of O_3 from the NO_x constitutes a null cycle. The net production of O_3 is observed when VOC are oxidized. The formation of O_3 is dependent upon its precursor (NO_x and VOC) and follows a relationship (Geddes et al., 2009). If the concentration of NO_X is lower the production of O_3 increases linearly with increase in NO_x. Conversely, if the concentration of NO_x is higher the production of O_3 will decrease. Therefore, for this case the production of O_3 is inversely proportional to NO_x level.

O_3 occurs naturally in the upper atmosphere. This O_3 referred to as good O_3 which blocks the transmission of harmful UV rays (WHO, 1979b). A small amount of O_3 is transferred from the upper into the lower layer of the atmosphere by atmospheric circulation.

The sources of ground level O_3 are not direct, because it is formed from NO_x and VOCs which are also termed as precursor compound of O_3. In order to figure out the sources of O_3 the emission inventory of VOC are listed separately in Fig 2-3. The NO_x inventory will be explained in section 2.1.4.

Pie Chart	Category	Percent
	Other Transportation	24%
	Printing/Surface Coating	19%
	General Solvent Use	18%
	Road Vehicles	14%
	Other Industrial Processes	14%
	Residential	8%
	Miscellaneous	3%
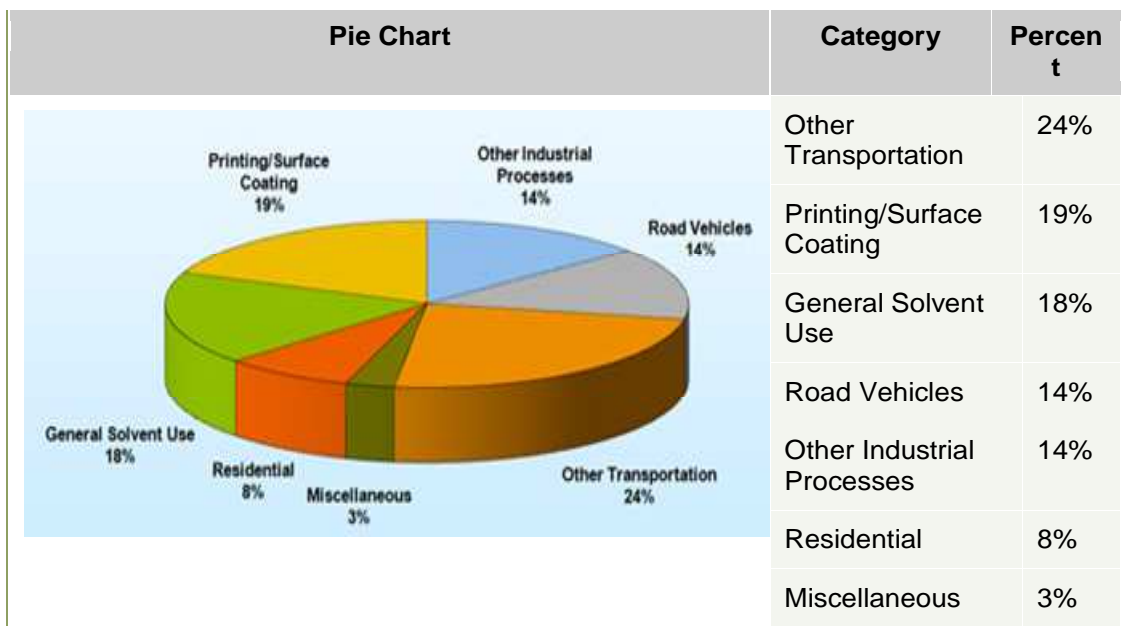
Fig 2-3: Ontario VOC Emissions by Sectors (MOE, 2007)

Overall, highest emissions of VOC were produced from the transportation sector (38%), printing and surface coating (19%) and general solvent use (18%) were found to be second and third largest source of VOC, respectively. In general, motor vehicle

exhaust, emissions from the industry and chemical solvents are considered to be major

sources of VOC from the transportation sector (38%).

Studies show that polluted air masses can travel from the urban and industrial

areas affecting the rural area in the direction of prevailing wind. This is also observed at

regional level, for instance in case of Ontario 50% of ground level O_3 is reported to come

from the United States (MOE, 2007). This suggests long-distance atmospheric transport

of pollutants. The seasonal and diurnal variation for O_3 in urban areas results from the

following factors: a) variation in O_3 precursor; b) variation in atmospheric transport and

dilution; c) atmospheric variables such as meteorological conditions.

The elevated level of O_3 is a significant concern for the living organism. Studies

indicate that higher level of O_3 can irritate the respiratory tract and eyes. The higher

exposure of O_3 may lead to chest tightness, coughing and wheezing among sensitive

people. Repeated exposure to O_3 pollution for several months may cause permanent lung

damage (USEPA, 2010a). These effects are more pronounced in case of children engaged

in outdoor activities. This is due to the reason that they have lower immunity system

besides, they acquire more air per pound of body weight than adults. Individuals with

pre-existing respiratory disorders, such as asthma and chronic obstructive pulmonary

disease (COPD), are also at greater risk. O_3 has been linked to increased hospital

admissions and premature death (MOE, 2007).

From the environmental perspective O_3 can have detrimental effects on plants and

ecosystems. It causes damages to the leaf of the plants making them more susceptible to

certain diseases, insects, other pollutants and harsh weather. It has been clearly

demonstrated that O_3 concentrations common in several areas of Canada are sufficient to

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reduce tree growth significantly. The damage done to the crops by O_3 has often yielded in economic losses to the country. For instance studies indicate that ground level O_3 was recently estimated to cost the province of Ontario several billions of dollars in economic losses due to human health impacts and an additional two hundred million dollars in agricultural crop damages each year (OMA, 2005).

2.1.4 Nitrogen Oxide (NO_x)

NO_x is a generic term which denotes various mixtures of nitrogen species. These species comprise of group of highly reactive gasses, which contains nitrogen and oxygen in varying amounts. The most important of these compounds with respect to air pollution are NO and NO_2 (Health Canada, 1998). NO is colorless and odorless gas which is slightly soluble in water. It can result from two processes: a) high temperature oxidation of molecular nitrogen from the combustion air; and b) oxidation of nitrogen present in certain fuel such as coal and heavy oil. The percentage of NO in the total emission of NO_x is 90-95% by volume depending upon sources and varies from one source to another. The predominant NO_x emitted by combustion processes is NO; NO_2 is produced in much smaller amounts. For instance the proportion of NO to NO_2 is 90:10 in case of fresh emission from vehicle. NO_2 on the other hand is a reddish brown gas with characteristic pungent odor. The photochemical reactions between O_3 and VOC convert NO to NO_2. The brown color of NO_2 causes discoloration and reduced visibility. NO_2 is corrosive and highly oxidizing in nature.

NO_x is produced by the natural processes and manmade activities. NO_x is produced naturally by the processes including lightening, volcanic eruptions and bacterial

action in the soil. The major anthropogenic source of NO_x is the combustion of fossil fuels occurring in the automobile and power plants. The quantities of NO_X produced by natural processes are greater in amount than the man-made activities (WHO, 1997). The total NO_x emissions in ON in the year 2006 are presented in Fig 2-4. NO_x emissions are generated in three major categories. They are: 1) transportation; 2) industrial processes; 3) miscellaneous. The transportation sector has been further classified into the category of road vehicles and other transportation. The *road vehicles* include the light, medium and heavy duty vehicles. On the other hand the *other transportation* includes railroad vehicles, air crafts, and ships on inland waterways. Cumulatively, transportation accounted for the highest NO_x emission of 68%. The other industrial processes and the industrial processes accounted for11% and 21% of emissions, respectively.

Pie Chart	Category	Percent
	Other Transportation	40%
	Road Vehicles	28%
	Other Industrial Processes	11%
	Utilities	8%
	Cement and Concrete	5%
	Miscellaneous	6%
	Smelters/Primary Metals	2%
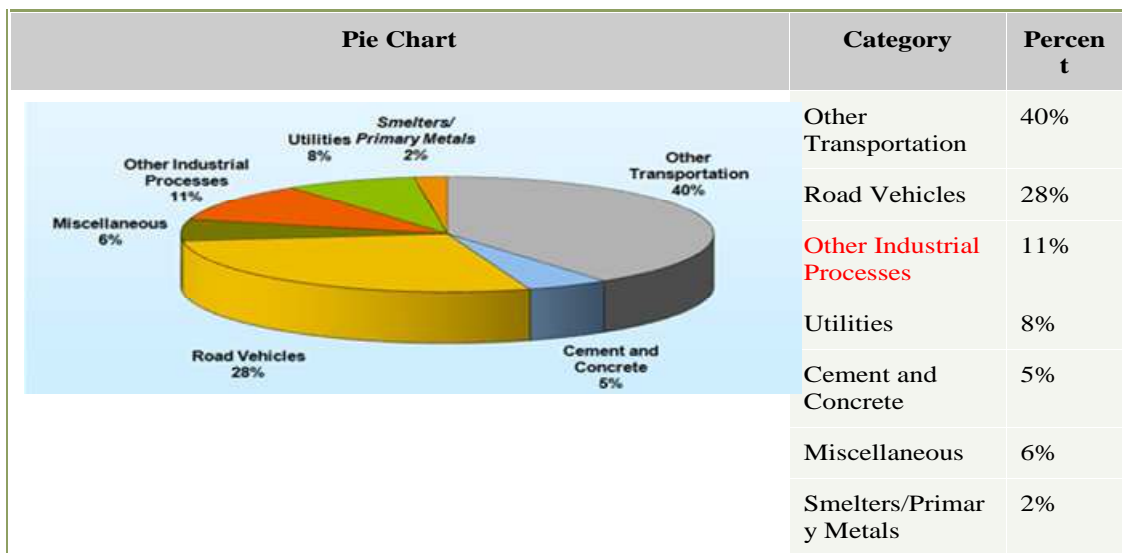
Fig 2-4: Ontario NO_x Emissions by Sectors (MOE, 2007)

The transport and dispersion of the various nitrogenous compounds is dependent on both meteorological and chemical parameters. Three phenomena of advection, diffusion and chemical transformation predominates to dictate the atmospheric residence time of pollutants. The atmospheric residence times are helpful in determining the geographic extent of transport of given species. The surface emissions are dispersed vertically and horizontally through the atmosphere by turbulent mixing processes. Turbulent mixing process is further dependent on the vertical temperature structure of the boundary layers and on the wind speed.

The vertical mixing of NO_x during the summer period follows a predictable diurnal cycle. This cycle is dependent to a fairly degree on the occurrence of inversion. Inversion normally develops during the night time and last till morning. Surface inversion restricts the vertical dispersion of pollutants, resulting in higher local concentrations at night. In the morning time the inversion breaks up which results in the vertical mixing and dispersing of pollutant at higher altitude. A study conducted by the NAPS (2004a) exhibits similar pattern of diurnal behavior for the NO_x. The peak concentrations of NO_x were observed in the morning hours, corresponding to the higher transportation activity. However, in the afternoon the concentration of NO_x decreased due to higher rate of photochemistry and turbulent mixing phenomena. At night time the concentration were found to be higher due to inversion.

NO_x consists of various derivative compounds such as NO_2, nitric acid, nitrous oxide, nitrates and NO. These compounds can cause various health and environmental related problems. Studies indicate that NO_2 has greater impact on human health than NO (Health Canada, 1998). There is a growing concern about NO_x emissions because of the

role they play in the formation of ground level O_3. In addition NO_2 transform chemically into nitric acid and when deposited contribute to the lake acidification (MOE, 2007). NO_X aggravates the existing heart diseases, leading to increased hospital admission and premature death (USEPA, 2010c). NO_x are smaller in size and can penetrate deeply into the lungs which can cause various respiratory diseases such as asthma, emphysema, and bronchitis.

Both NO and NO_2 contribute to the formation of acidic precipitation, which affects the growth of the forests. Nitrate particles can reduce the visibility by blocking the transmission of light. It also causes the corrosion of metals, fading of fabric dyes and degradation of textile fibers. People with asthma and chronic obstructive pulmonary disease (COPD), children, and the elderly may be at increased risks of suffering the adverse health effects of NO_x (Monette et al., 2004).

2.1.5 Particulate Matter

PM is generally referred to as the mixture of solid particles in the air. They are characterized in accordance with their size which ranges from 0.1 microns (µm) to over 100 microns. PM is either described as Total Suspended Particulate (TSP) or Suspended Particulate (SP) according to the sampling method. Particles vary in sizes, shapes and composition. PM2.5 consists of particles that are 2.5 microns in aerodynamic diameter and less. They have the ability to penetrate deep into the respiratory tract.

PM can be emitted directly into the atmosphere (primary particles) or they can be formulated in the atmosphere through chemical and physical transformations (secondary particles). The direct emission can occur from soot, metals, soil dust and fugitive

emissions from the grinding and crushing of material such as stones. On the other hand

precursor gasses involved in the formation of secondary particles include SO_2, NO_X,

VOCs and ammonia. PM is unique among atmospheric constituents in that it is not

defined on the basis of its chemical composition (CCME, 2007). It may include different

chemical species such as elemental carbon, organic carbon compounds, and oxides of

silicon, aluminum and iron.. The PM2.5 emissions in ON in the year 2006 are presented

in Fig 2-5.

Pie Chart		Category	Percent
		Residential	34%
		Transportation	24%
		Other Industrial Processes	21%
		Smelters/Primary Metals	12%
		Miscellaneous	6%
		Pulp and Paper	3%
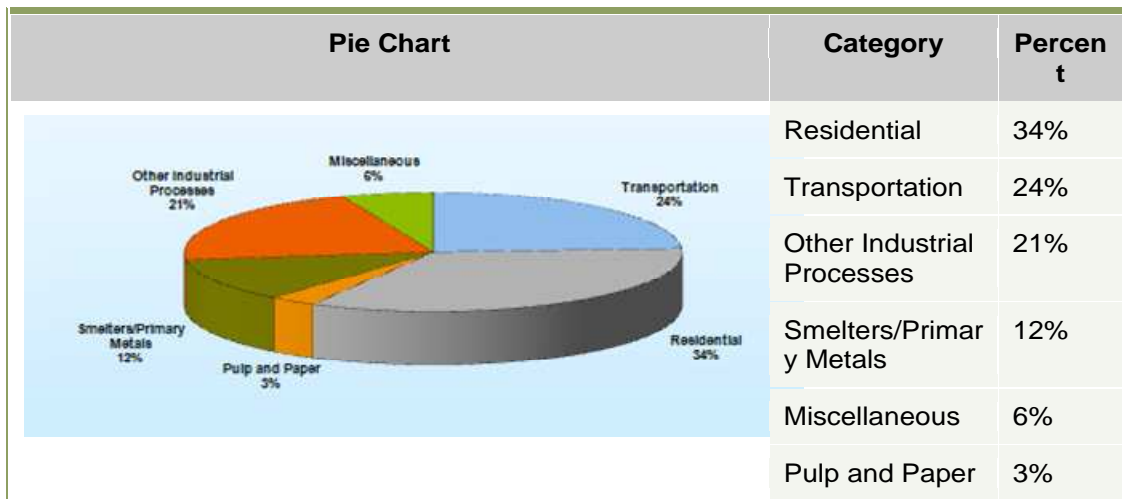
Fig 2-5: Ontario PM2.5 Emissions by Sectors (MOE, 2007)

High level of exposure to PM is linked with hospital admissions and can cause

serious health effects. PMs due to their small size can penetrate into the respiratory tract

causing pulmonary diseases. People who are already suffering from asthma,

cardiovascular or lung diseases are susceptible to the exposure of PM. Short term

exposure of PM 2.5 results into eye, nose and throat irritation. PM may cause a wide

spectrum of immunological disorders, and can aggravate lung infections, possibly by

reducing the body's ability to fight infection. Study indicates that prolonged exposure to PM resulted in chronic cough and bronchitis and in respiratory-related activity restrictions, which has lead to increased numbers of lost work days and school absences (Environment Canada & Health Canada, 1999).

In the case of plants the small PM enters the surface of the leaves and block stomata. This accumulation further reduces the light transmission thereby impeding the process of photosynthesis. Indirect effects include disturbances of soil pH and ionic composition; nutrient imbalances, through particle deposition to soils; and reduced light intensity due to particle loads in air (USEPA, 2011).

The accumulations of PM have also an adverse effect on the non-living organism. For instance the deposition of PM on the surfaces of metal, wood and painted surfaces have resulted in the phenomena of soiling and discoloration. It also causes damages to structures including corrosion on metal surfaces and paint. In addition the particles in the air absorb and scatter the light thereby reducing the visibility. Visibility is regarded as one of the most readily perceived indicators of poor air quality by the public (Environment Canada & Health Canada, 1999).

2.2 Monitoring Stations and Instrumentations

In order to ensure safety of public health and to maintain the quality of the environment, air quality monitoring networks are established at different places. These monitoring networks consist of monitoring stations that are scattered around various localities. These localities may vary in land use such as urban, rural or commercial. The basic purpose of establishing such network is to inform the public about the state of air

quality at different places. At the same time, this information is used by policy maker and scientist to devise new policy and track changes in air pollutants.

The monitoring networks in Canada operate at different levels of interest, including global, regional and national. Some important network in this regard are worth mentioning (EC, 2011c), such as: 1) Global Atmospheric Passive Sampling (GAPS) operating at global level; 2) Canadian Aerosal Baseline Measurement (CABM) and Integrated Atmospheric Deposition Network (IADN) operating at regional level; 3) The Canadian Air and Precipitation Monitoring Network (CAPMoN) and National Air Pollution Surveillance(NAPS) operating at national level. An interesting feature of these networks is that they measure different set of pollutants. For instance, both CAPMoN and NAPS operates at national level, but only CAPMoN network is used to measure mercury

At national level, NAPS constitute an important network consisting of monitoring stations scattered around different provinces of Canada. It was established in 1970 by the joint effort of government bodies that operates at federal, provincial, territorial and regional levels. The basic purpose and goal behind its existence was to measure the state of air quality in different cities of Canada. In the year 2007, NAPS and its ancillary stations were found to be 319 in number. These stations were operating in 216 communities in Canada and were equipped with 850 continuous monitors (NAPS, 2008). Initially NAPS limited itself to the continuous measurement of criteria pollutant which includes SO_2, CO, NO_2, ground-level O_3, and TSP. Later on in the year 1984, this was supplemented by inclusion of additional pollutants, PM and VOC, which are of primary health concern.

Some important objectives of NAPS include: a) determining nature and concentration level of pollutants; b) assessing the long term trend of pollutants; c) providing data for scientific research; d) assisting in development of air quality objectives and criteria; e) finding the occurrence of new pollutant in the ambient air; f) supporting air quality prediction and forecasting (NAPS, 2004a).

NAPS network is coordinated by different agencies that operate at provincial, territorial and regional level. For instance, in case of Ontario the Ministry of Environment (MOE) is responsible for overseeing the monitoring stations located at different places. The MOE has an extensive network of air monitoring stations. These stations are situated in selected cities across the province. According to a study conducted in 2009, the network was found to be comprised of 40 sites and 138 continuous monitoring instruments. These instruments are monitored and administered on daily basis by the staff of Environmental Monitoring Reporting Branch. Daily automatic internal zero and span checks are performed for checking the instrument precision. A telemetry system is employed in order to review span control charts. The ambient dataset further undergo through the process of quality assurance and quality control (QA/QC). This is done in order to ensure the accuracy, completeness and precision in data, and to figure out any anomalies in the data (NAPS, 2004b). Agencies participating in the NAPS network are listed in Table 2-1.

Table 2-1: Agencies Participating in the NAPS Network (EC, 2011c)

Provinces	Department	Website
Newfoundland and Labrador	Environment &Labour	www.env.gov.nl.ca/env
Prince Edward Island	Aquaculture and Environment	www.gov.pe.ca
Nova Scotia	Environment &Labour	www.gov.ns.ca/nse
New Brunswick	Environment and Local Government	www.gnb.ca
Québec	Ministère de l'Environnement	www.mddep.gouv.qc.ca
Ville de Montréal	Direction de l'environnement	www.ville.montreal.qc.ca
Ontario	Ontario Ministry of Environment	www.ene.gov.on.ca/en/air
Saskatchewan	Saskatchewan Environment	www.gov.sk.ca
Alberta	Ministry of Water, Land and Air Protection	www.environment.alberta.ca
British Columbia	British Columbia Ministry of Environment	www.env.gov.bc.ca/air
Metro Vancouver	Policy and Planning Department	www.metrovancouver.org
Government of the Northwest Territories	Environmental Protection Services	www.enr.gov.nt.ca

Since NAPS is coordinated by various agencies, therefore every agency has its own QA/QC program. These programs are further augmented with QA/QC conducted by the federal government. The purpose behind setting QA/QC by federal authority is to set a limit of guidelines which should be followed by ancillary agencies. The QA/QC by federal authority lists the minimum requirement which should be considered. However, the network agencies may have their own requirement operating in jurisdiction. The elements of QA/QC include a wide range of activities such as selection of site, sampling system requirement, site and analyzer requirement, site and analyzer operation, instrument calibration and reference standards, inter-laboratory testing and performance audit program, validation of data, training and technical documentation. The site selection

is done with the coordination of networking agencies. Several key criteria are considered including distribution, location, separation and spatial scale of representativeness (NAPS, 2004b).

The data collected from the NAPS are validated using manual and automated procedures. This procedure is also executed for NAPS agencies. However, the data from cooperating agencies are converted to NAPS compatible format. The data are checked to ensure that it conforms to the standard of United States Environmental Protection Agency (USEPA). The instrumentations employed in the NAPS network and their methodologies are listed in Table 2-2.

Table 2-2: Instrumentations used in the NAPS Monitoring Network (NAPS, 2004a)

Pollutant	Measurement Method	Monitor Type	Operating Range	Operating Temperature	Minimum Detection Limit
CO	Infrared Gas Filter Correlation	Continuous Automated	50 ppm	15 - 35 °C	0.1 ppm
SO_2	UV Fluorescence	Continuous Automated	1.0 ppm or 0.5 ppm	15 - 35 °C	0.002 ppm
NO_X	Chemiluminescence	Continuous Automated	1.0 ppm or 0.5 ppm	15 - 35 °C	0.002 ppm
O_3	UV Absorption	Continuous Automated	1.0 ppm or 0.5 ppm	15 - 35 °C	0.002 ppm
PM10, PM2.5	Beta radiation attenuation Virtual Impactors; gravimetric/filter; microbalance/filter.	Continuous Automated and manual gravimetric	Agency specific as per operators' procedures		1.0 $\mu g/m^3$

2.3 Ambient Air Quality Criteria

National ambient air quality standards are prepared under the context of Canadian Environmental Protection Act (CEPA). This act enabled the federal government to assess the air quality by framing a set of standard referred as National Ambient Air Quality objectives (NAAQOs). The quality of air is assessed by classifying them into three levels namely: 1) maximum acceptable level; 2) maximum desirable level; and 3) maximum tolerable level. The maximum acceptable level is defined as a long term goal for air quality. It further provides basis for an anti-degradation policy and for the pollution control technology. The maximum desirable level is prescribed with the intention to protect the natural life and the ecosystem. Finally, the maximum tolerable level denotes time based concentration beyond which causes damage to general population. Therefore, it requires prompt action and effective control measures (HC, 2010a). Table 2-3 provides NAAQS for selected pollutants in Canada.

Table 2-3: National Ambient Air Quality Objectives and Guidelines in Canada (HC, 2010a)

Pollutant	Averaging Time	Maximum Desirable Level	Maximum Acceptable Level	Maximum Tolerable Level
SO_2	annual 24 hours 1 hour	11 ppb 57 ppb 172 ppb	23 ppb 115 ppb 334 ppb	--- 306 ppb ---
TSP	annual 24 hours	60 µg/m3 ---	70 µg/m3 120 µg/m3	--- 400 µg/m3
CO	8 hours 1 hour	5 ppm 13 ppm	13 ppm 31 ppm	17 ppm ---
NO_2	annual 24 hours 1 hour	32 ppb --- ---	53 ppb 106 ppb 213 ppb	--- 160 ppb 532 ppb
O_3	annual 24 hours 1 hour	--- 15 ppb 51 ppb	15 ppb 25 ppb 82 ppb	--- --- 153 ppb

A parallel air quality standard is implemented at provincial level in Canada. This is referred as Canada Wide Standard (CCME, 2007). It provides an alternative regulatory tool for the management of environmental issue. The standards are set for the two pollutants of key interest, O_3 and PM are listed in Table 2-4.

Table 2-4: Canada Wide Environmental Standard (HC, 2010b)

Pollutant	Averaging	Standard	Year to be achieved	Comments
PM2.5	24 hours	30 µg/m^3	2010	Achievement based on the 98th percentile measurement annually, averaged over 3
O_3	8 hours	65 ppb	2010	Achievement based on the 4th highest measurement annually, averaged over 3 consecutive

2.4 Trend Analysis

Trend analysis refers to techniques for extracting an underlying pattern of behaviour in a time series. This is done by collecting, analyzing and finding the patterns in the data. The trend analysis can be used to predict the future. A real trend is defined as general increase or decrease in observed value of some variables (USEPA, 1989). From the statistical point of view, the goal of the trend detection is to determine the general increase or decrease in observed values of air quality variables. Trends fall into the major category of monotonic and step trend (Gilbert, 1987).

The detection and estimation of trend is important for environmental studies and it constitutes an integral part of monitoring agencies. The basic purpose for examining the trend is to look for increase or decrease in environmental pollution. This environmental pollution can results from various activities such as: a) growth in the size or population of the city; b) in the transportation activity referred to as mobile sources of pollution; c) opening up or close down of new industrial or hazardous waste storage facilities; d) trans-boundary influences. Trend detection helps to determine the change in the pollution levels, following initiation of pollution control program (Gilbert, 1987).

It is important to differentiate between the trend and the sequence of measurement which somehow appear like trend. Most often what appears to be a trend is just a random sequence of measurements. For this reason, the different types of trend and the random sequences have been classified. Some of the major classification includes; a) random; b) cycle + random; c) trend + random; d) trend + cycle + random; e) trend + non-random; f) trend + non-random.

Several factors affect the detection and estimation of trend in pollutant data. These factors are mostly related with the characteristics of pollutant data. These factors are; 1) changes in the procedure; 2) seasonality; 3) correlated data; 4) correction for flow (Gilbert, 1987). The first one is related with the change in the sampling or analytic procedure which can occur due to long-term period of study. These changes may cause shifting in the values of the readings. This problem can be avoided to some extent by the use of duplicate sample. In this way a comparison can be made by pairing old and new sampling methods which eliminate the inconsistencies. The major assumption employed in this technique is that the concentration of pollutant does not change in the sample. **Seasonal effect or cycles** present in the data make it difficult to detect long term trend. This problem is treated either by removing the seasonality before application of statistical test or by applying a test which is unaffected by seasonality. An example of one such test is the seasonal Kendall test. Finally, the ambient air quality is adjusted with the meteorological data for the **correction purpose**.

Three major methods are employed most commonly for the detection of trend. They include: 1) Linear regression method, 2) Mandkendell test detection method, and 3) Seasonal Kendel detection method (USEPA, 2006). These methods have been discussed one by one below.

2.4.1 Linear Regression Method

Linear regression method is the oldest employed method for assessing linear trends. The equation of simple linear regression line is given by equation (2.1).

$$Y = a + bX \qquad\qquad (2.1)$$

where a is the *y intercept* of the line, b is the coefficient which determines whether the line is increasing (b>0), decreasing (b<0), or no change (b=0), it is also known as the **slope** of the line. The term Y and X are termed as dependent and independent variables (Mendenhall, 2008).

In order to fit the regression line the common method of least square is used. In this method the best fit line is found by minimizing the sum of the squared differences between the data points and the line itself. In order to address the important question whether the trend exists or not, the linear relationship between X and Y is determined by conducting a test. This is done by testing the null hypothesis: Ho = Trend does not exist, against the alternative hypothesis: Ha = Trend exist. Whereas the null hypothesis is defined generally as the hypothesis researcher wishes to support, and the alternative hypothesis is contradiction of the null hypothesis.

The *p*-value is used to measure the statistical significance. The *p*-value or the observed significance level of a statistical test is the smallest value of α for which Ho can be rejected. It is the actual risk of committing a Type I error, if Ho is rejected based on the observed value of the test statistics. The *p*-value measures the strength of evidence against Ho. If the *p*-value is less than or equal to a pre-assigned significance level α, then the null hypothesis can be rejected and one can report that the trend is statistically significant at level α. Type I and Type II are the two kinds of error related with the test of hypothesis. The Type I error is defined as the error of rejecting the null hypothesis when it is true. The probability of making a Type I error is denoted by the symbol α. On the other hand Type II error is defined as the error of accepting the null hypothesis when it is

false and the alternative hypothesis is true. The probability of making a Type II error is denoted by the symbol β. They are further listed in Table 2-5.

Table 2-5: Type I and Type II errors

Null Hypothesis		
Decision	True	False
Reject Ho	Type I Error	Correct Decision
Accept Ho	Correct Decision	Type II Error

It is however important to establish the significance level α in order to accept or reject Ho. The common used sliding scale for the smallest value of p is listed below (Mendenhall, 2008)

- If the *p*-value is less than 0.01, Ho is rejected. The results are highly significant.

- If the p-value is between 0.01 and 0.05, Ho is rejected. The results are statistically significant.

- If the *p*-value is between 0.05 and 0.10, Ho is sometimes not rejected. The results are only tending towards statistical significant.

- If the *p*-value is greater than 0.10, Ho is not rejected. The results are not statistically significant.

The upward or downward trend is measured by the application of linear regression slope. A near zero values of regression slope supports the null hypothesis (there is no trend). A positive or negative value of slope indicates an upward or a downward trend respectively.

Linear regression analysis has several limitations such as: 1) it is based on the assumption that the relationship between two variables is linear; 2) it is sensitive to outlier; 3) it presents difficulty in handling observational data below the detection limit. It is for this reason that before performing regression analysis the data must be checked for cyclical patterns and outliers. Besides, the data should be above the detection limit (USEPA, 2006). In this study the linear regression method was used.

2.4.2 Man Kendall Test

The Man-Kendall test is one of the non-parametric tests for the detection of trend. It uses the relative magnitude of data rather than their measured values. Man-Kendall test (MK) is preferred sometimes due to the following reasons; 1) missing values are allowed, 2) data need not conform to any particular distribution; 3) the data below the detection can also be used in this test (USEPA, 2006).

The Man Kendell test take into account the S test and Z test. In the case of S test the value of S is computed by finding the difference between slope (USEPA , 2006). A positive S value indicates an increasing or upward trend in the data. A negative value in S indicates the decreasing trend. The null hypothesis: Ho= no trend.   It is important to note that for the time series with n <10 values the S test are used. The normal approximation Z is used when there are 10 values or more.

2.4.3 Seasonal Kendell Test

Seasonal Kendell (SK) test is useful for a set of data that contains component of seasonality. It is an extension of MK test which was proposed initially by Hirsh (Gilbert,

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1987) for use with 12 months. The important feature of this test is that it can be used with data set having missing, tied or below detection values. Besides, SK test doesn't require the normal distribution of data.

This test is conducted by calculating the test statistics S and Variance (VAR) from Man Kendell test. This is done separately for each month (season) with data collected over years. The null hypothesis of no trend is tested against alternative hypothesis of either upward or downward trend. This is done by computing the value of Z statistics. Finally, the Z statistic is computed to test the significance of trend.

2.4.4 Summary of some previous trend studies

Various studies have been conducted in the past to detect the trend for air pollutants. The length of the period for which the trend is to be analyzed constitutes an important part of trend analysis. Weatherhead, et al. (1998) suggested that the duration of collected data for trend should range from a decade to several decades. Data which is smaller than an interval of decade will not represent the long term trend.

Similarly, Blanchard (1999) suggested three factors for the utility of trend analysis. These include: 1) the length of the monitoring data; 2) meteorological driven variation in ambient pollutant concentration; 3) magnitude of pollutant emission and reduction.

Different statistical techniques are employed by researchers for the detection of trend. These techniques depend on the nature of the data. For instance, Hess et al. (2001) suggested six types of statistical procedure for the detection of trend. These methods

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range from Spearman partial rank correlation test, Seasonal Kendall test, to the generalized least square method.

Anttilla and Tuovinen (1997) employed four different methods for the detection of trend in the concentration time series. These methods are: 1) Generalized Least Square (GLS) with classical decomposition and autoregressive moving average (ARMA); 2) Ordinary Least Square (OLS) regression applied to de-seasonal monthly data; 3) OLS regression applied to annual data; 4) Non parametric Sen's slope estimation method with the nonparametric Mandkendell significance test, applied to annual data. The findings of the study suggest that handling of the serial correlation present in the time series with the ARMA processes improved the analysis of monthly values.

One of the most recent contributions in air quality trend analysis is made by Geddes et al. (2009). Simple linear regression method was used to calculate the long term trend using annual data collected in urban and rural sites of Toronto, Ontario.

2.5 Pollution Rose

A pollution rose is a graphical presentation of concentrations associated with each wind direction on a circular or polar plot using for example 10° angular resolution. The orientation of the wind sectors is further examined to figure out the predominant directions. The inherent assumption used is that the wind speed and direction remain constant from the source to the monitor site and the plot is indicative of the mean source strength relative to the overall source strength by wind direction. The pollution rose plots can be used to find the wind directional concentration of the pollutant. This further helps in identifying the direction associated with higher or lower concentrations. However,

pollutant rose alone cannot determine whether the upwind source is located at a short distance or far away from the monitoring site.

Pollution rose can be generated in two ways (Vallero, 2008). This can be done either by plotting the average concentration for each direction of the wind (simple pollutant rose) or the frequency of concentrations above some particular concentrations. In this study percentile pollution roses are used. The percentile pollutant rose is more useful in identifying the directions associated with frequent higher or lower concentrations. A higher frequency of high or low concentrations shows that the areas associated with that particular direction had a high impact on the receptor concentration by either having major sources or being relatively clean.

Pollution rose has been used in a number of studies to find the directional concentration and major source regions of the pollutant of interest. In a study of atmospheric mercury (Xu and Akhtar, 2009) the percentile pollution rose for Total gaseous Mercury (TGM) showed the higher concentrations of Hg (i.e. 75th percentile and 95th percentile) to be in the direction of north east and south west of Windsor ON. These concentrations were found to be associated with the direction of the prevailing wind.

Air monitoring data often have different time resolutions from 1-60 minutes to daily. A computational scheme is proposed by Coseman et al. (2008) using daily concentrations to produce high quality pollutant rose. The results show that those pollutant roses are comparable to pollutant roses made with 30-minutes concentrations.

An improved pollution rose was used in the study by (Lau et al., 2005) called circular pollution wind map (CPWM). In CPWM the frequency of wind were marked with contour lines. The contour lines were divided into 95%, 75%, 50% and 25% of the

measured wind speed and direction pairs. The wind direction was given by an angle with 10 degree resolution. The pollution rose map suggested regional transport instead of local emissions as the dominant sources contributing to high SO2 levels observed in the town of Long Yuong (Hong Kong).

CHAPTER III

DESIGN AND METHODOLOGY

3.1 Study Sites and Locations

Three criteria were used for the selection of sites. They are: 1) availability of data; 2) geographical location of the provinces; 3) site classification. The first criterion constitutes an important factor in the selection of sites. The sites showing maximum amount of data in the interval of year 1998-2007 were shortlisted. Thereafter, the sites were arranged according to the provinces namely: a) Ontario; b) Alberta; c) Quebec; d) British; Columbia; e) Nova Scotia. The data availability for all the stations in those provinces is shown in Tables A-1, A-2, A-3 and A-4. Finally, the sites were examined with the help of Google Earth and classified into urban, rural and residential localities. This classification was further cross checked with the default classification by NAPS (NAPS, 2010b). Stat Canada (1999) defines an urban area as "Areas have minimum population concentrations of 1,000 and a population density of at least 400 per square kilometer ". A total number of 11 monitoring stations were selected from eight cities in five provinces. Two stations were selected from the city of Windsor and Toronto. In the city of Montreal three stations were selected. This was done keeping into account the metropolitan aspect, the investigation of consistency within a city, and the importance of these cities. The monitoring stations located within the eight cities are shown in Fig 3-1.
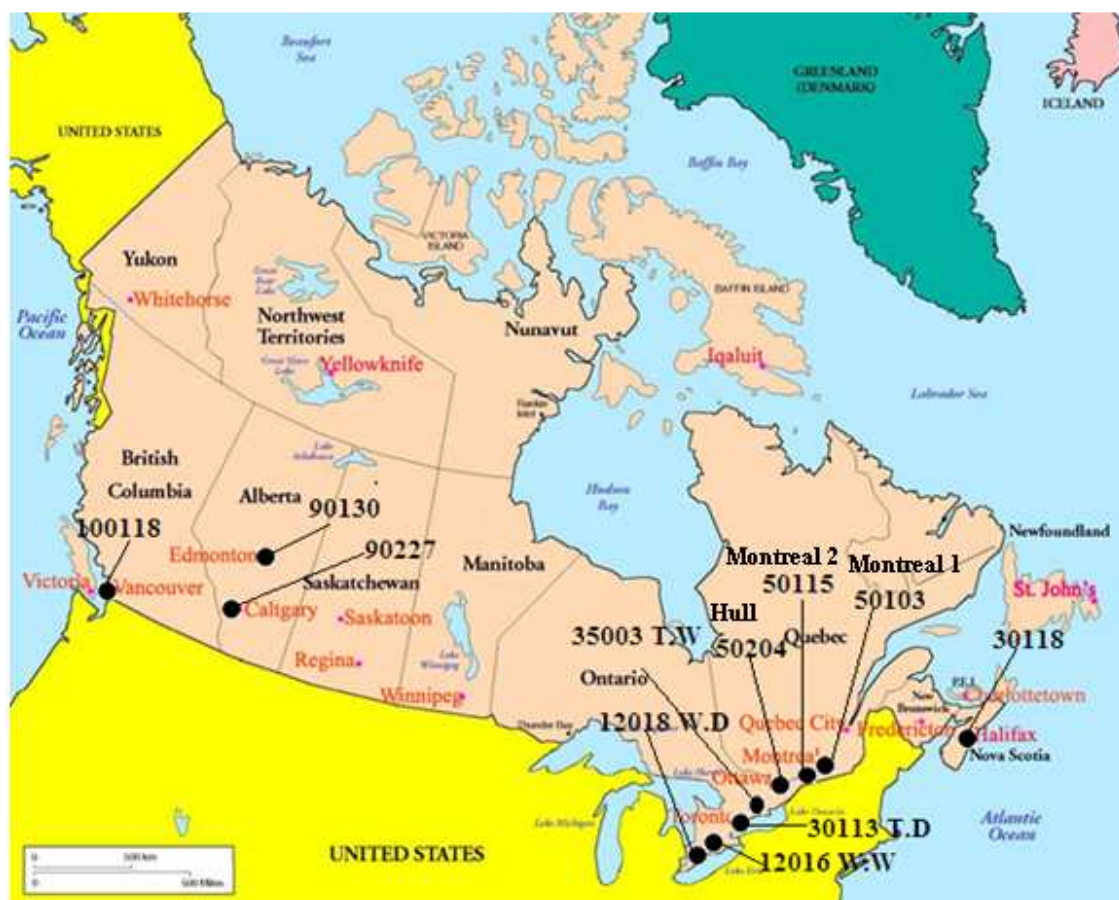
Fig 3-1: Map Showing the Locations of Selected Sites across Canada

Primarily, the sites selected were urban in nature. However, the sites located in
the city of Vancouver and Halifax was found to be residential and commercial
respectively. The station description and the parameters of the selected sites are listed in
Table 3-1. A description of the site in each city is discussed one by one below.

Table 3-1: Parameters of Selected Sites

Province	ID	Station Name	City	Network	Latitude (degree)	Longitude (degree)	Elevation above sea level (m)	Height (m)	Type
Ontario	12008	Windsor Downtown	Windsor	MOE	42.315778	-83.04366	176	8	U
	12016	Windsor West	Windsor	MOE	42.292889	-83.073139	180	4	U
	31103	Toronto Downtown	Toronto	MOE	43.662972	-79.388111	105	10	U
	35003	Toronto West	Toronto	MOE	43.709444	-79.5435	141	8	U
Alberta	90130	Edmonton Central	Edmonton	NAPS	53.54449	-113.49893	663	8.5	U
	90227	Calgary Central	Calgary	NAPS	51.04778	-114.07556	104	6	U
Quebec	50103	Montreal 1	Montreal	NAPS	45.64125	-73.499363	19	4	U
	50115	Montreal 2	Montreal	NAPS	45.50083	-73.57528	56	4	U
	50204	Hull	Gatineau	NAPS	45.435718	-75.72328	62	16	U
British Columbia	100118	Vancouver Kitsilano	Vancouver	NAPS	49.26167	-123.16333	39	4	R
Nova Scotia	30118	Roy Building	Halifax	NAPS	44.646323	-63.573381	18	9	C

U: Urban
C: Commercial
R: Residential

- Two stations were selected from the city of Windsor: Windsor Downtown (WD) (12008) and Windsor West (WW) (12016). These two stations were found to be urban in nature as shown in Fig B-1. Ambassador Bridge, the busiest international border crossing in North America, was located at a distance of 1.5 km from the sites. In the extreme south are industrial facilities.

- The sites selected from the city of Toronto include Toronto Downtown (TD) (31103) and Toronto West (TW) (35003).The two sites are classified as urban as shown in Fig B-2. There are no major point sources within 15 km of either site. The harbour area is situated near the TD at a distance of approximately 3 km. The surrounding of TW site indicates that it is bounded by major road such as MacDonald Cartier Freeway 401.

- Only one site (090130) having max amount of data was selected from the city of Edmonton. This site is located in the downtown part of the city and is surrounded by high rise buildings and parking lots. The urban location of the site is further presented in Fig B-3.

- The site located in the city of Calgary (090227) was classified as an urban site as shown in Fig B-3. The site surrounding includes a major arterial road at a distance of 0.5 km and a highway (Queen Elizabeth) at a distance of approximately 3 km.

- Two sites were selected from the city of Montreal. They are Montreal 1 (050103) and Montreal 2 (050115). Montreal 1 is located close to the petro and industrial facilities. It is bounded on the south west by oil refineries. On the other hand Montreal 2 is situated in the urban core of the city and is located near some minor and major roads. The two sites are shown in Fig B-4.

- One site (050204) was selected from the city of Hull. This station was found to be urban in nature as shown in Fig B-5. Two major bridges (Alexandria and MacDonald) were located close to the station in the direction of south east. They were situated at a distance of 1.3 and 1.1 km respectively.

- Station 030118 in the city of Halifax was found to be commercial in nature as shown in Fig B-6. This station was surrounded by many industrial facilities. Some key feature of the surrounding includes: a) Halifax harbour at a distance; b) Mackay and Murray Bridges at a distance of 4.2 and 3.0 km, respectively.

- In the city of Vancouver only one station (100118) was selected as shown in Fig B-7. The surroundings of the station indicate an urban locality. This station was found close to the two major bridges, Gatineau and Alexandria. They were located at a distance of 1.3 and 1.1 km respectively from the monitoring station.

3.2 Data Collection

The data used in this study can be broadly classified into two types: pollutant concentration and weather data. The hourly concentration data were downloaded from the NAPS website (NAPS, 2010a) and the MOE Air quality Ontario website (MOE, 2009). The pollutants were selected due to negative health effect related to them. The MOE data from the website was available from a period of 2000-2007. In order to obtain the data from 1998-1999 a request was made to MOE authorities. The raw data from NAPS and MOE are listed together in Table 3-2.

Table 3-2: Raw Data Availability NAPS and MOE (1998-2007)

ID	CO	SO$_2$	NO	NO$_x$	NO$_2$	PM10	PM2.5	O$_3$
12008	1998-2007[a]	1998-2007	1998-2007	1998-2007	1998-2007	N.D	2003-2007	1998-2007
12016	N.D	1998-2007	2000-2007	2000-2007	2000-2007	N.D	2003-2007	2000-2007
31103	1998-2007[d]	1998-2007[c]	1998-2007	1998-2007	1998-2007	N.D	2003-2007	1998-2007
35003	1998-2007[d]	1998-2007[f]	1998-2007	1998-2007	1998-2007	N.D	2003-2007	1998-2007
090130	1998-2007	N.D	1998-2007	1998-2008	1998-2007	N.D	N.D	1998-2007
090227	1998-2007	N.D	N.D	1998-2007	1998-2007	1998-2007	N.D	1998-2007
050103	1998-2007	1998-2007	1998-2007	N.D	1998-2007	N.D	N.D	1998-2007
050115	1998-2007	1998-2007[e]	1998-2007	N.D	1998-2007	N.D	N.D	1998-2002
050204	1998-2007	1998-2007	1998-2007	N.D	1998-2007	N.D	N.D	1998-2007
030118	1998-2007[b]	1998-2007	1998-2007[a]	1998-2007[a]	1998-2007[a]	N.D	N.D	1998-2007[b]
100118	1998-2007	1998-2007	2000-2001[b]	1998-2007	1998-2007	1998-2007	N.D	1998-2007

N.D: No Data
Missing Data
a:2003   d:2000-2002
b:1999   e:2004-2005
c:1999-2002   f:2002

Meteorological data were downloaded from the National Climate Data and Information Archive operated by Environment Canada (EC, 2010). The weather file for a single meteorological station was downloaded on monthly basis from 1998-2007. These hourly weather data files were arranged in ascending order from 1998-2007. The meteorological stations nearest to the air quality monitoring stations were investigated by using the Google Earth. Overall the monitoring and meteorological stations were found to be in the same city. However, for the Hull station (050204), the nearest meteorological

station was found to be in the city of Ottawa. The distance between the monitoring and meteorological stations were further calculated as shown in Table 3-3.

Table 3-3: Meteorological Stations Locations

MONITORING STATIONS				NEAREST METEREOLOGICAL STATION		Distance (km)
ID	Station Location	Latitude	Longitude	WMO-ID	MET Station Location	
12008	WINDSOR, ON	42.315778	-83.043667	71538	WINDSOR A	7.94
12016	WINDSOR, ON	42.292889	-83.073139	71538	WINDSOR A	9.42
31103	TORONTO, ON	43.662972	-79.388111	71624	TORONTO LESTER B. PEARSON INT'L A	19.55
35003	TORONTO, ON	43.709444	-79.5435	71624	TORONTO LESTER B. PEARSON INT'L A	7.69
090130	EDMONTON, AL	53.54449	-113.49893	71123	EDMONTON INT'L A	25.53
090227	CALGARY, AL	51.04778	-114.07556	71877	CALGARY INT'L A	7.93
050103	MONTRÉAL, QC	45.64125	-73.499363	71627	MONTREAL INT'L A	27.27
050115	MONTRÉAL, QC	45.50083	-73.57528	71627	MONTREAL INT'L A	14.05
050204	HULL, QC	45.435718	-75.72328	71628	OTTAWA MACDONALD-CARTIER INT'L A	13.52
030118	HALIFAX, NS	44.646323	-63.573381	71395	HALIFAX STANFIELD INT'L A	26.32
100118	VANCOUVER, BC	49.26167	-123.16333	71892	VANCOUVER INT'L A	6.96

3.3 Data Pre-Processing

The raw data files were arranged one by one according to the station, pollutant and year. The data files were then pre-processed on a yearly basis. The pre-processing of the data was done in three steps namely: 1) missing data points; 2) invalid data points; 3) missing days. The first step requires searching the data for missing points, which are flagged as 999 in the raw data. The presence of missing data in the dataset can be caused by various factors including the shutdown or malfunctioning of the instrument. Secondly, the data was searched for the invalid data points flagged as:-999. The invalid data points appear due to unusual high concentrations in recording (MOE, 2008). Finally, the time intervals for the missing days were identified. The frequency of invalid data point for SO_2

and CO, O_3 and PM, NO_2 and NO_x and NO are reported in Tables C-1, C-2, C-3 and C-4, respectively.

A cutoff point of 40% was selected in case of missing, invalid and zero data points combined. In cases where a pollutant showing valid data percentage value less than 60% (i.e. less than 5250 hours) during a year, that pollutant in that year was excluded from further analysis, as shown in Table C-5. The reduction of data resulted in a new dataset for all the stations, as listed in Table 3-4.

Table 3-4: Data availability after Pre-processing

ID	CO	SO_2	NO	NO_x	NO_2	PM10	PM2.5	O_3
12008	1998-2007[a]	1998-2007	1998-2007[a]	1998-2007[a]	1998-2007[a]	**N.D**	2003-2007	1998-2007
12016	**N.D**	2003-2007	2001-2007	2001-2007	2001-2007	**N.D**	2003-2007	2000-2007
31103	1998-2007[c]	1998-2007[c]	1998-2007	1998-2007	1998-2007	**N.D**	2003-2007	1998-2007
35003	1998-2007[d]	1998-2006[f]	1998-2007	1998-2007	1998-2007	**N.D**	2003-2007	1998-2007
090130	1998-2008	**N.D**	1998-2007	1998-2008	1998-2007	**N.D**	**N.D**	1998-2007
090227	1998-2007	**N.D**	**N.D**	1998-2007	1998-2007	1998-2007	**N.D**	1998-2007
050103	1998-2007	1998-2007	1998-2007	**N.D**	1998-2007	**N.D**	**N.D**	1998-2007
050115	1998-2008	1998-2008[e]	1998-2007	**N.D**	1998-2007	**N.D**	**N.D**	1998-2002
050204	1998-2007	1998-2007	1998-2007	**N.D**	1998-2007	**N.D**	**2003**	1998-2007
030118	1998-2007[h]	1998-2006	1998-2007[g]	1998-2007[i]	1998-2007[g]	**N.D**	**N.D**	1998-2006[b]
100118	1998-2007	1998-2007	2000-2001[b]	1998-2007	1998-2007	1998-2007	**N.D**	1998-2007

N.D: No Data
Missing Years

a-2003	d-2000-2002	g-1999,2003,2004
b-1999	e-2004-2005	h-1999,2006
c-1999-2002	f-2002	i-1999,2002

3.4 Data Processing and Annual Means

Data processing was performed in five steps; 1) rearrangement of data files in Excel; 2) rearrangement of data files in Minitab; 3) assembling hourly concentration data files with hourly weather data file; 4) calculation of annual means; 5) comparison of annual mean with NAPS and MOE. The data was rearranged in the excel sheet by using the matrix approach (365x24). This step was repeated for the two variables of concentration and date. In the second step the matrix of date and concentration from excel was imported into the Minitab (Minitab, 2010) for statistical analysis. The matrixes of concentration and date were stacked independently in the Minitab. As a result, two parallel columns of date and concentration were created. The third column of variable hours was generated by using the data generator in the Minitab.

The next step requires assembling weather data with the concentration data in Minitab as shown in Table D-1. This was done to figure out any missing hour and day that may occur in the data. The annual means by pollutant and by station were calculated using the processed data. The calculated annual mean for all pollutants were compared with the annual means observed and reported in NAPS and MOE website. The percentage difference with the NAPS and MOE is shown in Tables D-2 and D-3. In the case of NAPS the percentage difference was found to be 0%. This clearly shows the reliability of the calculation conducted in this study. However, the comparison with the MOE yielded some small differences in the case of CO.

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3.5 Long Term Detection

In order to observe the long term trends of pollutants the conventional method of linear regression (ordinary least square) was used in this study. The *p*-value was calculated in Minitab.

A significance level of .1 or 10% was used to measure the statistical significance. The upward and downward trend was further examined by using the sign of the slope of the regression line (b). A positive value of the slope with *p*-value <0.1 indicates an upward trend with time for that pollutant and that station. On the other hand, a negative value of the slope with *p*-value <0.1 indicates a downward trend.

3.6 Pollution and Wind Rose

In order to find the direction of prevailing wind the wind rose plots were analyzed in conjunction with pollution rose plots. The wind rose was generated with WRPLOT View (Lakes Environmental, 2010). The meteorological data including hour, day, month, year, hourly wind direction and wind speed were obtained from the National Climate Data and Information Archive operated by Environment Canada (EC, 2010). These meteorological inputs were imported from the weather data files into the software. The data interval of 10 year (1997-2007) was selected for each meteorological station.

The data files containing both hourly concentrations and hourly wind directions were used to produce pollutant rose. The hourly wind direction has a raw format of integer number. Therefore, wind direction was converted into 10 degree intervals: 0-10, 10-20, 20-30…..…350-360. Next, the concentrations were unstacked with respect to

wind direction. As a result the concentrations which lie in the particular interval of wind direction are assembled in that column.

The percentile values, i.e. 5, 25, 50, and 75, 95th of concentrations in each of the 36 directions were calculated in Excel. Then the 5th percentile value of concentration was subtracted from the 25th percentile. This was done to calculate the inter-percentile range between 5th and 25th percentile. In the similar way the inter-percentile ranges between other values were calculated. Next, a transposed matrix was imported into Grapher software (www.graphersoftware.com) to plot the pollutant rose using polar bar charts. The 5th percentile and inter-percentile ranges were further identified with different colours: cyan, red, green, yellow and indigo denoting 5th, 25th, 50th, 75th and 95th inter-percentile respectively. A longer bar indicates a higher inter-percentile concentration. Detailed steps can be found in Appendix E.

Using the wind rose and pollutant rose, the pollutants were further classified into four major categories: 1) very local; 2) local; 3) source specific; 4) regional. The "very local" refers to pollutants that are generated locally in the area by mobile or transportation activities. In terms of degree of intensity the "local" and "very local" are further differentiated from each other. The third category of "source specific" is used for the pollutants that are coming from sources in specific directions. Finally "regional" was classified for those pollutants that are transported long distance. The shape of the pollution rose plot was studied in conjunction with the Google map. For example, the pollution rose plot showing uniform distribution of shape, i.e. (0-360°) along with local sources were classified as" very local". Similarly if the higher percentile bar is inclined in a specific direction and the Google map shows regional sources of pollutants in that

direction, that pollutant is classified as "Regional". Furthermore, if the higher percentile bars are inclined in specific directions and the Google map shows the presence of sources in that direction, the pollutant is classified as "Source Specific".

CHAPTER IV

ANALYSIS OF RESULTS

4.1 Long Term Trend Analysis

The plots used in the long term trend analysis from 1998-2007 using annual means are presented in Appendix F. The summary of trend based on the p-values and slope of the regression line are further elaborated in Table 4-1. The trend is discussed one by one by site in the following sections, taking into account the advancements in emission control technology and regulations in the past 10 years.

4.1.1 City of Windsor

The annual mean concentration for WD and WW are shown in Figs F-1 and F-2, respectively. The summary is further listed in Table 4-1. In the two Windsor stations, only WD collects CO data, showing a downward trend with $p<0.1$. The annual concentration in CO decreased by 64% from 1997-2007. MOE (2007) shows transportation as the major contributor of CO accounting for an overall 85% of CO emissions. According to Statistics Canada (2008) the number of registered vehicle in the province of Ontario has increased by approximately 700,090 from year 2000 to 2007. Therefore the decreasing trend in CO indicates that the states of vehicles have been improved for the city of Windsor.

Table 4-1: Summary of *p*-values and Long Term Trend 1998-2007 for Selected

Pollutants

Site	SO$_2$			CO		
	Slope	***p* value**	**Trend**	**Slope**	***p* value**	**Trend**
Windsor Downtown	-0.24	<0.001	↓	0.04	0.047	↓
Windsor West	-0.78	<0.001	↓	-	-	-
Toronto Downtown	-0.24	0.010	↓	-0.10	0.001	↓
Toronto West	-0.31	<0.001	↓	-0.09	<0.001	↓
Edmonton	-	-	-	-0.05	<0.001	↓
Calgary	-	-	-	-0.06	<0.001	↓
Montreal1	-0.07	0.548	N.S	-0.01	0.096	↓
Montreal2	-0.25	0.012	↓	-0.06	<0.001	↓
Hull	-0.10	<0.001	↓	-0.03	0.003	↓
Halifax	-0.60	0.079	↓	-0.06	0.028	↓
Vancouver	-0.16	<0.001	↓	-0.04	<0.001	↓
Site	**NO**			**NO$_2$**		
	Slope	***p* value**	**Trend**	**Slope**	***p* value**	**Trend**
Windsor Downtown	-0.96	0.004	↓	-0.73	0.009	↓
Windsor West	-1.12	0.077	↓	-0.73	0.009	↓
Toronto Downtown	-1.64	<0.001	↓	-1.16	<0.001	↓
Toronto West	0.47	0.481	N.S	-0.12	0.643	N.S
Edmonton	-1.45	<0.001	↓	-0.69	<0.001	↓
Calgary	-	-	-	-0.77	<0.001	↓
Montreal1	-0.63	0.004	↓	-0.05	0.736	N.S
Montreal2	-2.97	<0.001	↓	-0.71	<0.001	↓
Hull	-1.59	<0.001	↓	-0.43	<0.001	↓
Halifax	1.30	0.083	↑	-0.53	0.002	↓
Vancouver	-	-	-	-0.43	<0.001	↓
Site	**NO$_x$**			**O$_3$**		
	Slope	***p* value**	**Trend**	**Slope**	***p* value**	**Trend**
Windsor Downtown	-1.63	0.007	↓	0.63	0.013	↑
Windsor West	-0.96	0.015	↓	0.93	<0.001	↑
Toronto Downtown	-2.69	<0.001	↓	0.69	<0.001	↑
Toronto West	0.38	0.678	N.S	0.01	0.962	N.S
Edmonton	-2.11	<0.001	↓	0.14	0.097	↑
Calgary	-2.07	<0.001	↓	0.25	0.009	↑
Montreal1	-	-	-	-0.02	0.841	N.S

Montreal2	-	-	↓	0.71	0.094	↑
Hull	-	-	-	-0.03	0.787	N.S
Halifax	-2.34	0.037	↓	-0.73	0.073	↓
Vancouver	-1.71	<0.001	↓	0.15	0.115	N.S

↓ Decreasing trend significant at p<0.1
↑ Increasing trend significant at p<0.1
N.S: Not Significant.
"-" Data not available

SO_2 shows a downward trend ($p<0.1$) for the two stations. Overall from 1998-2007 the concentration of SO_2 decreased by 26% and 56% for WD and WW respectively. The downward trend indicates effective control emission policy at provincial, regional and international levels. Some key initiatives taken by the provincial government of Ontario in the past 10 years are worth mentioning (MOE, 2006). They are: 1) countdown acid rain program/ Canada-wide acid rain strategy; 2) low sulphur content in transportation fuels; 3) shutting down of some coal fired generating stations; 4) control orders for Ontario smelters.

NO, NO_2 and NO_x show a downward trend with $p <0.1$ for both sites in Windsor. The annual mean concentrations generally decreased from 1998-2007 except for the year 2003. Major sources of nitrogen compound near the station are: 1) Ambassador Bridge which is an international border crossing; 2) Huron Church Road at 1.5 km from both stations. Therefore, a downward trend suggests reduced local traffic emissions.

O_3 shows an overall increase in concentration from 1998-2007 for WD and WW. NO which is considered as a precursor of O_3 has shown a downward trend for Windsor. Therefore, it is concluded that this increase of O_3 may result from trans-boundary influence from neighboring states or less titration. The results were in line with MOE (2007) which suggests that 50% of O_3 in Ontario is transported regionally across border.

However, due to absence of VOC data which is considered as other precursor the exact reason of this increasing trend is unclear.

PM2.5 shows no trend for WD and WW as shown in Table 4-2. Year 2005 recorded the highest level of concentration for PM2.5 in both sites (Figs F1 and F2). A record number of 15 smog advisories covering 53 days were issued in that year (MOE, 2006) for fine particulate matter. An autumn PM2.5 episode occurred in the month of October, outside the traditional smog season. However it didn't change the annual mean of 2005 which was calculated to be 10.4 $\mu g/m^3$ with or without this episode.

Table 4-2: Summary of *p*-values and Long Term Trend 1998-2007 for PM2.5 and PM10

Site	PM2.5			PM10		
	Slope	*P* value	Trend	Slope	*P* value	Trend
Windsor Downtown	-1.63	0.674	N.S	-	-	-
Windsor West	0.0107	0.955	N.S	-	-	-
Toronto Downtown	-0.200	0.426	N.S	-	-	-
Toronto West	-0.446	0.096	↓	-	-	-
Edmonton	-	-	-	-	-	-
Calgary	-	-	-	-0.110	0.735	N.S
Montreal 1	-	-	-	-	-	-
Montreal 2	-	-	-	-	-	-
Hull	-	-	-	-	-	-
Halifax	-	-	-	-	-	-
Vancouver	-	-	-	-0.190	0.026	↓

↓ Decreasing trend significant at *p*<0.1
↑ Increasing trend significant at *p*<0.1
N.S Not significant

4.1.2 City of Toronto

  The annual mean concentrations for TD and TW are shown in Figs F-3 and F-4, respectively. The summary is further listed in Table 4-1. SO_2 showed a decline in the concentration at both sites; by 52% and 64% from 1998-2007 for TD and TW, respectively. However, the TD trend should be taken cautiously due to unavailability of data from 1999-2002. There are several industries scattered around the city of Toronto. The downward trend indicates the regulatory provision and strict compliance with the standards. CO concentrations have a decreasing trend for both stations in Toronto. As in the case of Windsor, this trend suggests improvement in the vehicle emission control and enforcement of strict vehicle emission standards. In the case of O_3 no trend was observed for TW. However, TD shows an upward trend. This increase in ozone could be due to a steady decrease in NO during 1998-2007 (Fig F-3) hence less titration (Geddes et al., 2009). The inverse relationship between NO and O_3 is quite evident at both sites.

  A downward trend was shown by PM2.5 in Toronto West (TW) as seen in Table 4-2. However no statistically significant trend was observed at TD. TW is surrounded by industrial facilities such as Keele Fill Landfill gas power station. According to NPRI this facility released 62 tons of PM2.5 in the year 2003 which dropped to 16 tons in the year 2007 (NPRI, 2008). At both stations, the annual mean concentration generally decreased from 1998-2007 except for the year 2005. The year 2005 as explained earlier has experienced worst smog episode across the province of Ontario (MOE, 2006).

4.1.3 City of Edmonton

The annual mean concentration for the city of Edmonton is shown in Fig F-5. The summary is listed in Table 4-1. CO shows a downward trend, with overall concentration decreasing by 56% from 1998-2007. The monitoring station is surrounded by parking lots, major highways and high rise buildings considered to be important sources of CO. Hence, the downward trend in CO suggests reduced local emissions. NO, NO_2 and NO_x show downward trend with $p<0.1$ as shown in Table 4-1. The even proportion of NO: NO_2 (Fig F-5) is indicative of fresh emissions from the vehicles. According to Statistics Canada, the number of registered vehicle in the province of Alberta has increased by approximately 54, 0000 from 2000-2007 (Statistics Canada, 2008). Despite increases in the number of vehicles there is a downward trend in NO_x which indicates improvement in vehicle emission control technologies and the increased use of oxygenated fuels. The annual mean concentration of O_3 increased from 1998-2007. The year 2002 had a significant increase in the O_3 concentration from 16 ppb in 2001 to 17.7 ppb in 2002. The upward trend could be explained by less titration by NO.

4.1.4 City of Calgary

The annual mean concentration for Calgary is shown in Fig F-6. Trends of pollutants are listed in Table 4-1. CO shows a steep decline from 1998-2007 with $p<0.1$. The site is significantly influenced by vehicular emissions due to its proximity with features such as major and minor roads, bridges and high rise buildings. Therefore it is concluded that for the city of Calgary local emissions and state of vehicle have been improved. NO_x, NO_2 and NO all show downward trend ($p<0.1$). As in other provinces,

the annual registered vehicles in Alberta has increased from 1998-2007 (Statistics Canada, 2008). Therefore, a downward trend in NO_x and CO indicates effective emission control standards adopted at provincial level. O_3 shows an increasing trend from 1998-2007. The city of Calgary has no regional borders with major industrial cities. Hence it is concluded that an upward trend is likely due to: 1) titration effect of NO; 2) weather phenomena governing the photochemical oxidant rate. The trend for PM10 is statistically not significant.

4.1.5 City of Montreal

The annual mean concentrations for Montreal 1 and Montreal 2 are shown in Figs F-7 and F-8 respectively. The statistical summary is further listed in Table 4-1. CO shows a downward trend for the two stations. The concentration of CO decreased by 67% and 44% for the Montreal 1 and Montreal 2 stations respectively from 1998-2007. Montreal 2 showed higher CO concentrations than Montreal 1 due to its proximity with major roads and marine ports. However, the downward trend for the two stations is indicative of overall improvement.

The trend for SO_2 is downward for both stations located in Montreal which is indicative of effective emission control in the past decade. However, the trend is only marginally significant (p=0.012) for the Montreal2 Station. Montreal1 is close to the industrial facilities therefore it has higher SO_2 concentrations than Montreal 2.

NO and NO_2 showed a downward trend for the two stations. The concentrations of NO and NO_2 were much higher in Montreal 2 than Montreal 1. This further substantiates the urban core location of Montreal 2. O_3 behaved differently by showing

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no trend for Montreal 1 and a downward trend for Montreal 2. The O_3 concentration in Montreal 1 was almost twice as high as at Montreal 2**.** This could be explained by much higher NO concentrations at Montreal 2, leading to stronger titration reaction thus lower O_3 levels. An interesting feature of the result is the significant drop in the concentration of O_3 in the year 2000. This year requires more investigation in future studies.

4.1.6 City of Hull

The annual mean concentration for the city of Hull is shown in Fig F-9. The trends are further listed in Table 4-1. CO shows a downward trend *(p<0.1)* despite the station being surrounded with heavy traffic sources. For instance two bridges namely Gatineau and Alexandria are situated at a distance of 1.3 km and 1.1 km respectively from the monitoring station. The traffic count on the Alexandria Bridge is approximately 15,000/day (Public Works and Government Services Canada, 2011). Hence it can be concluded that vehicles have become cleaner in the city of Hull resulting in less emissions. NO and NO_2 both shows downward trends *(p<0.1)* as shown in Table 4-1 and Fig F-9. This again shows improved state of vehicle in the city of Hull.

SO_2 shows a downward trend ($p<0.1$) for the city of Hull. The city of Hull is lying at border with the city of Ottawa which is heavily industrial. Therefore, a decrease in SO_2 indicates effective implementation of emission control policy. O_3 shows variation by having alternate increase and decrease in concentrations. The *p* value in Table 4-1 suggests no trend for O_3.

4.1.7 City of Halifax

The annual mean concentration for the city of Halifax is shown in Fig F-10. The trends are further elaborated in Table 4-1. There is a downward trend for CO ($p<0.1$). The monitoring station is located at a distance of 4.2 km and 1.8 km from Macdonald and Murray Mackay Bridges respectively. There is a heavy flux of traffic on these bridges. The downward trend shows an improved state of vehicles for the city of Halifax. NO_x and NO_2 show a downward trend. This once again indicates reduced vehicular emissions. However, NO was increasing over the years. The concentration of SO_2 remains high indicating sources of SO_2 near the monitoring station. The small p value (<0.1) indicates an overall downward trend for the city of Halifax because of implementation of strict emission control policies in the past 10 years. O_3 shows a downward trend with the lowest concentration of 13.3 ppb in the year 2005. The concentration of O_3 decreases by 22% in the 10 years interval. The downward trend of O_3 could be due to increased NO or changes in VOC levels or meteorological variation affecting the photochemical oxidant rate.

4.1.8 City of Vancouver

The annual mean concentration for the city of Vancouver is shown in Fig F-11. The trend is listed in Table 4-1. CO indicates a downward trend for the city of Vancouver. This site is heavily influenced by traffic due to its proximity with two major bridges. The downward trend is indicative of cleaner vehicles. NO_x, NO and NO_2 showed a decline in concentration. Statistic Canada (2008) indicates that from 2000-2007 the

annual registered vehicles in the province of British Columbia have increase by 327750. This shows once again the overall improvement in the fleet of vehicles.

Overall, the concentration of SO_2 decreased significantly (by 34%) from 1998-2007. However, the concentration increases from 2.6 ppb in 1999 to 3.2 ppb in 2000. The downward trend suggests effective policy to control the emissions. O_3 shows an upward trend (not significant) with large year to year variation indicating the influence of meteorology and photochemical oxidant. PM10 has an overall downward trend as shown in Table 4-2. The monitoring station in Vancouver is located in the residential sector with no major sources of PM. Hence, it indicates the cleaner condition of the city.

4.1.9 Comparative Analysis of Trend

The comparative analysis of pollutant was done for all the sites. The analysis showed downward trends for SO_2 and CO in all the stations. This indicates effective emission control strategy and improved state of vehicle across major cities of Canada.

NO, NO_2 and NO_x showed downward trend for nearly all the stations. However, in Toronto West the trend was not statistically significant. Halifax showed an upward trend for NO but a downward trend for NO_2 and NO_x.

Most sites have an upward trend but Halifax has a downward trend for O_3. There is no trend for the stations located in TW, Montreal 1, Hull and Vancouver, since not much change over the last 10 years or a large year to year variability thus the trends were not statistically significant. Large year to year variability is observed for most of the cities including Toronto, Montreal, Hall, and Vancouver. This is not unexpected since the variation in meteorological condition affects the photochemical oxidation rate of O_3.

The stations located in the same city have more or less similar trends for all pollutants. The two stations in the city of Montreal (Montreal 1 and Montreal 2) showed more or less downward trend for all the pollutants. The only exception was O_3 which has no trend for Montreal 1 and an upward trend for Montreal 2. The two sites in the city of Toronto didn't have similar trend. O_3 has no trend for the TW while it has a downward trend for TD. The TW station is very close to major roads, therefore NO_x and NO has an upward trend for this station (although not significant).

Another grouping was made for the stations in the same province. Edmonton and Calgary have very similar trend for all the pollutants. The city of Montreal and Hull shared more or less similar trend. However, O_3 was found to behave differently for the two cities. Among the four stations in Ontario, the pollutants more or less showed similar trend. Hence it is concluded that at provincial level the trends are similar for most pollutants, however O_3 has mixed results.

4.2 Wind and Pollution Rose Analysis

The second part of analysis deals with generating the pollution roses for the selected stations scattered across Canada. The pollution rose as explained earlier gives us the mean strength of the source. In other words it identifies the direction of the sources by specifying which direction is associated with higher or lower concentrations. The spatial surroundings and the industrial facilities located around the monitoring stations may change with the passage of time. In order to have conclusive idea about the mean direction of the source strength a period of 10 years was selected. The pollution rose plots have been drawn one by one for the selected pollutant and by site. The analysis was

conducted by taking into consideration the major sources of each pollutant and their geological locations near the monitoring stations.

4.2.1 City of Windsor

The pollution rose plots for the two Windsor Stations are shown in Figs G-1 and G-2 respectively. Wind rose showing the prevailing wind direction is included with pollution rose. Classification of sources based on wind and pollutant rose are in Table 4-3. High levels of SO_2 were found to be in the direction of SW (180 -270º) for both WD and WW. Southwest of Windsor, there are several coal fired power plants that are located along the Lake Erie. It is also observed that the prevailing wind is coming from the southwest direction as shown in Fig G-1. Therefore, it is concluded that SO_2 is source specific. The pollution rose for the compound belonging to nitrogen family suggests local contributions being the major source. NO and NO_x showed local distribution (0-270º). NO_2 was found to be very local (0-360º). This pattern was common to both sites in Windsor. There are many local sources of NO_x near the two monitoring stations. Ambassador Bridge which is one of the busiest international border crossings between United States and Canada is located at a distance of 1.5 km from both sites. There are no major industrial facilities emitting NO_x near the monitoring stations. Hence it was concluded that NO_x is generated locally in the city of Windsor. CO shows uniform distribution of sectors (0-360º) thus classified as local source dominant.

Table 4-3: Classification of Pollutants into Categories

Station	City	Local	Very Local	Source Specific	Regional
12008	Windsor Downtown	NO, NO_x, CO	NO_2	SO_2, PM2.5	O_3
12016	Windsor West	NO, NO_x	NO_2	SO_2, PM2.5	O_3
31103	Toronto Downtown	NO, NO_2	NO_x, CO	SO_2, PM2.5	O_3
35003	Toronto West	NO, NO_x, CO	NO_2	SO_2, PM2.5	O_3
90130	Edmonton	NO, NO_x, O_3,	NO_2	CO	
90227	Calgary	O_3, NO_x	PM10, NO_2	SO_2	
50103	Montreal1	NO, NO_2, CO		SO_2	O_3
50115	Montreal2	NO, NO_2, CO		SO_2	O_3
50204	Hull	NO, NO_2, CO		SO_2, PM2.5	O_3
30118	Halifax	NO, NO_x CO	NO_2	SO_2	O_3
100118	Vancouver	CO, SO_2, NO NO_x,PM10	NO_2,		O_3

High O_3 concentrations were in the direction of south (135-225º), for both sites.
To the south of Windsor, there are the industrial states of Ohio and Indiana (United
States). A study conducted by MOE (2007) shows that 50% of ozone is transported
regionally from the US into Ontario. The results for the city of Windsor were in line with
MOE findings. Hence, it was concluded that O_3 is regional as shown in Table 4-1 and
mostly coming from across the border. PM was found to be high in the south direction
(135-225º) for both WD and WW. As already shown, there are several industrial facilities
in the south west and the bordering states of US in the south. This analysis reveals that
PM can be both sources specific or regional as shown in Table 4-3.

4.2.2 City of Toronto

The pollution rose and wind rose plots for the two Toronto stations TD and TW are shown in Figs G-3 and G-4 respectively. Pollutants are further classified in Table 4-1. SO_2 is found to be source specific in the direction of south for both TW and TD. Major sources in the south include: 1) Red Path Sugar Ltd-Toronto Refinery located at a distance of 2.6 km from TD; 2) the harbour and marine vessels. NO_2 and NO_x are found to be very local (0-360º) with NO being local. This pattern is common to both sites of Toronto. Since both sites are located near the major and minor roads, therefore it is concluded that nitrogen compounds are produced locally. CO shows an even distribution of sectors (0-360º), suggesting local production by transportation related activities for both sites in Toronto. O_3 is high in the direction of south (90-270º) for both sites. In the extreme south are located the industrial states of United States such as New York, Ohio and Pensylvania. Hence it is concluded that O_3 is transported regionally across the border. PM2.5 is high mainly in the direction of south for both sites in Toronto. To the south are sources of PM2.5 (NPRI, 2007) such as: 1) Walton Street steam plant (annual emissions of 8.1 tonnes); 2) Canada Building Material (2.3 tonnes); 3) Red Path Sugar Ltd (1 tonne). Therefore it is concluded that PM2.5 is generated locally.

4.2.3 City of Edmonton

The pollution rose plots for city of Edmonton are shown in Fig G-5. The pollutants are further classified in Table 4-3. Wind rose as shown in Fig G-6 indicate that prevailing wind direction is in the SW. High CO is mainly in the direction of south. In the south of monitoring station are two major highways situated at a distance of 0.5 km and 5

km respectively. As already explained CO is mainly generated by traffic activity. Hence, CO is generated locally. NO, NO_2 and NO_x vary from local to very local. The site is surrounded by parking lots and two bridges. Hence local contribution is the major source for the city of Edmonton. O_3 is found to be evenly distributed in all direction (0-360º). The city of Edmonton shares no major border with other populated regions. Hence it is concluded that O_3 is generated locally. PM2.5 shows an even distribution suggesting once again local production.

4.2.4 City of Calgary

The pollution rose plots for the city of Calgary (090227) are shown in Fig G-6. Table 4-3 further shows the classification of pollutants into different categories. High SO_2 is in the direction of SW (180-270º). Wind rose suggests prevailing wind from SW. The south of monitoring station is bounded by industrial facilities, which are rich sources of SO_2. Hence, it is concluded that SO_2 is source specific for the city of Calgary. NO_2 and NO_x show a more or less uniform distribution of sectors for the pollution rose plots. This can be expected given the surrounding of monitoring station with major and minor roads. Therefore, both of these compounds are considered local. PM behaved in a similar manner with similar concentration levels in all direction (0-360º) thus is generated locally. O_3 shows a uniform distribution of all sectors. The site investigation reveals no neighbouring industrial facility causing trans-boundary transportation of O_3. Hence O_3 is generated locally for the city of Calgary.

4.2.5 City of Montreal

The pollution rose plots for the two stations (Montreal 1 and Montreal 2) are presented in Figs G-7 and G-8 respectively. Pollutants are further classified in Table 4-3. High SO_2 is found to be in the direction of SW. Many industrial facilities are located in the SW direction of the monitoring station, which emit SO_2 in huge quantities. Sulphur Plant, a chemical industry, is situated at a distance of 1 km from the Montreal 1 monitoring station. It is reported to emit 231.5 tonns of SO_2. A petroleum industry operated by Shell Canada is also located in the SW direction. It is reported to emit 4699 tons of SO_2 (NPRI, 2008). The wind rose plot suggests that prevailing wind is coming from the west. Therefore the analyses suggest that SO_2 is source specific. Montreal2 has sources in the north direction and is found to be source specific. The wind rose plot suggests that prevailing wind is coming from the west. Therefore the analyses suggest that SO_2 is source specific.

CO shows uniform distribution of sectors suggesting local distribution. The two sites are traffic influenced sites with major and minor roads. Hence it is concluded that CO is produced locally for the city of Montreal. NO and NO_2 shows somehow uniform distribution of sectors for the two stations in Montreal. The pollution rose sectors for Montreal 1 is more in the direction of east. To the east of the station is located the Saint Laurent River. However, overall analysis reveals local production of NO and NO_2. The wind rose in Fig G-8 shows that prevailing wind is coming from the west. This shows that the stations in the Montreal are located in the downwind direction of industrial states of United States such as Michigan, Ohio, Indiana and Illinois, and Toronto and Ottawa in

Ontario. Furthermore high O_3 is found to be in the direction of SW (180-225º) for both Montreal 1 and Montreal 2 which suggest that O_3 is regional for the city of Montreal.

4.2.6 City of Hull

The wind rose and pollution rose plot for Hull is shown in Fig G-9. The trends of the pollutant are listed in Table 4-3. High SO_2 is mainly coming from the direction of south (90-225º). In the south of the station, there are many industrial facilities located along the Ottawa River bank. For instance a major pulp and paper mill industry (Domtar Inc) is located along the bank of Ottawa River in the south. This facility releases 398 tons of SO_2 per year (NPRI, 2007) and is situated at a distance of 1.3 km from the monitoring station. Thus, SO_2 is found mainly to be source specific coming from industrial facility.

High CO is mainly coming from the east (45-180º). Two large bridges (Alexandria and MacDonald) are situated in the east of the monitoring station. The sites are heavily influenced by traffic. Hence, it is concluded that CO is activity based and mostly generated from local transportation.

High NO and NO_2 occurs frequently in the direction of southeast (135-180º). The southeast of the station is heavily traveled with two bridges. The western part of the station is mainly residential in nature. Hence, it was concluded that NO and NO_2 are generated from local activity mainly transportation. O_3 shows almost even distribution (0-360º). The city of Hull is sharing no border with populated regions. Thus O_3 appears to be generated locally.

High PM 2.5 appears to be more inclined in the direction of south. Industrial facilities located in the south direction include: 1) *Trans-Atlanta Co, generation LP*: generating 6.1 tonns of PM2.5 per year; 2) *Hanson Brick Ottawa,* generating 1.2 tonns of PM2.5 per year (NPRI, 2007). Thus PM2.5 is found to be source specific. It should be noted that only one year (2003) of PM2.5 data were available in Hull Station.

4.2.7 City of Halifax

Fig G-10 shows pollution and wind rose plots for the station located in the Halifax city. Pollutants are classified in the Table 4-3. SO_2 is oriented in the direction of NW (315-0º) and SE (90-135º). To the NW is a major oil refinery which is approximately at a distance of 1 km from the monitoring station. Oland brewery plant is also located in the same direction at a distance of 2.4 km. This facility releases 55 tonns of SO_2 to the air (NPRI, 2007). The prevailing wind direction is from the west as indicated by wind rose. The SE direction of SO_2 is explained by the Oil power plants in that direction, which generates SO_2. Thus SO_2 is source specific for the city of Halifax.

An even distribution of sectors is seen in case of CO. This suggests the local production of CO from the surrounding major roads. NO_2 is found to be very local produced by transportation and industrial activity. The monitoring station is located at a distance of 4.2 km and 1.8 km from Macdonald Bridge and Murray Mackay Bridge respectively. These bridges are influenced heavily from traffic. Besides, various industrial facilities are scattered around the monitoring stations. Therefore, the very local production of NO_2 can be clearly understood. NO_x and NO show the similar distribution and falling in category of local pollutant. O_3 is found to be in the direction of south. The

prevailing wind is in the direction of SW as shown in the wind rose plot in Fig G-10. In the extreme SW are located the industrial states of United States. Therefore, it is concluded that O_3 is regional for the city of Halifax.

4.2.8 City of Vancouver

Pollution and Wind rose plots for city of Vancouver are shown in Fig G-11. Table 4-3 shows the classification of the pollutants. SO_2 is uniformly distributed (0-360°) in all direction. This is explained by the residential location of the monitoring station and the absence of strong source near the monitoring station. Hence, SO_2 is local for the city of Vancouver.

The symmetric distribution of pollution rose sectors confirms the <u>local</u> generation of CO. Trans-Canada highway was located at a distance of 9.8 km from the monitoring station. Thus for the city of Vancouver CO is mainly generated by transport activities. NO, NO_2 and NO_x are very local to local as shown in Table 4-3. There are no major point sources near the monitoring station. Besides, the station is surrounded by minor roads on all sides. Therefore, the local production of pollutant belonging to nitrogen family can be expected.

However, high O_3 was found to be in the direction of SW (180-270°). To the south of the station are located many industrial facilities. In the extreme south direction we find many industrial facilities. Besides, the neighbouring industrial state of United States, Washington, is also located in the extreme south of the monitoring station. Thus O_3 is found to be regional for the city of Vancouver. PM10 is distributed evenly (0-360°) and found to be local.

4.2.9 Comparative Analysis of Wind and Pollution Rose

The pollution rose plots were studied one by one for every pollutant. The following results were observed. SO_2 is mainly found to be directional associated with specific source for all stations with the exception of Vancouver where SO_2 sources were considered local. CO showed more or less uniform distribution of all wind sectors and is found to be produced locally within a city. Nitrogenous compounds such as NO, NO_2 and NO_x vary from local to very local for all stations. NO_2 in most cases was found to be very local with uniform distribution of sectors (0-360º). Hence it was concluded that in all major Canadian cities studied, NO, NO_2 and NO_x are primarily generated by transportation activity.

In the cities of Windsor, Toronto, Montreal, Hull, Halifax, and Vancouver high O_3 is mostly oriented in the direction of neighboring US states of Ohio, Michigan, Pennsylvania, and Washington. Hence, it was concluded that for these cities O_3 is transported regionally across the border. The wind rose plots further confirm this by showing the direction of prevailing wind which is coming from the United States. However, in the cities of Calgary and Edmonton that are not downwind of major industrial or metropolitan areas O_3 showed no regional influence and found to be local. PM2.5 which was present only in Windsor, Toronto, and Hull (one year) was found to have sources in the direction of South. This indicates that PM2.5 is source specific or regional. PM10 data were only available in Calgary and Vancouver, the sources were primarily local.

The station lying within the same city were compared to assess the pattern of pollution rose plots. The two stations in the city of Windsor have very similar plots for all

the pollutants. The same pattern was observed for the two stations located in the city of Toronto. This indicates the same emission sources within a city. The two stations in the city of Montreal show more or less similar trends for all the pollutants. This shows that in the city of Montreal the pollutant concentration is also sharing the common sources.

Interesting results were obtained by grouping the plots at provincial level. The two cities of Ontario: Windsor and Toronto, have similar trends in all pollutants. Montreal and Hull located in the province of Quebec showed somewhat similar trend in the three stations. The trends of NO_2, O_3 and SO_2 were statistically non significant for the Montreal1 station. However, the station located in Montreal2 and Hull showed difference in the trend only for O_3. Thus it is concluded that on a broader scale of province the trend are both same and different. In other words, the trend in one or two cities may not be overall indicative of the trend in the province.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

SO$_2$ had a downward trend across major cities of Canada and the concentration is found to be influenced by specific source thus indicating that the regulatory provision and standards in the past decade are effective.

CO shows a downward trend ($p<0.1$) for all the stations, suggesting that emission standard for vehicles have improved in the past decade across Canada. The pollution rose plots indicate the local production being the major sources of CO in all cities studied. NO, NO$_2$ and NO$_x$ have a downward trend ($p<0.1$) for nearly all stations and source origins tend to vary from very local to local The only exception is Toronto West where the trend were statistically non significant. Overall, the downward trends suggest once again the improvement in the emissions and cleaner fleet of vehicle across major cities of Canada.

O$_3$ showed mixed results. Some stations (Windsor Downtown, Windsor West, Edmonton and Vancouver as shown in Table 4-1 and Fig F1, F2, F5 and F11) had little change over the past 10 years, others (Hull, Toronto West and Montreal 1, as shown in Table 4-1 and Fig F4, F7 and F9) had large year to year variation indicative of variation in meteorological conditions and titration effects by NO. Most cites had an upward trend of O$_3$. Furthermore, an inverse relationship existed between the NO (decreasing except Halifax) and O$_3$ (increasing except Halifax) in most of the cities studied. This explains the titration reaction where lower NO leads to higher O$_3$. Another possible reason of the large inter-annual variability is the levels of VOC which is a precursor compound of O$_3$

in addition to NO. However, the absence of VOC data in this study makes it difficult to pin point the reasons of the observed O_3 trend. The pollution rose plots suggest O_3 sources to be regional or local. For cities such as Windsor, Toronto and Montreal O_3 is regional and transported across the border. The direction of the wind rose further confirmed the regional transport of O_3. These results were in line with the findings of MOE (2007) which suggest O_3 is mainly transported regionally. However, in the cities of Calgary, Edmonton, Vancouver and Halifax where there is no large urban and industrial centers nearly, O_3 showed no regional influence and found to be local.

Among the 11 stations, the commercial station in Halifax showed higher concentrations of pollutants in comparison with the remaining 10 urban sites. The stations located within the same city shared both similar and different long-term trends. Hence it is concluded that one station may not always be sufficient to represent an overall trend for a major city of Canada. In terms of using wind and pollution rose to diagnose major sources, similar patterns were observed by stations located within the same city. This indicates mostly common source of pollutants.

5.2 Recommendations

- Future studies should include VOC data to understand better the long-term trend for O_3.
- A better understanding of temporal and spatial trend in a city could be possible by inclusion of more monitoring stations.

- Seasonal regression could be used to study the trend of pollutant in different seasons. This can be useful for pollutant such as O_3 which shows higher intra-annual and inter-annual variation.

- The seasonal and diurnal variation of the pollutants and its association with major sources can be investigated in future studies.

- Backward trajectory such as HYSPLIT (NOAA, 2011) can be used to confirm the sources of pollutant such as O_3.

- The spatial trend exhibited by pollution rose plot can be done on yearly basis. Furthermore it can be compared with the 10 year plot. This will help in understanding whether the sources of pollutant have changed on annual basis.

- Increasing the study period from 10 years to 20 years will increase the reliability of the conclusions.

- The stations selected in this study are mostly urban in nature. Future studies should take into account commercial and residential stations. Thus comparison among the three types of sites can be made more effectively.

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APPENDICES

APPENDIX A

APPENDIX A: DATA AVAILABILITY

Table A-1: Data Availability Stations British Columbia

ID	TYPE	CO	SO$_2$	NO	NO$_X$	NO$_2$
100110	R	1998-2008	1998-2008	1998-2008	1998-2008	1998-2008
100111	I	1998-2008	1998-2008	1998-2008	1998-2008	1998-2008
100112	C	1998-2008	1998-2008	1998-2008	1998-2008	1998-2008
100118	R	1998-2008	1998-2008	1998-2008	1998-2008	1998-2008
100119	R	2000-2008	2000-2008	1998-2008	1998-2008	1998-2008
100120	R			1998-1999	1998-1999	1998-1999
100121	R	2000-2008	2000-2008	1998-2008	1998-2008	1998-2008
100124	R			1998-1999	1998-1999	1998-1999
100125	R			1998-2008	1998-2008	1998-2008
100126	R			1998-2008	1998-2008	1998-2008
100127	R	2000-2008		1998-2008	1998-2008	1998-2008
100128	R	2000-2008	2000-2008	1998-2008	1998-2008	1998-2008
100132	R	2000-2008	2000-2008	1998-2008	1998-2008	1998-2008
100134	R	2000-2008	2001-2008	1998-2008	1998-2008	1998-2008
100135	R	2000-2008		2000-2008	2000-2008	1998-2008
100202	C	2002-2008	2001-2008	1998-2008		1998-2008
100203	C					
100205	R		2005-2008			
100304	C	1998-2008	1998-2008	1998-2008		1998-2008
100307	R	2004-2005	2004-2005	2002-2008		2002-2008
100314	R	2006-2008		2006-2008		2006-2008
100315	R	2005-2008	2005-2008	2005-2006/2008		2005-2007
100402	C	2001-2008	2001-2008	1998-2008		1998-2008
100701	C	2001-2008	2001-2008	1998-2008		1998-2008
101003	R	2000-2008	2000-2008	1998-2008	1998-2008	1998-2008
101004	R		2005-2006	2003-2008	2003-2008	2003-2008
101101	R	2000-2008	2001-2008	1998-2008	1998-2008	1998-2008
101202	R	2000-2007	2000-2004/2006-2008	1998-1999/2006-2008	1998-2008	1998-2004/2006-2008
101301	U	1998-2008	2003-2008	1998-2008	1998-2008	1998-2008
101401	U	2000-2008		1998-2008	1998-2008	1998-2008
101501	R	2000-2008		1998-2008	1998-2008	1998-2008
101601	R		2000-2005/2007	2005/2007		2005-2006
101701	R	2006-2008	2006-2008	2003-2008		2003-2008
101702	R					
101703	R					
101704	R					
101803	A	2005-2007	2005-2007	2005-2007		2005-2007
102102	R		2006-2008	2006-2008		2006-2008
102201	R		2000-2008			
102301	R		2000-2004	1999-2005/2007-2008		1998-2005/2007-2008
102302	C		2001-2004			
102401	R	2001-2008		1998-2008		1998-2008
102501	R					
102601	R					

Table A-2: Data Availability Stations Alberta

ID	TYPE	CO	SO$_2$	NO	NO$_X$	NO$_2$
090120	R	2005-2008		2005-2008	2005-2008	2005-2008
090121	I	1998-2008	1998-2007	1998-2008	1998-2008	1998-2008
090122	R	1998-2005		1998-2005	1998-2005	1998-2005
090130	C	1998-2008		1998-2008	1998-2008	1998-2008
090131	R		2001-2004			
090218	I	1998-2008	1998-2008	1998-2008	1998-2008	1998-2008
090222	R	1998-2008		1998-2008	1998-2008	1998-2008
090227	C	1998-2008		1998-2008	1998-2008	1998-2008
090228	C	1998		2008	2008	2008
090302	C	2001-2008	2001-2008	2000-2008	2000-2008	2000-2008
090402	R	1998		2004-2006/2008	2004-2005	2004-2007/2008
090502	R	2004-2008	2004-2008	2004-2008	2004-2006/2008	2004-2008
090601	R	1998-2008	1998-2008	1998-2008	1998-2008	1998-2008
090602	A		2004-2008		2004-2005/2007-2008	2004-2008
090603	I		2004-2008	2004-2008	2004-2005/2007-2008	2004-2008
090604	U		2004-2008			
090605	A			2004-2008	2004-2005/2007-2008	2004-2008
090701	R	998-2002/2003-2008	2004-2007	998-2002/2004-2008	998-2002/2004-2008	998-2002/2004-2008
090702	R		98-02/2004-2008	1999-2008	998-2002/2004-2008	1999-2008
090703	I		2005-2008	2005-2008	2005/2007-2008	2005-2008
090801	R		1998/2001-2008	1999-2008	1999-2008	1999-2008
090802	F		2004-2008			
090803	F		2001-2008			
090804	F		2001-2008			
090805	F		2001-2008			
090806	F		2004-2006/2008	2004-2006/2008	2004-2005/2008	2004-2006/2008
091001	U					
091101	U					
091201	F		2001-2004/2007-2008	2000-2003/2007-2008	2000-2004/2007-2008	2000-2004/2007-2008
091301	A		2001-2008	1998-2008	1998-2008	1998-2008
091401	A		2001-2008	1998-2008	1998-2008	1998-2008
091501	A		2001-2008	1998-2008	1998-2008	1998-2008
091601	A		2001-2008	1998-2008	1998-2008	1998-2008
091701	F		2001-2003	2000-2003	2000-2003	2000-2003
091801	U		2001-2008	1999-2008	1999-2008	1999-2008
091901	A		2001-2008	2000-2008	2000-20008	2000-2008
092001	R	2004-2008	2004-2008	2004-2008	2004-2005/2007-2008	2004-2008
092101	I		2004-2008	2004-2008	2004-2005/2007-2008	2004-2008
092201	A		2004-2006/2008	2004-2006/2008	2004-2005/2008	2004-2006/2008
092301	I		2004-2008	2004-2008	2004-2005/2007-2008	2004-2008
092401	A		2005	2005	2005	2005
092501	R		2005	2005	2005	2005
092601	R		2005-2008	2005-2008	2005/2007-2008	2005-2008
092701	R		2005-2008	2005-2007		2005-2007

Table A-3: Data Availability Stations Nova Scotia

ID	TYPE	CO	SO₂	NO	NOₓ	NO₂	PM10	PM2.5
030115	I		1998-1999				NA	
030116	C						NA	
030117	C						NA	
030118	C	1998-2007	1998-2007	1998-2007	1998-2008	1998-2007	NA	
030119	R						NA	
030120	R		2006-2007	2006-2007	2006-2007	2006-2007	NA	2001-2005
030201	R		2003-2007				NA	
030309	I						NA	
030310	C	2005-2006	1998-2007	2006	2006	2006	NA	1998-1999/2001-2005
030409	R						NA	
030501	U						NA	1998-2004
030601	U						NA	
030701	U						NA	
030801	U						NA	
030901	R						NA	
031001	R			2003-2007	2003-2007	2003-2007	NA	
031101	A						NA	

Table A-4: Data Availability Stations Quebec

ID	TYPE	CO	SO$_2$	NO	NO$_x$	NO$_2$	PM10	PM2.5	O$_3$
050102	R		1998-2008	1998-2008	N/A	1998-2008			1998-2008
050103	R	1998-2008	1998-2008	1998-2008	N/A	1998-2008			1998-2008
050104	C	1998-2008		1998-2008	N/A	1998-2008			1998-2008
050105	C	1998-2008			N/A			1998-2003	
050106	R	1998-2008			N/A				
050107	R	1998-2008			N/A				
050108	R	1998-2008			N/A				
050109	C	1998-2008	1998-2001	1998-2008	N/A	1998-2008	1998-2000	2001-2003	1998-2008
050110	C	1998-2008		1998-2008	N/A	1998-2008	1998-2000	2001-2003	1998-2008
050113	R	1998-2008		1998-2008	N/A	1998-2008		2003	1998-2008
050114	C				N/A				
050115	C	1998-2008	1998-2008	1998-2008	N/A	1998-2008			1998-2008
050116	R		1998-2002	1998-2008	N/A	1998-2008			1998-2008
050119	R			1998-2008	N/A	1998-2008			1998-2008
050120	R				N/A				
050121	R		1998-2008	1998-2008	N/A	1998-2008		2003	1998-2008
050123	R				N/A				1998-2008
050126	R			1998-2008	N/A	1998-2008		1998-2003	1998-2008
050127	R				N/A				
050128	C	1998-2008		1998-2008	N/A	1998-2008		2000-2003	1998-2008
050129	A	2001-2007			N/A			1998-2003	2000-2008
050130	C	1999		1999	N/A	1999			1998-1999
050131	C				N/A			2001-2003	
050132	C				N/A				
050133	C		2008	2008	N/A	2008			
050134	R			2008	N/A	2008			2008
050204	R	1998-2008	1998-2008	1998-2008	N/A	1998-2008		2003	1998-2008
050306	R				N/A				1998
050307	R	1998	1998	1998	N/A	1998-2008			1998
050308	R	1998-2008	1998-2008	1998-2008	N/A	1998	1998	1998-2003	1998-2008
050309	R			1998-2002	N/A	1998-2002			1998-2005
050310	R				N/A			2003	2000-2008
050311	R				N/A				2005-2008
050404	R				N/A			2003	2003-2008
050501	C				N/A				
050502	R				N/A				
050503	C				N/A				
050504	R				N/A			2002-2003	2002-2008
050602	C		1998-2002		N/A				
050604	R		2001/2003-2008		N/A				2003-2008
050701	C				N/A				
050801	R		1998-2008		N/A			1998-2003	1999-2008
050901	R				N/A				
050902	R		1998-2008		N/A				

APPENDIX B: STATION MAPS

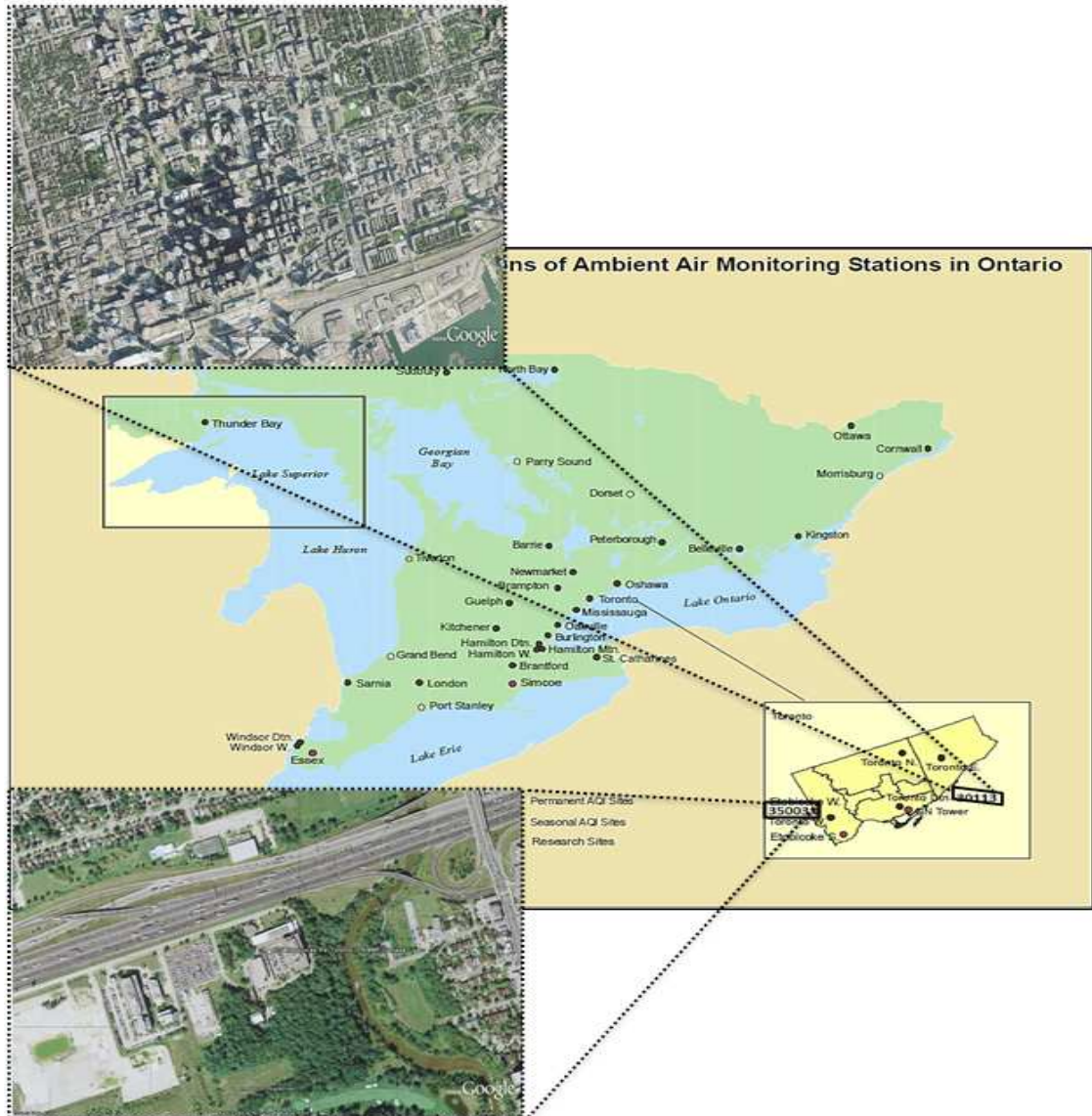**Fig B-1: Map Showing Windsor Downtown (12008) and Windsor West (12016) Stations.**

Fig B-2: Map Showing Toronto Downtown (top, 31103) and Toronto West (bottom, 35003) Stations.
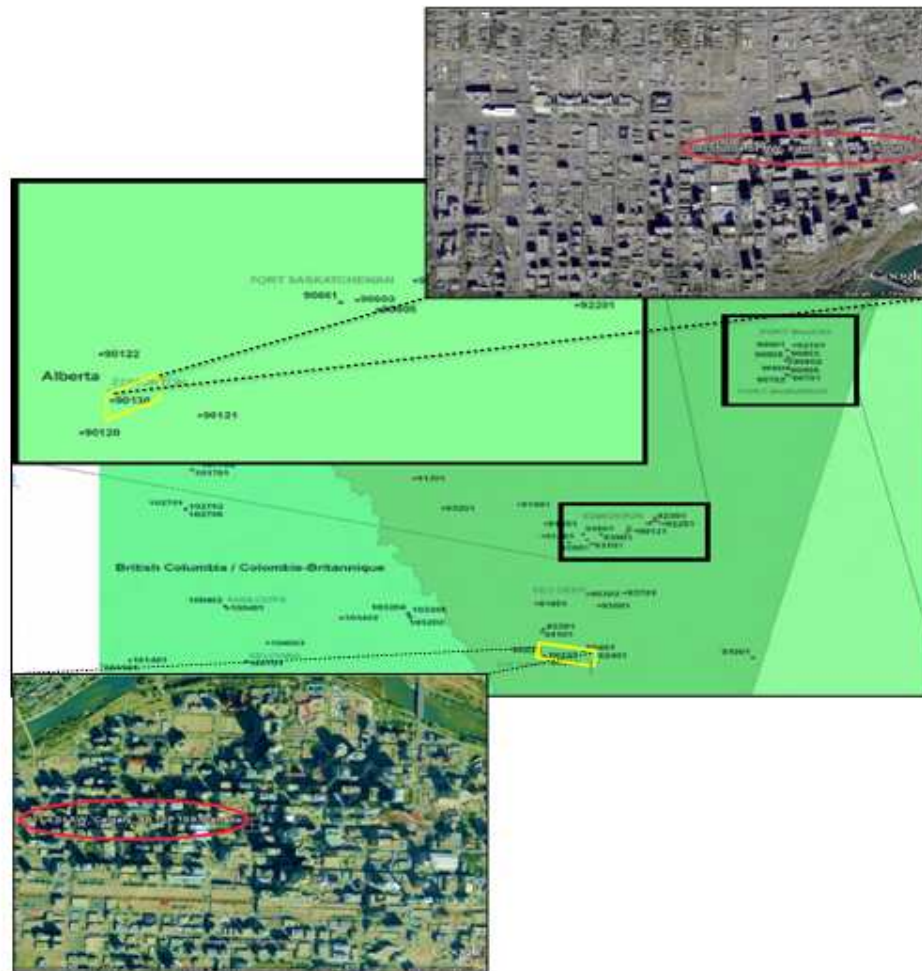
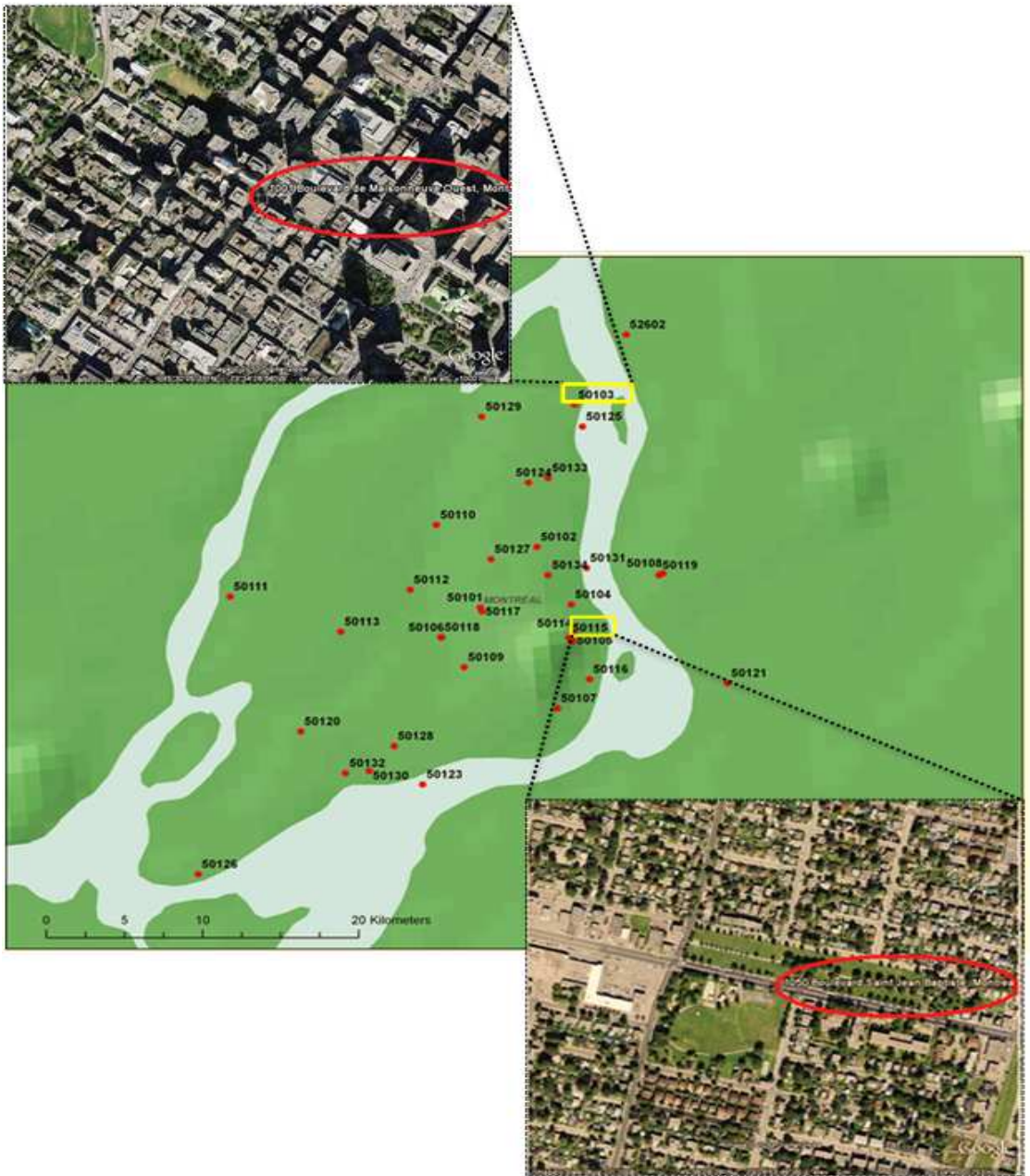**Fig B-2: Map Showing Calgary (top, 90130) and Edmonton (bottom, 90227) Stations.**

Fig B-3: Map Showing Montreal 1 (top, 50103) and Montreal 2(bottom, 50115) Stations.

Fig B-4: Map Showing Hull Station (50204).

Fig B-5: Map Showing Halifax Station (30118).

Fig B-6: Map Showing Vancouver Station (100118).

APPENDIX C: DATA PRE-PROCESSING

Table C-1: Invalid Data Chain Longer than 24 hrs for SO₂ and CO

ID	SO$_2$	CO
12008	1998 (Mar 29)	1998(Jan2-14,Apr10-13)
	1999 (Mar 6-8,21-22)	1999(Mar21-22)
	2002 (May 5-9, **Mar13-May4**)	2000(April23-28
	2003 (Aug 15-19)	2001(July31-Aug8)
	2005 (Jun6-21)	2002(Mar13- 5May)
	2006(Jan5-6)	2005(Oct7-Nov2
		2006(May27-29 July30-Aug31
	1998 (April10-13)	
12016	1999 (Feb11,Apr5-6,July4)	
	2001 (Jun 16-18,23-25,Oct 8-9)	
	2002 (Feb1-2,May5-9,**Mar13-May4**)	
	2003 (July16-Aug12, Oct25-Nov11)	
35003	1998 (**Dec10-14**,29jan-8feb,27-31mar,12nov-9dec)	1998(May7-11,27-31mar,12nov-9dec
	1999 (*July18-21*, Mar22-July16)	1999(July18-19,Mar22-July16
	2000 (Sep27-Oct3)	2003(Jan1-Mar4
	2001 (Sep29-Oct1)	2006(May9-11,Jun8-16,Jan22-23
	2004 (Jan10-13, Sep25-27)	2007(Mar24-26
	2006 (Jan22-23)	
	2007 (Mar24-26)	
50103	1998 (9-10jan,25-27april)	1998 (9-10jan,6-9feb,2-13july)
	1999 (22-26july)	2000 (5-11april,Nov3)
	2000 (3,nov)	2001 (19-26june,11-16sep,22-23sep)
	2003 (10,dec)	2002 (10-11april,15-19nov)
	2004 (27may-3june ,1-2aug)	2003(22july,13-14dec)
	2005 (2-3july,24-25july)	2004(27may-13june,23june,1august)
	2006 (5-6August)	2005 (July 2-4,24-25)
	2007 (23-25june)	2006(13june,5-7august)
		2007 (23-25june,31dec)
50115	1998 (Jan 10-11)	1998 (10-11jan)
	1999 (18-19 may)	1999(18-19may)
	2000 (nov,2)	2000(nov,2)
	2007 (11-29oct)	2007(11-29oct)
30118	1998(27june-10july 31july-8August	1998(8-9july)
	2000(4-5march,17-27aug,27-31Oct,10,Dec,16-31Dec,)	2000(17-31aug,27oct-31dec)
	2001(1-25Jan,11nov-14dec,)	2001(1-28jan,31jan-1feb)

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	2002(19-25march,23-31Aug,31,Dec)	2002(2-7feb,1june-24july,31,Dec)
	2003(1,jan,10-14jan,15-16feb)	2003(1jan,15-16feb,7-15july)
	2004(18feb-25march)	2005(1jan-6march,13-21july,1-14dec)
	2005(7-10jan,23Nov-14Dec)	2007(13Apr-31Dec)
	2007(8July-9Dec)	
100118	2000 (18-19Oct)	1998(June14) 2003(22-24Nov)
	2002 (14-15sep,2-3Nov,*24-27Aug,15-17Nov)*	2005(May-7)
	2003 (22-23Nov)	
31103	1998(27-31 Mar)	1998(May26-28,*27-31 Mar)*
	2004(Jan28-30)	1999(Mar10-Dec31)
	2006(July17-Aug11)	2003(Apr11-13 Jun29-30 July18-20,28-29July,Aug8-12
		2004(Jan28-30,Apr6-9,May27-Jun30, July14-Aug10, Sep26-29
		2005(Jun30-July4,July19-Aug1
		2006(Jun8-15
		2007(July17-Aug25 Oct31-11
90227		2000 (18-19Oct)
		2002(14-15,2-3Nov)
90130		1998 (Aug 16,26)
		2001 (28-29Apr)
		2002 (July 27)
		2007(1-31Dec)
50204	2000 (Jan23-24,Jun21-30,July1-9)	2000 (Jun21-30,July1-10)
	2002 (Oct7)	2002 (Oct7-9)
	2003 (Feb2-6,July4-7,15-18,Oct8-14)	2003 (Feb2-6,12-14,Oct8-14)
	2004 (Mar4-9,Nov5-16)	2004 (Mar4-8,27-31)
	2006 (Aug31-Sep27)	2007 (May1-23,*Apr1-30)*
	2007 (Nov23-24)	

Italic indicates: Missing data (flagged -999)   Bold indicates: Missing days

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Table C-2: Invalid Data Chain Longer than 24 hrs for O$_3$ and PM2.5

ID	O$_3$	PM2.5
12008	1998(Mar29)	2003(Aug15-19 ,Sep9,Oct1)
	1999(May29-31)	2006(July 30-Aug 2)
	2000(July10-12)	
	2002(May5-9,***Mar13-May4***)	
	2003(Aug15-19 ,Oct9-10)	
	2005(Apr1-30)	
31103	1998(**May26-28**,27-31 Mar)	2005(***Oct23***)
	1999(11Mar-16Apr)	
	2000(Jun14-19)	
	2004(Jan28-30, Nov23-24)	
12016	1998(Jan2-14,Apr10-13)	2003(Apr-09)
	1999(Feb11,Apr5-6,uly4)	
	2001(Jan28-29,Apr5-9, Jun16-18 ,24-25,Oct8-9	
35003	1998(27-31mar,12nov-9dec)	2004(Nov20-25,Dec17-21, Dec29-31)
	1999(Mar22-July16)	2005(Jan1-3,May 8,Jan22)
	2001(Mar20-21, Sep29-Oct1)	2006(Dec19-21)
	2002(Apr13-May7)	2007(March24-25)
	2003(Jan24-27)	
	2006(Jan22-23)	
	2007(Mar24-26)	
90130	1998(16,aug)	
	2000(28-29oct)	
	2001(28-29april,29-31dec)	
	2007(1-31dec)	
50103	1998(9-10jan)	
	2000(18jan,3nov)	
	2004(27may-3june,1-2aug)	
	2005(28march,4-25may,19-20nov)	
	2006(5-6aug,10-13aug,1-3sep,25sep-27nov,*1-31oct*)	
	2007(23-25june)	
50115	1998(10-11jan,6-8feb)	
	2001(1-22oct)	
30118	1998(8-9july)	
	2000(17-27Aug,10dec,*1jan-31mar*)	
	2001(6-11jan)	
	2002(31,dec)	
	2003(1,jan)	
	2004(24-29dec)	

	2007(29july-31dec)	
100118	1998(19-20dec)	
	2003(25-26oct,22-23nov)	
	2005(31march-3april)	
	2006(22-27april)	
90227	1998(19-20Dec)	
	2005(31march-3april)	
50204	1998 (Mar5,Dec14-17)	2003 (July4-7,15-18,Aug7-11,Oct8-14,
	2000 (Jun21-10July,18-20)	2000 (Dec23-26,*Jan1-Apr15*)
	2002 (Oct7-9)	
	2003 (Feb2-6,July4-7,July15-18,Oct8-15)	

Italic indicates: Missing data (flagged -999)   Bold indicates: Missing days

Table C-3: Invalid Data Chain Longer than 24 hrs for NO and NO$_2$

ID	NO	NO$_2$
12008	1998 (6-8 mar,21-22mar)	1998 *(Mar29)*
	1999 (Jan19-20,Mar21-22)	1999 (Mar21-22)
	2000 (Sep13-19)	2000 (Sep13-19)
	2001 (Sep14-17)	2001(Sep14-17)
	2002 (Mar13-May9)	2002(May5-9,***Mar13-May4***)
	2003(Feb1-Sep8)	2003(Feb1-Aug8)
	2004(June4-11)	2004(Jun4-11)
	2005(Dec8-14)	2005(Dec8-14)
31103	1998 (27-31 Mar)	1998 (27-31 Mar)
	1999(Oct25-28,*11Mar-16Apr*)	1999(Oct25-28,*11Mar-16Apr*)
	2000 (Jun14-19, Sep6-18, Oct1-5)	2000 (Jun14-19, Sep6-18, Oct1-5)
	2004 (Jan28-30)	2004(Jan28-30)
12016	2000 (July19-26,1jan-21june)	2000(July19-26,*1jan-21june*)
	2001 (Jun16-18 ,Jun23-25 ,Oct8-9)	2001(Jan28-29 ,Apr5-9,Jun 16-18,24-25,Oct8-9)
	2002 (Feb1-2 ,May5-9 *,Mar13-May4*)	2002 (Feb1-2 May5-9 *,**Mar13-May4***)
	2003 (Mar27-July7)	2003(Mar27-July7)
	2005 (Sep23-26)	2005(Sep23-26)
	2006 (Mar16-21)	2006(Mar16-21 Mar25-28)
35003	1998 (**Oct26-27**,27-31mar,12nov-9dec)	1998 (27-31mar,12nov-9dec)
	1999 (**July18-21**,Mar22-July16)	1999(**July18-19**,Mar22-July16)
	2001 (Sep29-Oct1)	2003(Jan1-Mar5 ,Mar21-24)
	2003 (Jan1-Mar5,Mar21-24)	2006(Jan22-23)
	2006 (Jan22-23)	2007(Mar24-26)
	2007 (Mar24-26)	
90130	1998(16,aug)	1998 (16,aug)
	2001 (28-29april,29-31dec)	2001(26-29april,29-31dec)
	2002 (17sep,28sep)	2002(17sep,28-29sep)
	2003 (18,june)	2003(18,june)
	2004(27-29aug,12sep)	2004(12,aug,27-29aug)
	2007 (*1-31dec*)	2007(1-31dec)
50103	1998 (9-10jan,4-5july)	1998(9-10jan)
	1999 (30jan-1feb,31,march,6,april)	1999(30jan-1feb,Apr 3-6,10,17,23,29-20aug ,Nov6-7,13-14,Dec17-18
	2001 (20-21jan,9-11march,16-17oct)	2000(9-12march,16,july,3,nov)
	2002 (12-13march)	2001(20-21jan,9-11march,1-3sep,9,sep,16-17oct)
	2004 (27march-1april,27may-7june,1-	2002 (12-13march)

	3aug,11-12nov)	
	2005 (2-4july,24-25july)	2004(27-31march,27may-7july,1-3aug)
	2006 (9-15feb,5-7aug)	2005(2-3july,24-25july)
	2007 (23-25june)	2006(9-15feb,5-6aug)
		2007(23-25june)
50115	1998 (10sep,1-4oct)	1998(10-11jan,10sep,1-4oct)
	2000 (26,sep)	2000(26,sep)
	2003 (6-9dec)	2003(6-8dec)
	2007 (29-31jan,2-4june)	2007(29-31jan,17-29april,2-4june)
30118	1998 (7-10march,8-9july)	1998(7-10March,8-9july)
	2000 (17aug-4sept,9-11sep ,29-30oct,1-31dec)	2000(17aug-4sep,9-11sep,29-30oct,1-31dec)
	2001 (6-11jan,20mar-30may,30oct,15-16dec)	2001(6-11jan,20-30March,30oct)
	2002 (25oct-31dec)	2002 (30 May,25oct-31dec)
	2004 (1jan-22july,1oct-4oct)	2004(1jan-22july,1oct-4oct)
	2005 (14jan-2march,8-23march,2april-17may)	2005(14jan-2march,8-23march,2april-17may)
	2007 (19Aug-25Oct)	2007(19Aug-25Oct)
100118	1998 (19-20dec)	1998(19-20dec)
	1999 (28-30nov)	1999(28-30nov)
	2000 (*7-12sep*)	2000(6-13sep)
	2002 (16-17sep)	2002(16-17sep,*27aug-28nov*)
		2003(22-23nov)
		2007(*13mar*)
90227	1998 (19-20dec)	1998(19-20Dec)
	1999 (28-30nov)	1999(28-30Nov)
	2002 (16-17Sep)	2002(16-17sep)
50204	1998 (Feb4-Mar11)	1998 (Feb4-28,Mar1-11)
	1999 (Apr5-12)	1999 (Apr5-12)
	2000 (Jun21-July10)	2000 (Jun21-July10)
	2002 (Oct7-9)	2002 (Oct7-9)
	2003 (Feb2-6,July4-7,15-18,Oct8-14)	2003 (Feb2-6,18-19,July4-6,15-18,Oct8-14)
	2004 (Mar4-9)	2004 (Mar4-8)
	2007 (Feb27-Mar3,Nov23-25)	2005 (Feb27-Mar3)

Italic indicates: Missing data (flagged -999)   Bold indicates: Missing days

Table C-4: Invalid Data Chain Longer than 24 hrs for NO$_x$

ID	NO$_x$
12008	1998 (*Mar29)*
	1999 (Jan19-20,Mar21-22)
	2000 (Sep13-19)
	2001(Sep14-17)
	2002 (May5-9,***Mar13-May4***)
	2003(Feb1-Sep9)
	2004(Jun6-11)
	2005(Dec8-14)
31103	1998(27-31 Mar)
	1999(**Oct25-28**,11Mar-16Apr)
	2000(July19-26)
	2004(Jan28-30)
12016	2000(July19-26,*1jan-21june*)
	2001(Jan28-29 ,Jun16-18,Jun24-25 Oct8-9)
	2002(Feb1-2,May5-9,***Mar13-May5***)
	2003(Mar27-July7)
	2005(Sep23-26)
	2006(Mar16-21 ,Mar26-28)
35003	1998(**Oct26-27**,27-31mar,12nov-9dec)
	1999(**July18-19**,Mar22-July16)
	2001(Sep29-Oct1)
	2003(Jan1-Mar5,Mar21-24)
	2007(Apr24-26)
90130	1998(16,aug)
	2001(28-29april,29-31dec)
	2002(17sep,28-29sep)
	2003(18,june)
	2004(27-29Aug,12sep)
	2007(1-31dec)
30118	1998(7-10march,8-9july)
	2000(17aug-4sep,9-10sep,29-30oct,1-31dec)
	2001(6jan-11jan,20mar-30may,30oct)
	2002(30may,25oct-31dec)
	2004(1jan-22july,1oct-4oct)
	2005(14jan-2march,8-23march,2april-17may)
	2007(19aug-25oct)
100118	1998(19-20dec)
	1999(29-30Nov)
	2002(16-17Sep,27-31Aug,1sep-31oct,29-30Nov)
	2003(22-23Nov,21-25May)
	2007(*13Mar*)

90227	1998(19-20dec)
	1999(28-30Nov)
	2002(16-17sep)

Italic indicates: Missing data (flagged -999)   Bold indicates: Missing days

Table C-5: Deleted Years for Each Station

Station	Year	Pollutants	% Missing	% Zero	% Invalid	Total # of Hours*
12008	2003	NO	0.29	0.08	61	8760
12008	2003	NO_x	0.02	0.03	61	8760
12008	2003	NO_2	0.29	0.06	61	8760
12016	2000	NO	0.32	2.2	4.8	4632
12016	2000	NO_2	0.32	0.15	4.8	4632
12016	2000	NO_x	0.32	0.11	4.8	4632
31103	1999	CO	0.55			1644
35003	2007	SO_2	0.75	40	0.19	8760
30118	2000	SO_2	12	36		7725
30118	2007	SO_2	45	2.3		8760
30118	2006	CO	3.9	78		8760
30118	2004	NO_2	57			8784
30118	2007	O_3	42			8760
30118	2004	NO	57			8784
30118	1999	NO	100			8760
30118	1999	NO_2	100			8760
30118	1999	NO_x	100			8760

* Number of hours with data reported

APPENDIX D: DATA PROCESSING

Table D-1: Year and Pollutants <8670 hours

Station	Year	Pollutant	Hours of Valid data
12008	1998	SO_2	8668
12008	1999	SO_2	8517
12008	1998	NO	8736
12008	1999	NO	8546
12008	1998	NO_2	8736
12008	1999	NO_2	8641
12008	1998	NO_x	8736
12008	1999	NO_x	8529
12008	1998	CO	8597
12008	1999	CO	8619
12008	1998	O_3	8671
12016	1998	SO_2	8575
12016	1999	SO_2	8575
12016	1998	O_3	8249
12016	1999	O_3	8575
31103	1998	NO	8640
31103	1999	NO	7837
31103	1998	NO_2	8640
31103	1999	NO_2	7837
31103	1998	SO_2	8608
31103	1998	NO_x	8640
31103	1999	NO_x	7837
31103	1998	O_3	8605
31103	1999	O_3	7837
31103	1998	CO	8180
31103	1999	CO	1641
35003	1998	SO_2	7641
35003	1999	SO_2	5908
35003	1998	NO	7968
35003	1999	NO	5908
35003	1998	NO_2	7968
35003	1999	NO_2	5908
35003	1998	NO_x	7968
35003	1999	NO_x	5908
35003	1998	CO	7922
35003	1999	CO	5908
35003	1998	O_3	7926
35003	1999	O_3	5908
30118	2000	SO_2	7725

30118	2000	O_3	6600
90103	2007	CO	8016
90103	2007	NO_2	8016
90103	2007	O_3	8016
90103	2007	NO	8016
90103	2007	NO_x	8016
100118	2002	SO_2	8352
100118	2003	SO_2	8732
100118	2000	NO_2	8640
100118	2002	NO_2	8604
100118	2003	NO_2	8592
100118	2007	NO_2	8736
100118	2003	O_3	8664
100118	2006	O_3	8640
100118	2002	PM10	5280
100118	2003	PM10	6288
100118	2007	PM10	8712
100118	2000	NO	8640
100118	2002	NO_x	6504
100118	2003	NO_x	8592
100118	2007	NO_x	8736
100118	2003	CO	8712
100118	2006	CO	8736
50204	2007	O_3	8040
50204	2003	PM2.5	6264

Table D-2: Comparison of Calculated Annual Means with (MOE, 2008)

ID	City	Pollutants	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
12008	Windsor Downtown	CO	-3%	2%	8%	12%	9%	-	3%	3%	2%	1%
12008	Windsor Downtown	NO	0%	0%	0%	0%	0%	-	0%	0%	0%	0%
12008	Windsor Downtown	NO_X	0%	0%	0%	0%	0%	-	0%	0%	0%	0%
12008	Windsor Downtown	SO_2	0%	1%	0%	0%	-1%	0%	0%	0%	0%	0%
12008	Windsor Downtown	NO_2	0%	0%	0%	0%	0%	-	0%	0%	0%	0%
12008	Windsor Downtown	O_3	0%	0%	0%	0%	0%	0%	0%	3%	0%	0%
12008	Windsor Downtown	PM2.5	-	-	-	-	-	-	-	-	-	-
12016	Windsor West	CO	-	-	-	-	-	-	-	-	-	-
12016	Windsor West	NO	-	-	-	-	-	-	-	-	-	-
12016	Windsor West	NO_X	-	-	-	-	-	-	-	-	-	-
12016	Windsor West	SO_2	0%	0%	0%	0%	0%	-1%	1%	0%	-1%	0%
12016	Windsor West	NO_2	-	-	-	-	-	-	-	-	-	-
12016	Windsor West	O_3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
12016	Windsor West	PM2.5	-	-	-	-	-	-	-	-	-	-
31103	Toronto Downtown	CO	-	-	-	-	-	-	-	-	-	-
31103	Toronto Downtown	NO	0%	0%	0%	0%	0%	0%	0%	-1%	-1%	0%
31103	Toronto Downtown	NO_X	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
31103	Toronto Downtown	SO2	-	-	-	-	-	-	-	-		-
31103	Toronto Downtown	O_3	-	-	-	-	-	-	-	-	-	-
31103	Toronto Downtown	NO_2	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
31103	Toronto Downtown	PM2.5	-	-	-	-	-	-	-	-	-	-
35003	Toronto West	CO	-	-	-	-	-	-	-	-	-	-
35003	Toronto West	NO	-	-	-	-	-	-	-	-	-	-
35003	Toronto West	NO_X	-	-	-	-	-	-	-	-	-	-
35003	Toronto West	SO_2	-	-	-	-	-	-	-	-	-	-
35003	Toronto West	O_3	-	-	-	-	-	-	-	-	-	-
35003	Toronto West	NO_2	-	-	-	-	-	-	-	-	-	-
35003	Toronto West	PM2.5	-	-	-	-	-	-	-	-	-	-

Table D-3: Comparison of Calculated Annual Mean with NAPS (NAPS, 2010)

ID	CITY	POLLUTANT	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
50103	Montreal 1	SO_2	0%	0%	0%	0%	0%	0%	0%	0%	-	-
50103	Montreal 1	CO	0%	0%	0%	0%	0%	0%	0%	0%	-	-
50103	Montreal 1	NO_2	0%	0%	0%	0%	0%	0%	0%	0%	-	-
50103	Montreal 1	O_3	0%	0%	0%	0%	0%	0%	0%	0%	-	-
50103	Montreal 1	NO	0%	0%	0%	0%	0%	0%	0%	0%	-	-
50115	Montreal 2	SO_2	0%	0%	0%	0%	0%	0%	-	-	-	-
50115	Montreal 2	CO	0%	0%	0%	0%	0%	0%	0%	0%	-	-
50115	Montreal 2	NO_2	0%	0%	0%	0%	0%	0%	0%	0%	-	-
50115	Montreal 2	O_3	0%	0%	0%	0%	0%	-	-		-	-
50115	Montreal 2	NO	0%	0%	0%	0%	0%	0%	0%	0%	-	-
90130	Edmonton	CO	0%	0%	0%	0%	0%	0%	0%	0%	-	-
90130	Edmonton	NO_2	0%	0%	0%	0%	0%	0%	0%	0%	-	-
90130	Edmonton	O_3	0%	0%	0%	0%	0%	0%	0%	0%	-	-
90130	Edmonton	NO	0%	0%	0%	0%	0%	0%	0%	-1%	-	-
90130	Edmonton	NO_X	0%	0%	0%	0%	0%	0%	0%	0%	-	-
90227	Calgary	CO	0%	0%	0%	0%	0%	0%	0%	0%	-	-
90227	Calgary	NO_2	0%	0%	0%	0%	0%	0%	0%	0%	-	-
90227	Calgary	O_3	0%	0%	0%	0%	0%	0%	0%	0%	-	-
90227	Calgary	NO_X	0%	0%	0%	0%	0%	0%	0%	0%	-	-
90227	Calgary	PM10	0%	0%	0%	0%	0%	0%	0%	0%	-	-
100118	Vancouver	SO_2	0%	0%	0%	0%	0%	0%	0%	0%	-	-
100118	Vancouver	CO	0%	0%	0%	0%	0%	0%	0%	0%	-	-
100118	Vancouver	NO_2	0%	0%	0%	0%		0%	0%	0%	-	-
100118	Vancouver	O_3	0%	0%	0%	0%	0%	0%	0%	0%	-	-
100118	Vancouver	NO	0%	0%	0%	0%	-	0%	0%	0%	-	-
100118	Vancouver	NO_X	0%	0%	0%	0%	-	0%	0%	0%	-	-
100118	Vancouver	PM10	0%	0%	0%	0%	-	-	-	0%	-	-
30118	Halifax	SO_2	0%	-	0%	0%	-	0%	0%	-	-	-
30118	Halifax	CO	0%	-	-	0%	0%	0%	0%	-	-	-
30118	Halifax	NO_2	0%	-	0%		-	-	-	-	-	-
30118	Halifax	O_3	0%	-		0%	0%		0%	0%	-	-
30118	Halifax	NO	0%	-	0%	-	-	-	-	-	-	-
30118	Halifax	NO_X		-	0%	-	-	-	-	-	-	-
50204	Hull	SO_2	0%	0%	0%	0%	0%	0%	0%	0%	-	-
50204	Hull	CO	0%	0%	0%	0%	0%	0%	0%	0%	-	-
50204	Hull	NO_2	0%	0%	0%	0%	0%	0%	0%	0%	-	-
50204	Hull	O_3	0%	0%	0%	0%	0%	0%	0%	0%	-	-
50204	Hull	NO_X	0%	0%	0%	0%	0%	0%	0%	0%	-	-

APPENDIX E POLLUTION ROSE MANUAL

Step 1: Arrange hourly weather data files in succession from 1998-2007. Wind direction is in degree format. *Software Excel*

Step 2: Arrange hourly concentration data files in succession from 1998-2007. Excel Format [date-hour-concentration]

Step 3: Merge concentration data files in step 2 and weather data file in step 1 in a single excel spread sheet. This will enable to counter check any missing data.

Step 4: Copy and paste the variable **wind direction** and **concentration** from step 3 file into Minitab. Next unstack concentration in the Minitab by using subscript in the wind direction. This will results in bracketing placing concentration with respect to 10 degree band (10, 20, 30, 40,……350, 360).

Step 5: Copy Minitab unstacked column into a new excel sheet to calculate the percentile value of concentration. Insert a new column in this excel sheet immediately before the first column. The number 5, 25, 50, 75, 95 are inserted consecutively in the rows of the first column. These values indicate the *radius axis* of the pollution rose. This is done in order to represent the percentile values of concentration. Insert row immediately above the percentile values. Insert the average values of (0-10, 10-20, 20-30,…….. 340-350) in this row and the second column. This row represents the angle axis of the pollution rose.

Step 6: Calculate the 5th, 25th, 50th, 75th and 95th percentile values for the concentration column listed in the degree interval (0-10, 10-20….340-350). For example:

5th Percentile = Percentile (Array, 0.05)

Step 7: Calculate the Inter-percentile range between 5th and 25th percentile by subtracting 5th percentile value of concentration from the 25th percentile. Repeat this for 75th and 95th percentile values of concentrations. The 5th percentile being the lowest one is not subtracted.

Step 8: Import transposed matrix into **Grapher software** and draw polar bar charts.

Step 9: Identify percentile values with different colours indicating percentile concentrations.

APPENDIX F:LONG TERM TREND ANALYSIS
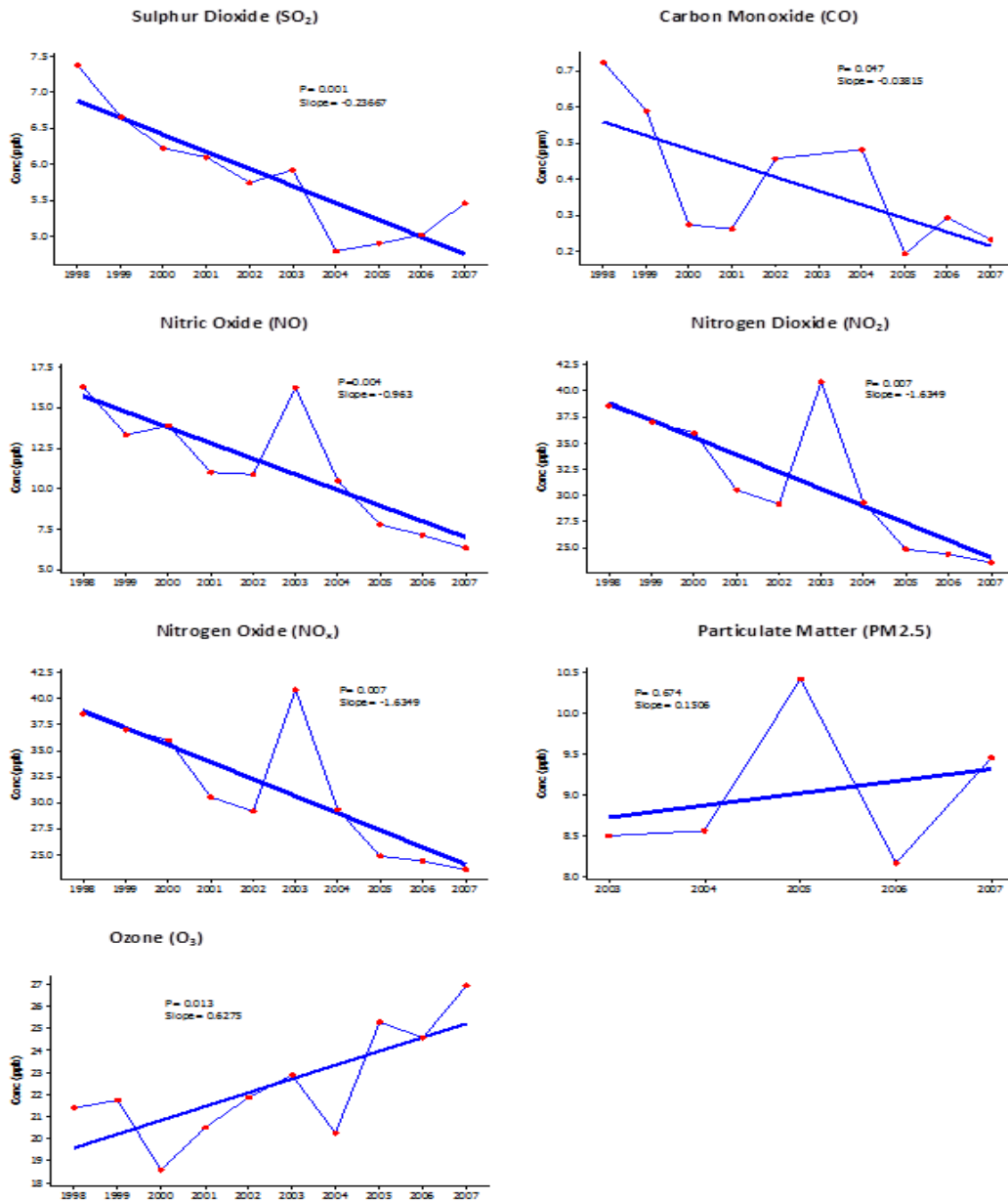
Fig F-1: Annual Mean Trend Windsor Downtown (12008) 1998-2007.
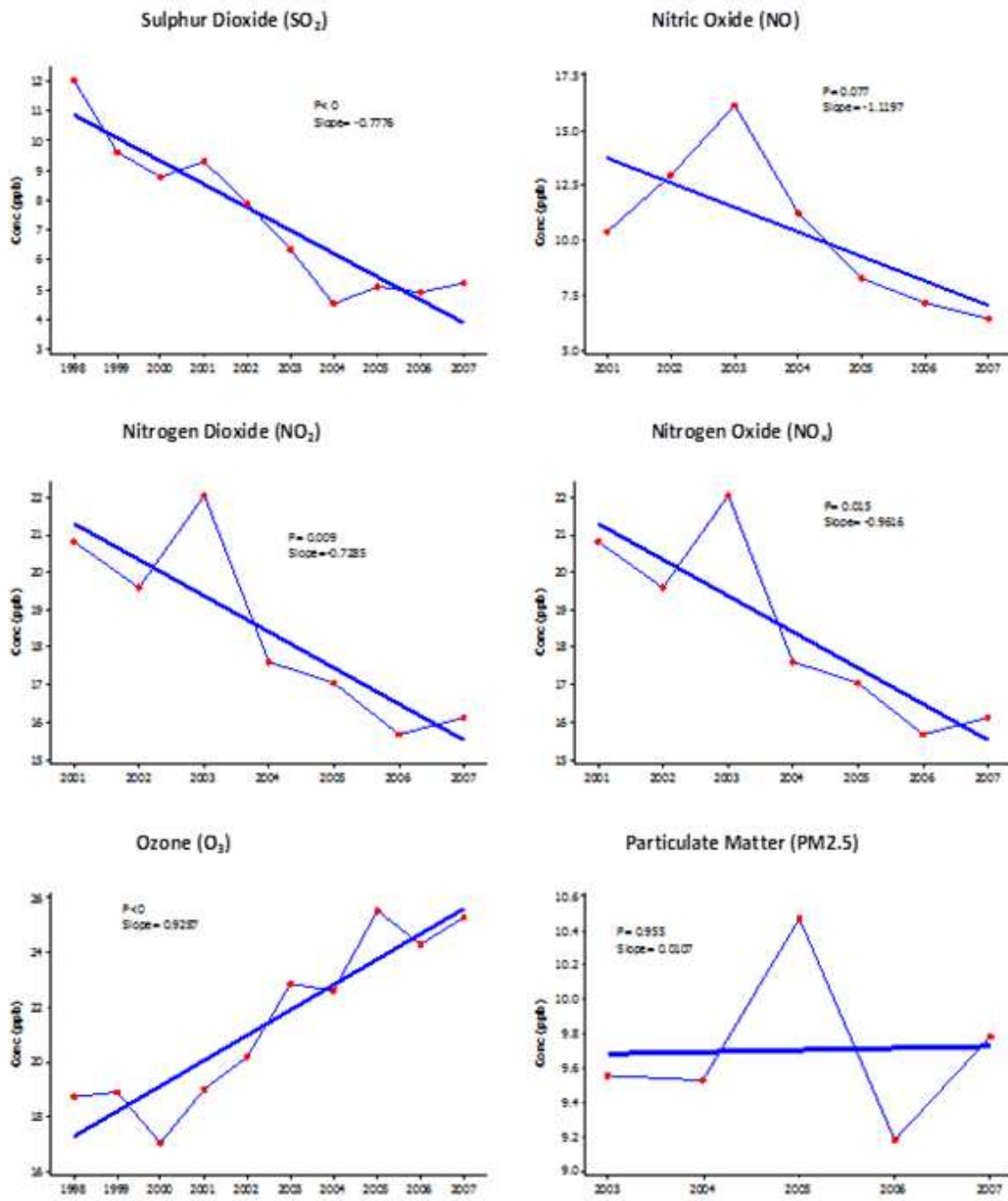
Fig F-2: Annual Mean Trend Windsor West (12016) 1998-2007.
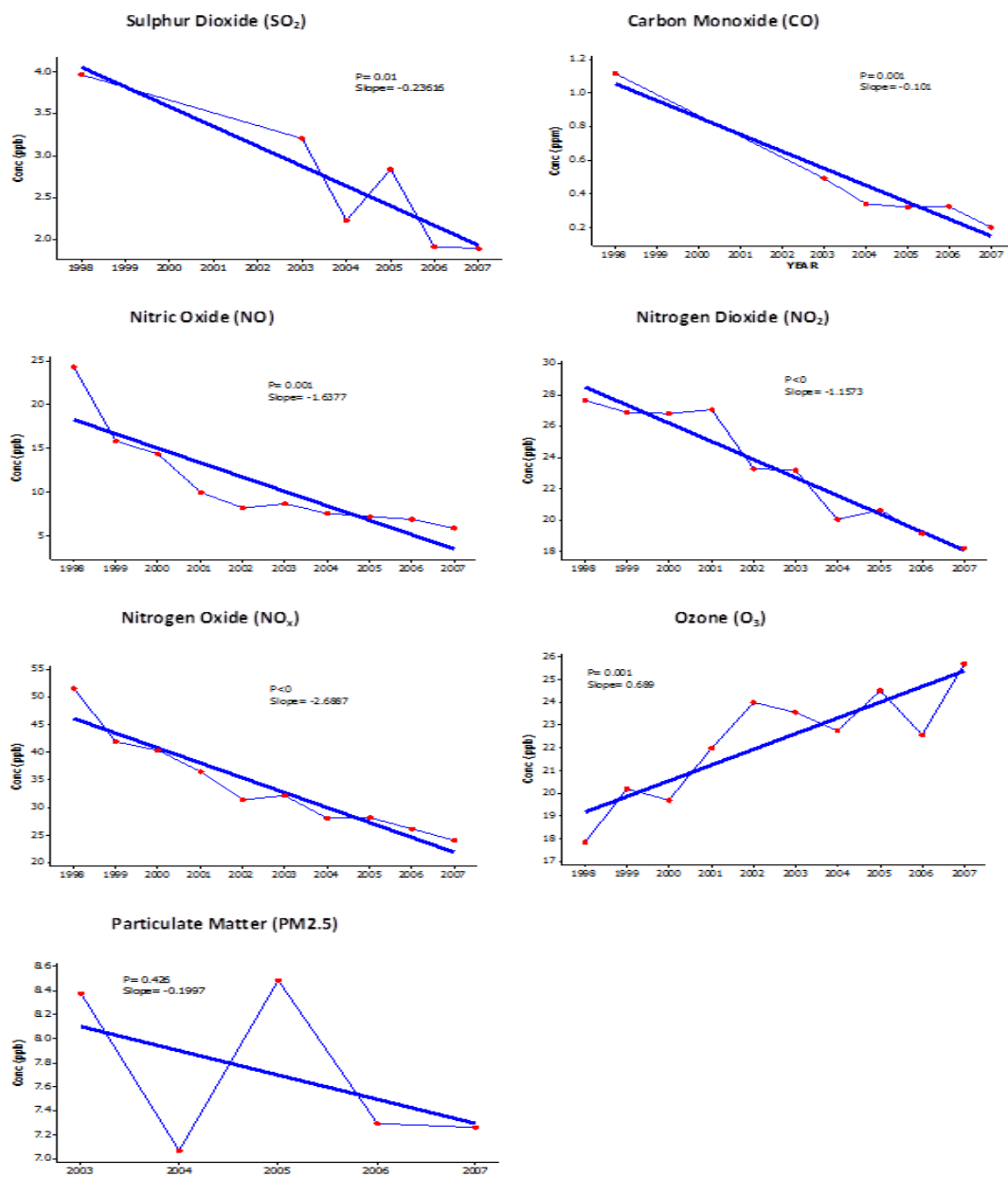
Fig F-3: Annual Mean Trend Toronto Downtown (31103) 1998-2007.
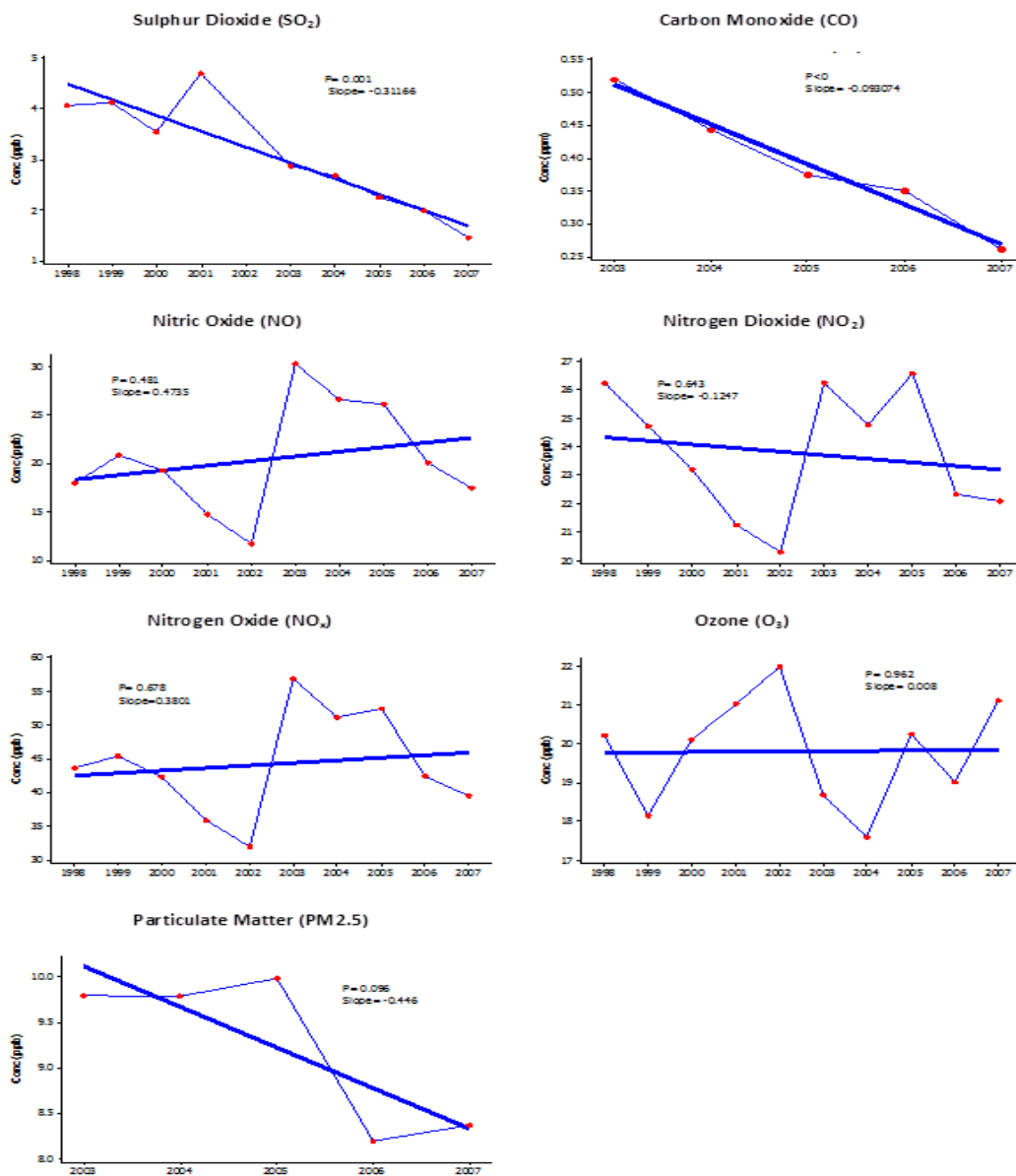
Fig F-4: Annual Mean Trend Toronto West (35003) 1998-2007.
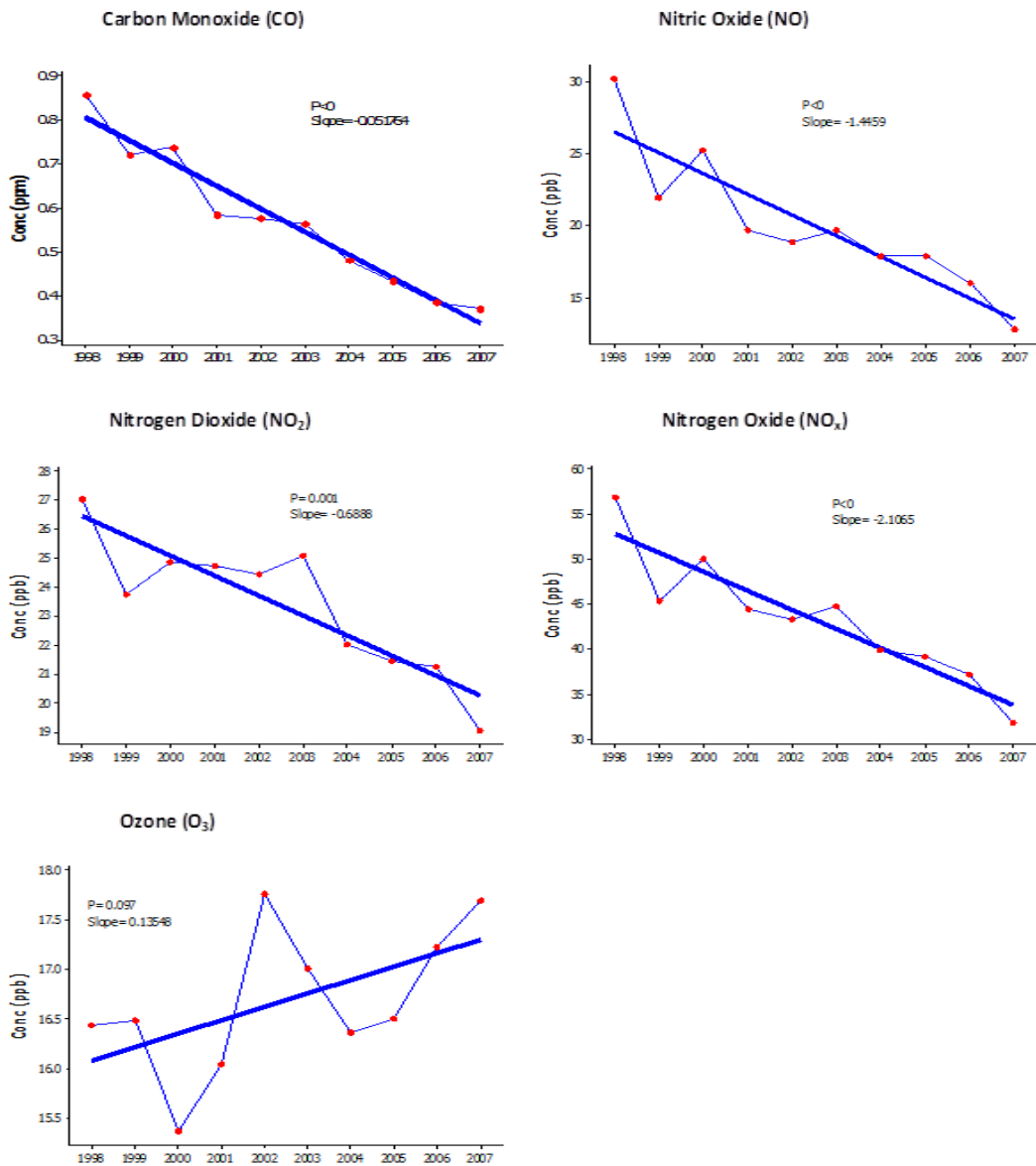
Fig F-5: Annual Mean Trend Edmonton (090130) 1998-2007.
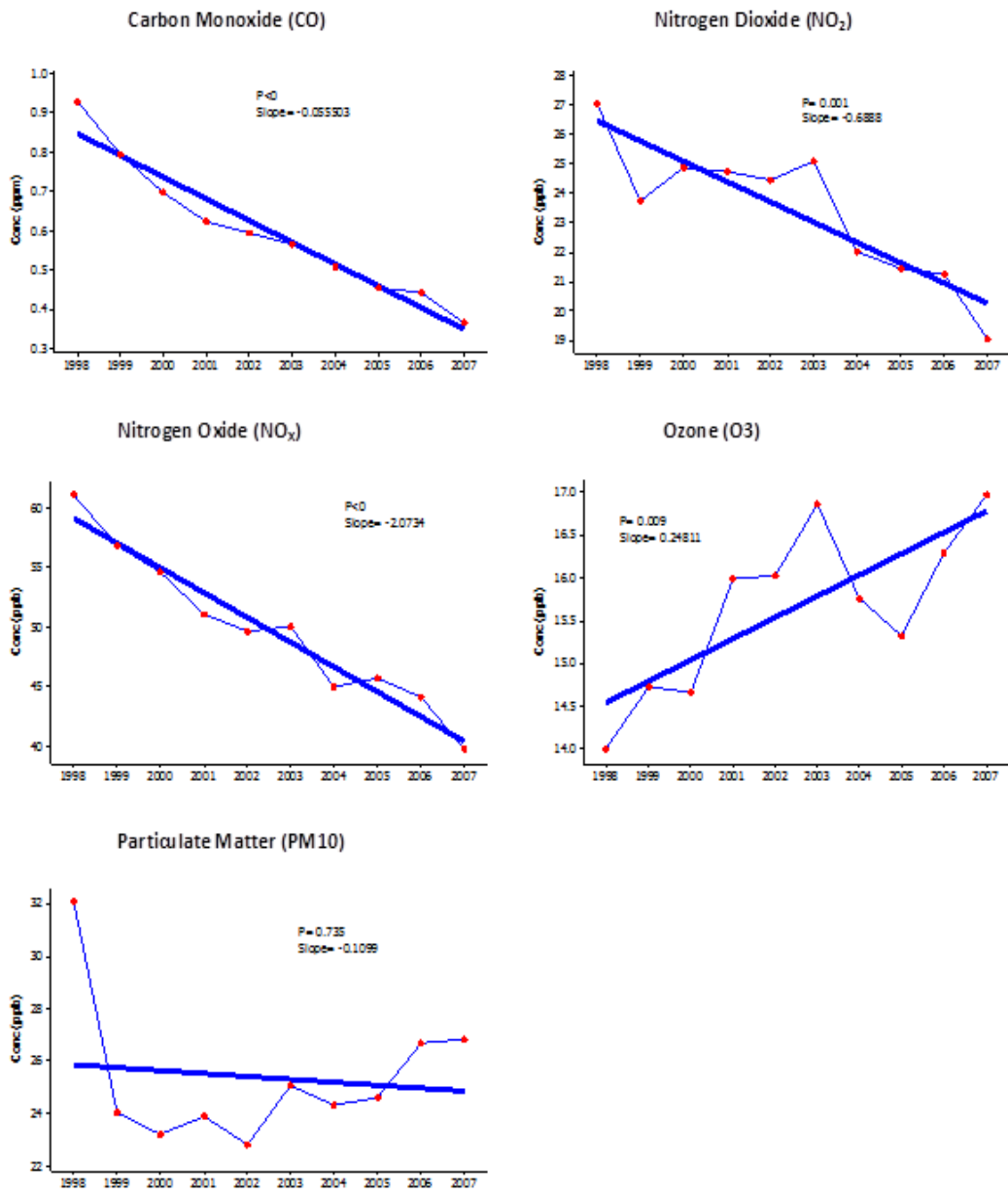
Fig F-6: Annual Mean Trend Calgary (090227) 1998-2007.
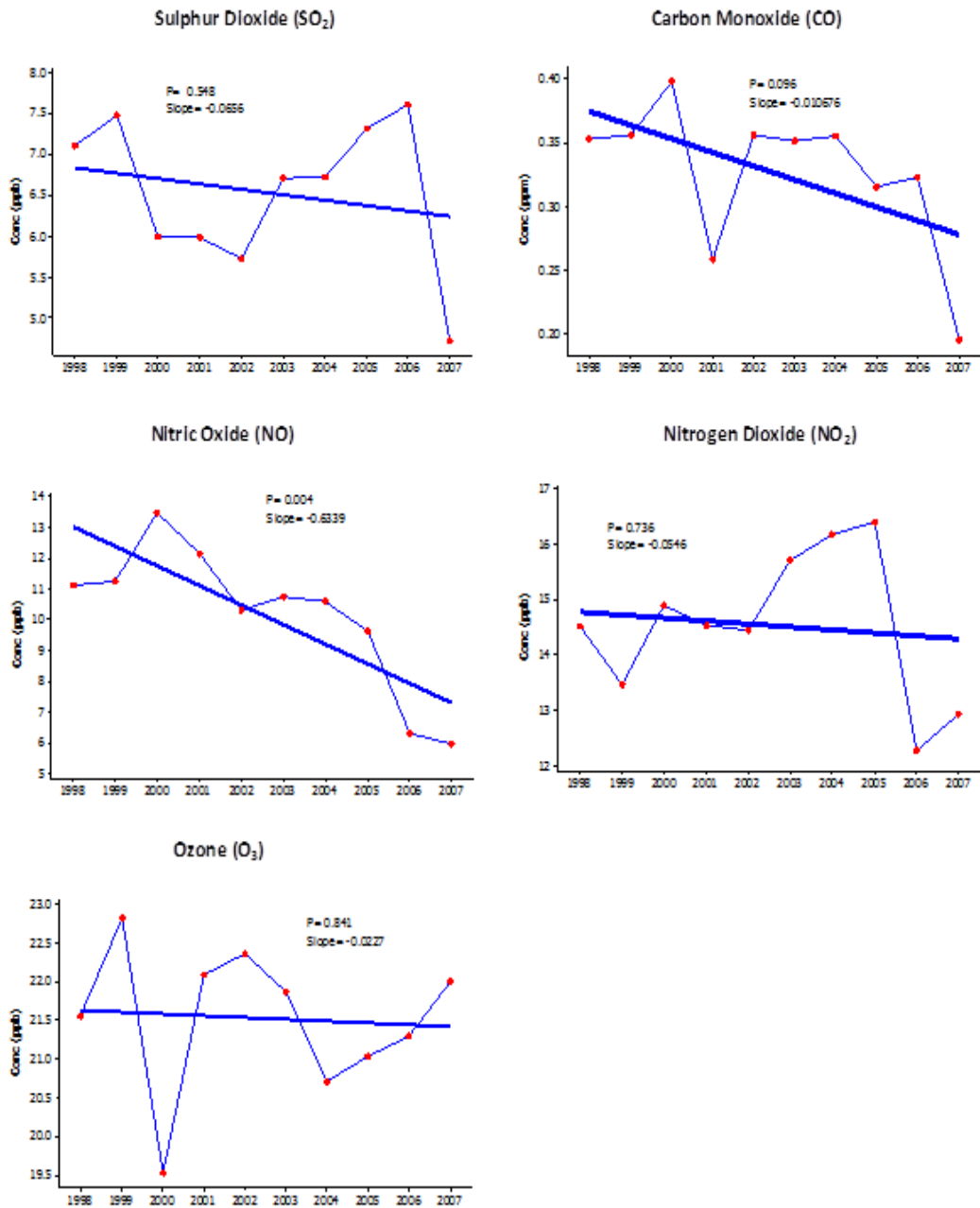
Fig F-7: Annual Mean Trend Montreal 1 (050130) 1998-2007.
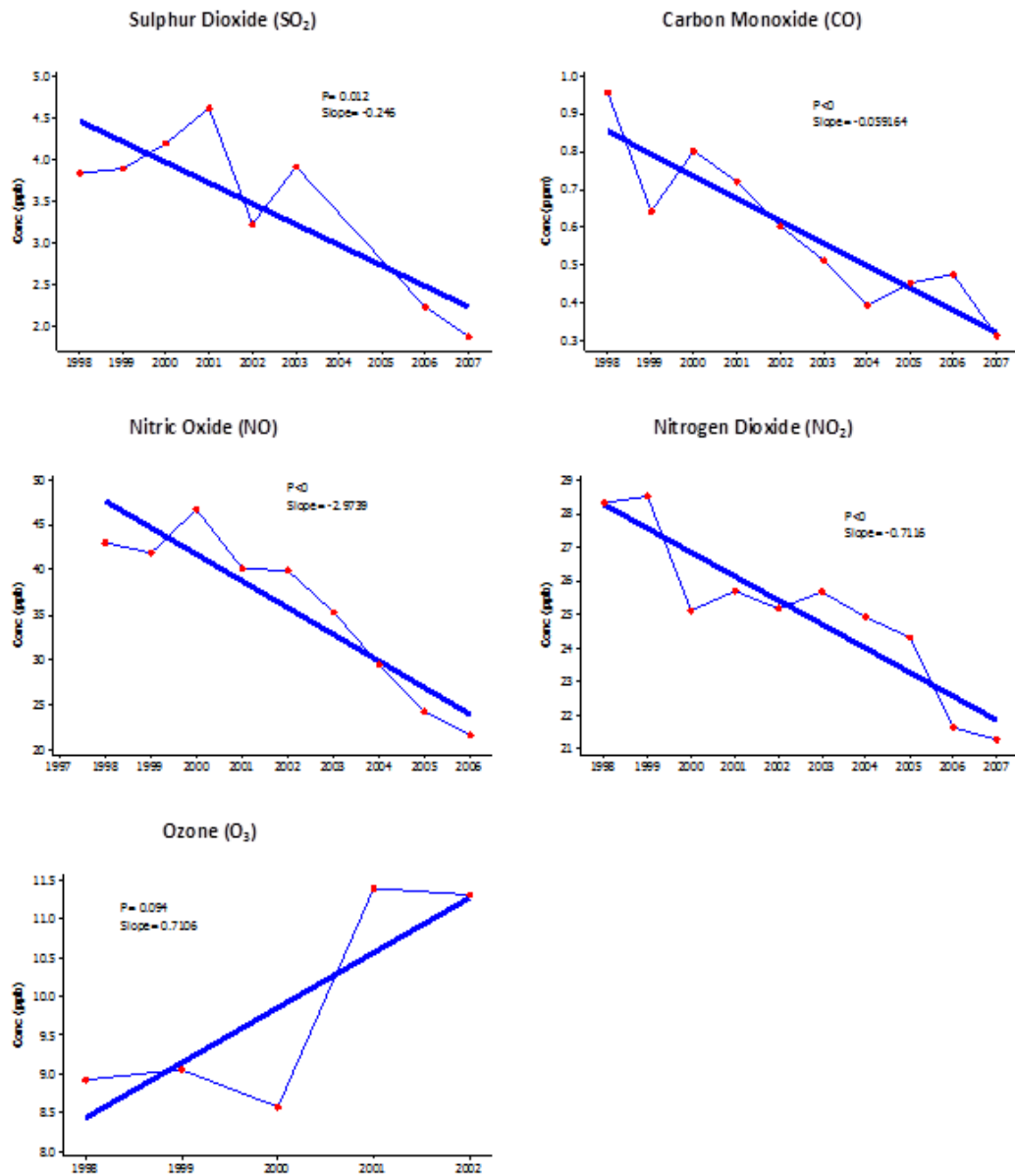
Fig F-8: Annual Mean Trend Montreal 2 (050115) 1998-2007.
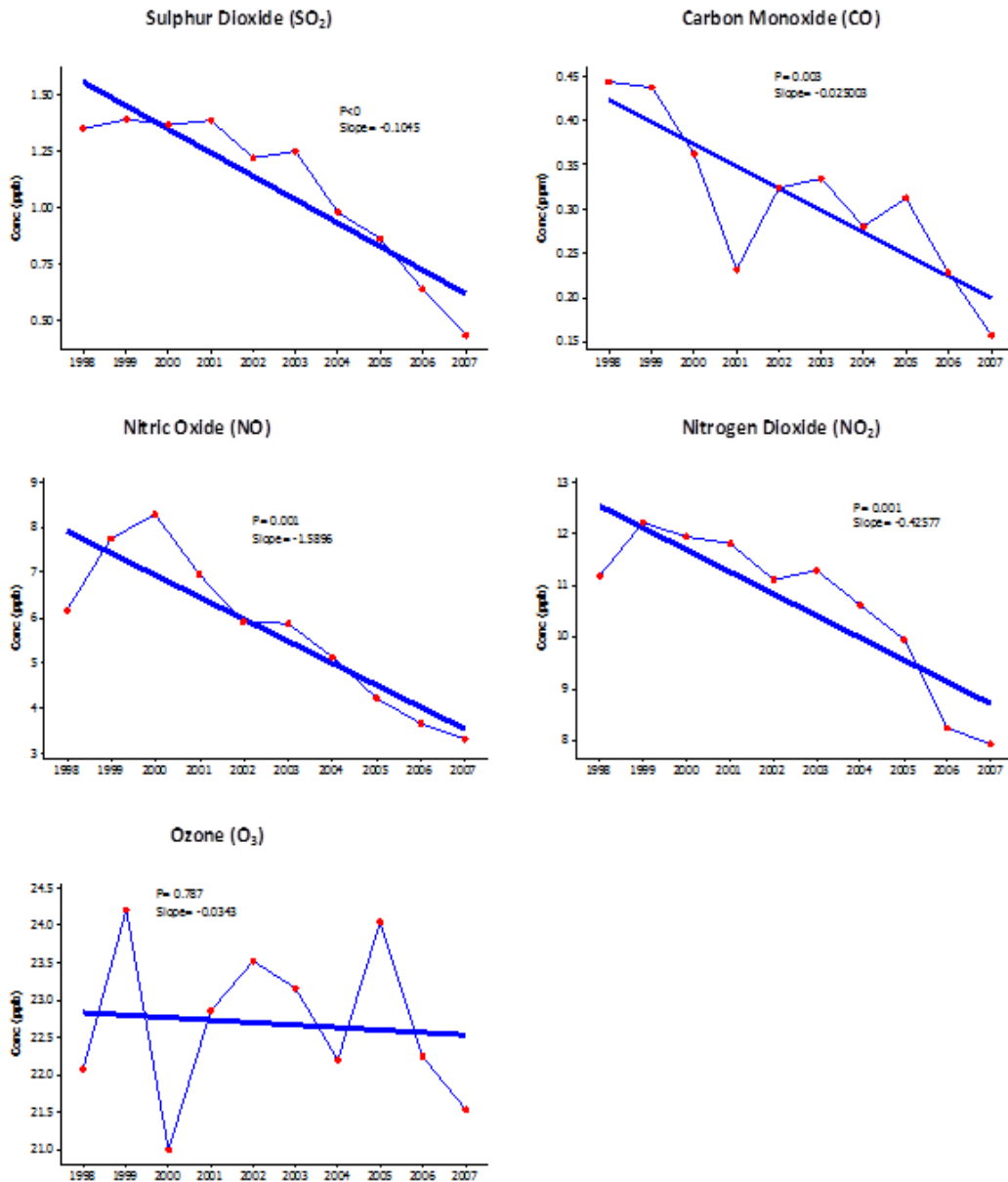
Fig F-9: Annual Mean Trend Hull (050204) 1998-2007.
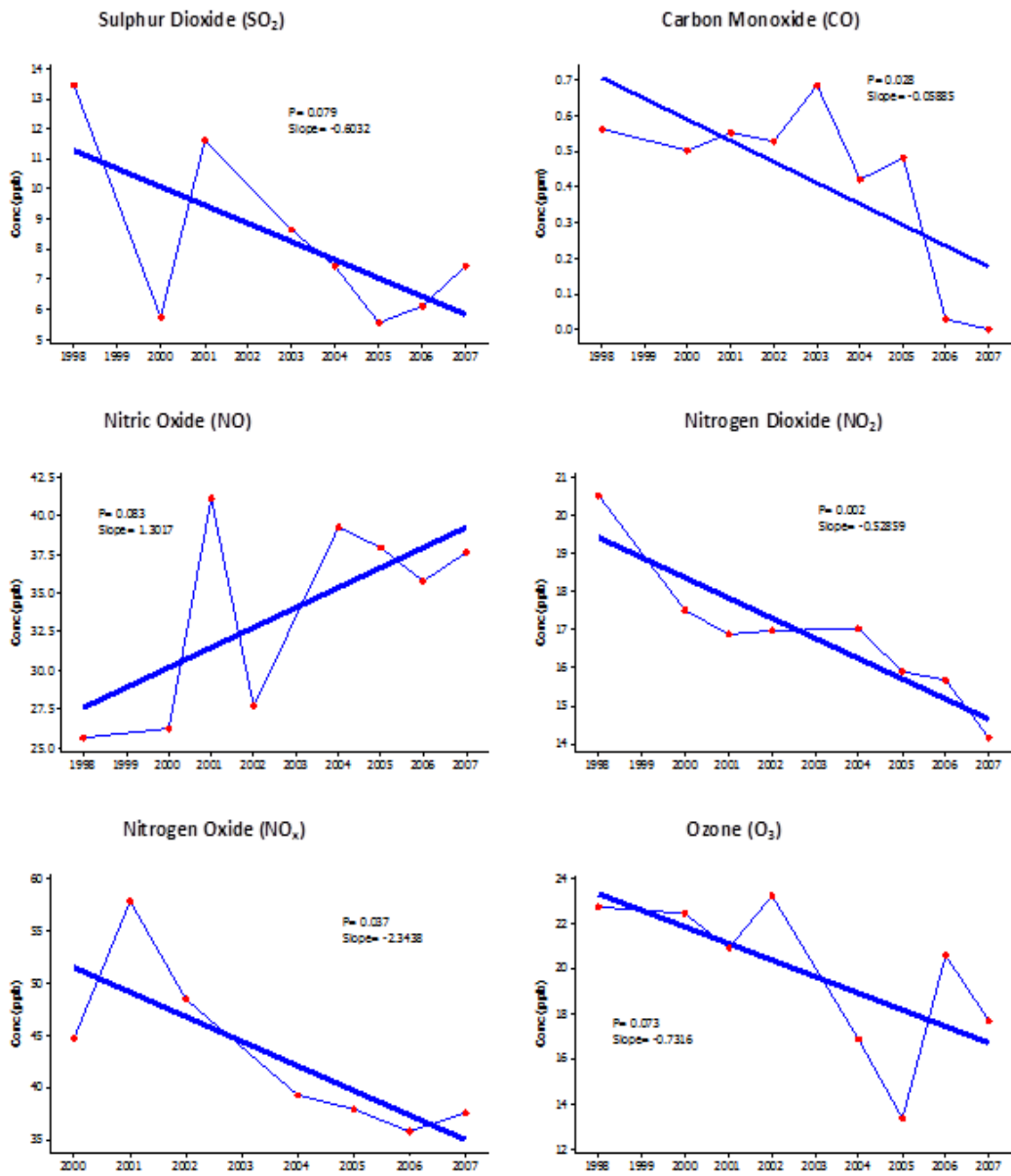
Fig F-10: Annual Mean Trend Halifax (030118) 1998-2007.
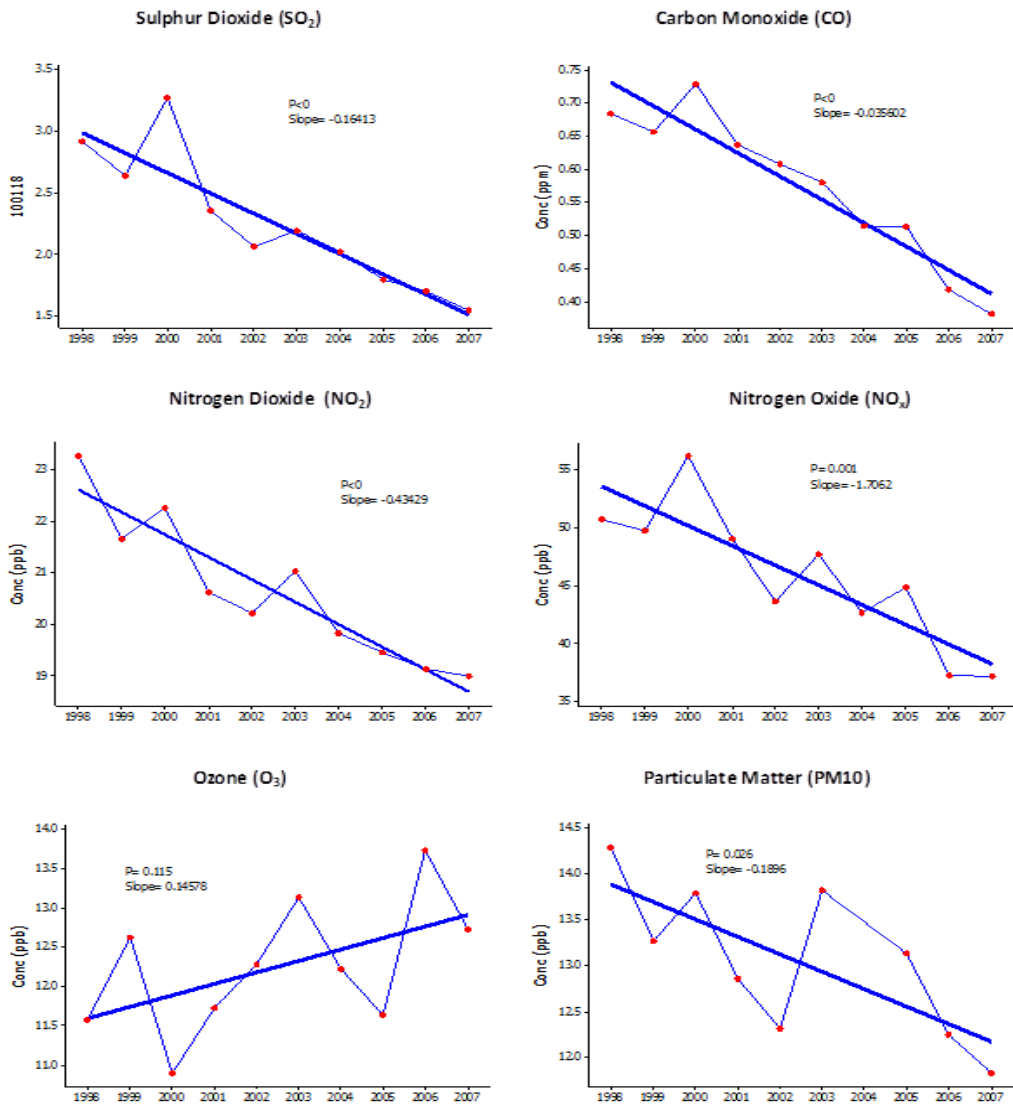
Fig F-11: Annual Mean Trend Vancouver (100118) 1998-2007.
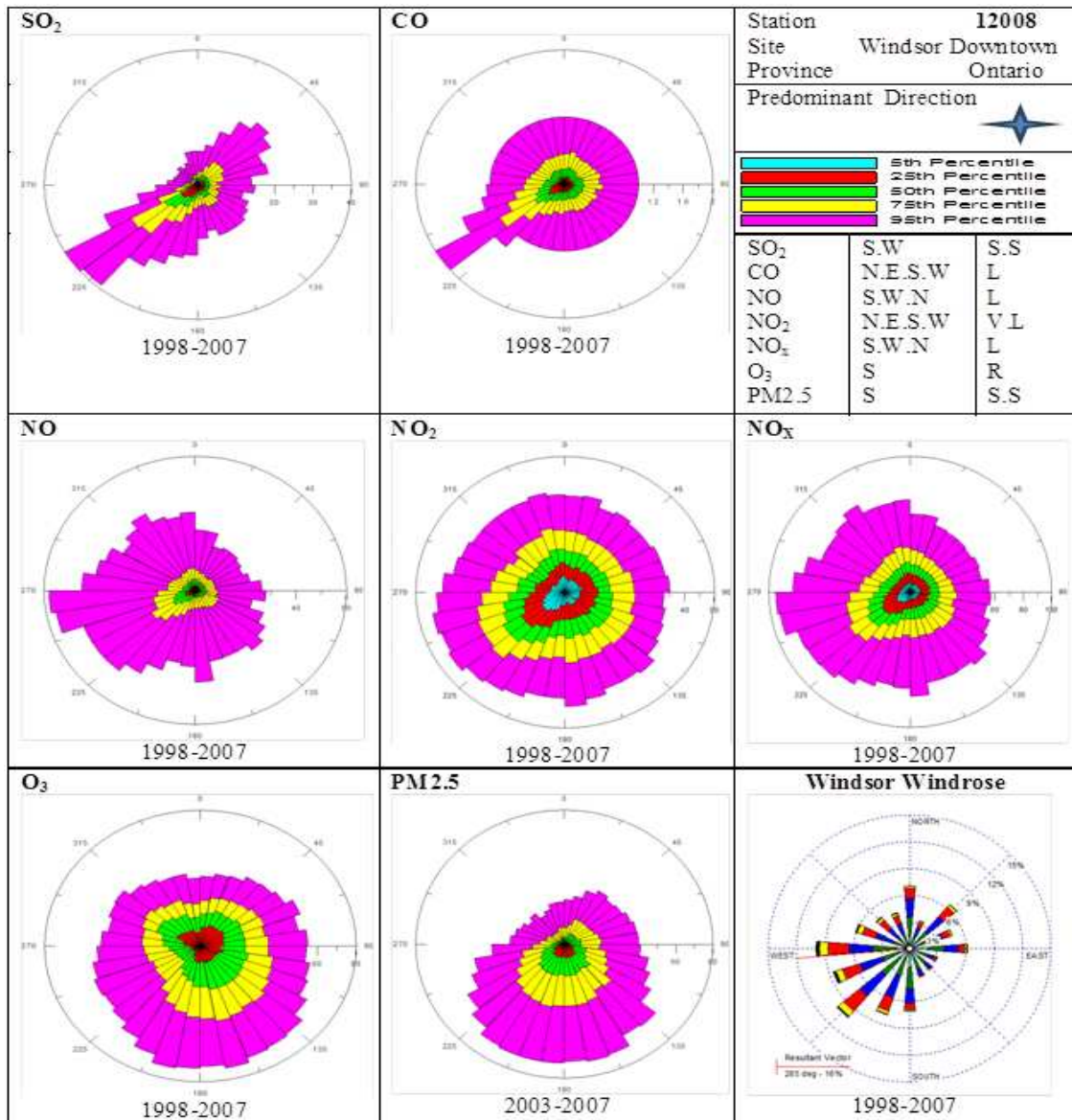
Fig G-1: Windsor Downtown (12008) Wind and Pollution Rose Plots

S.S: Source specific
L: Local
V.L: Very Local
R: Regional
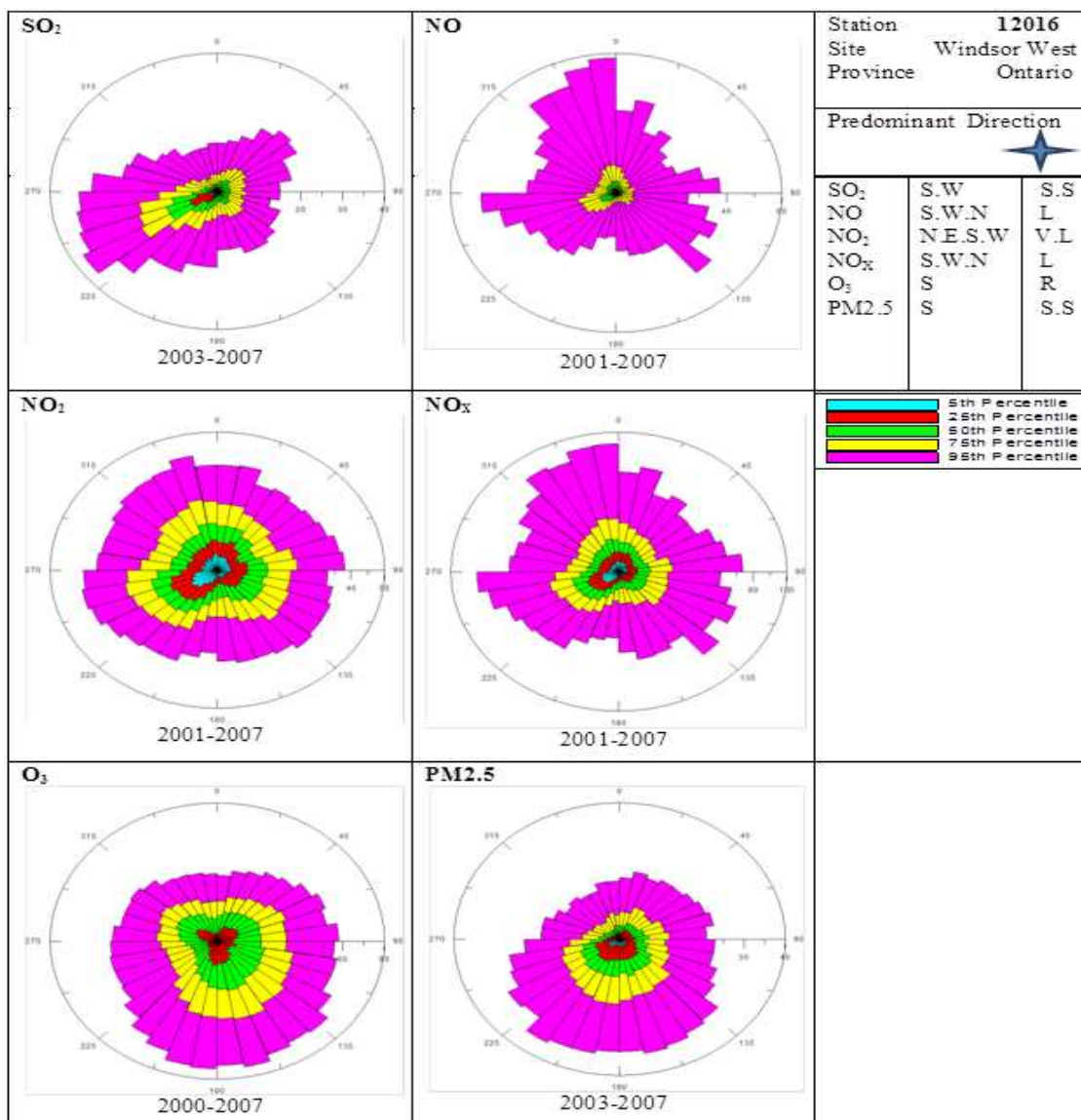
Fig G-2: Windsor West (12016) Wind and Pollution Rose Plots

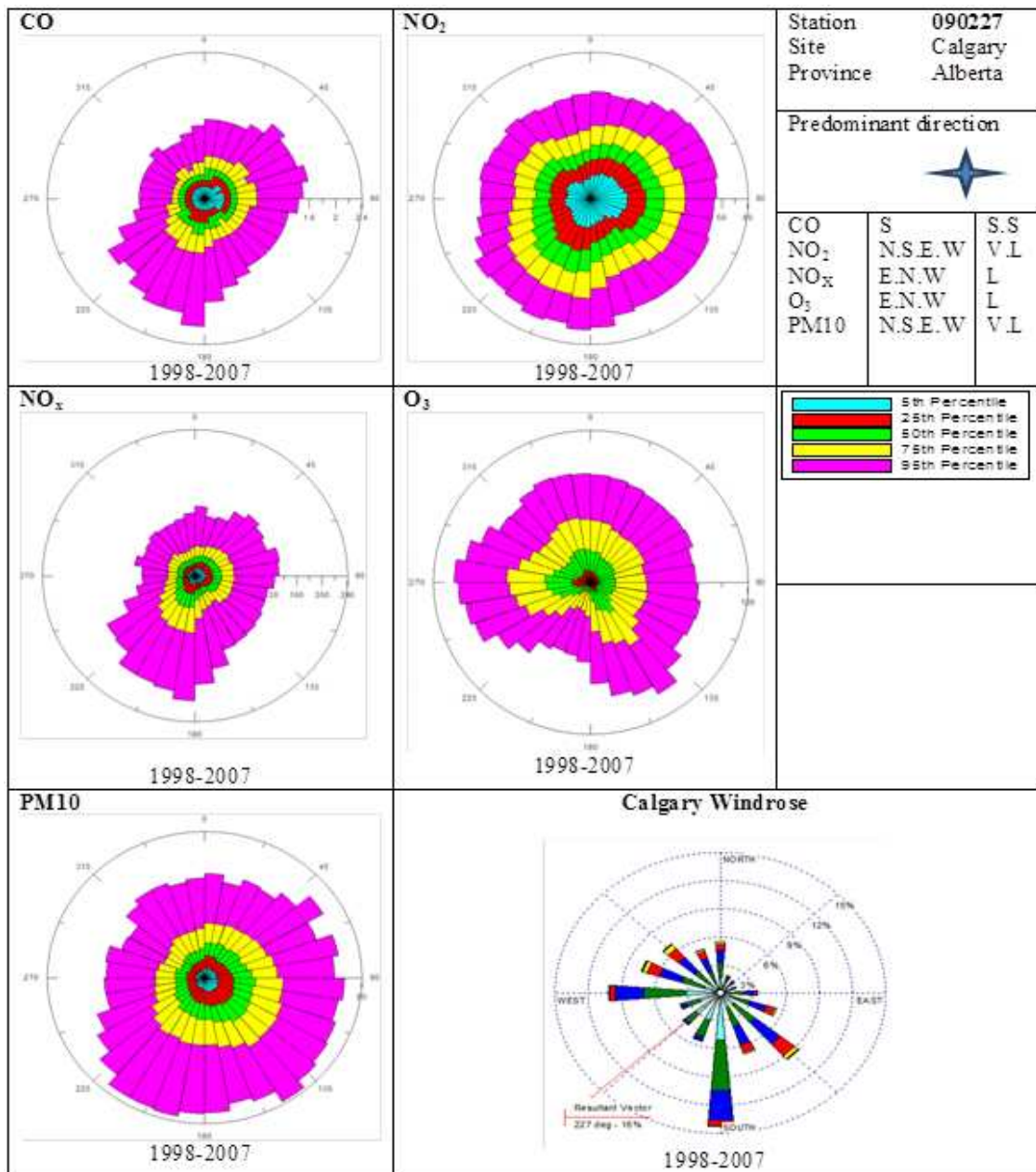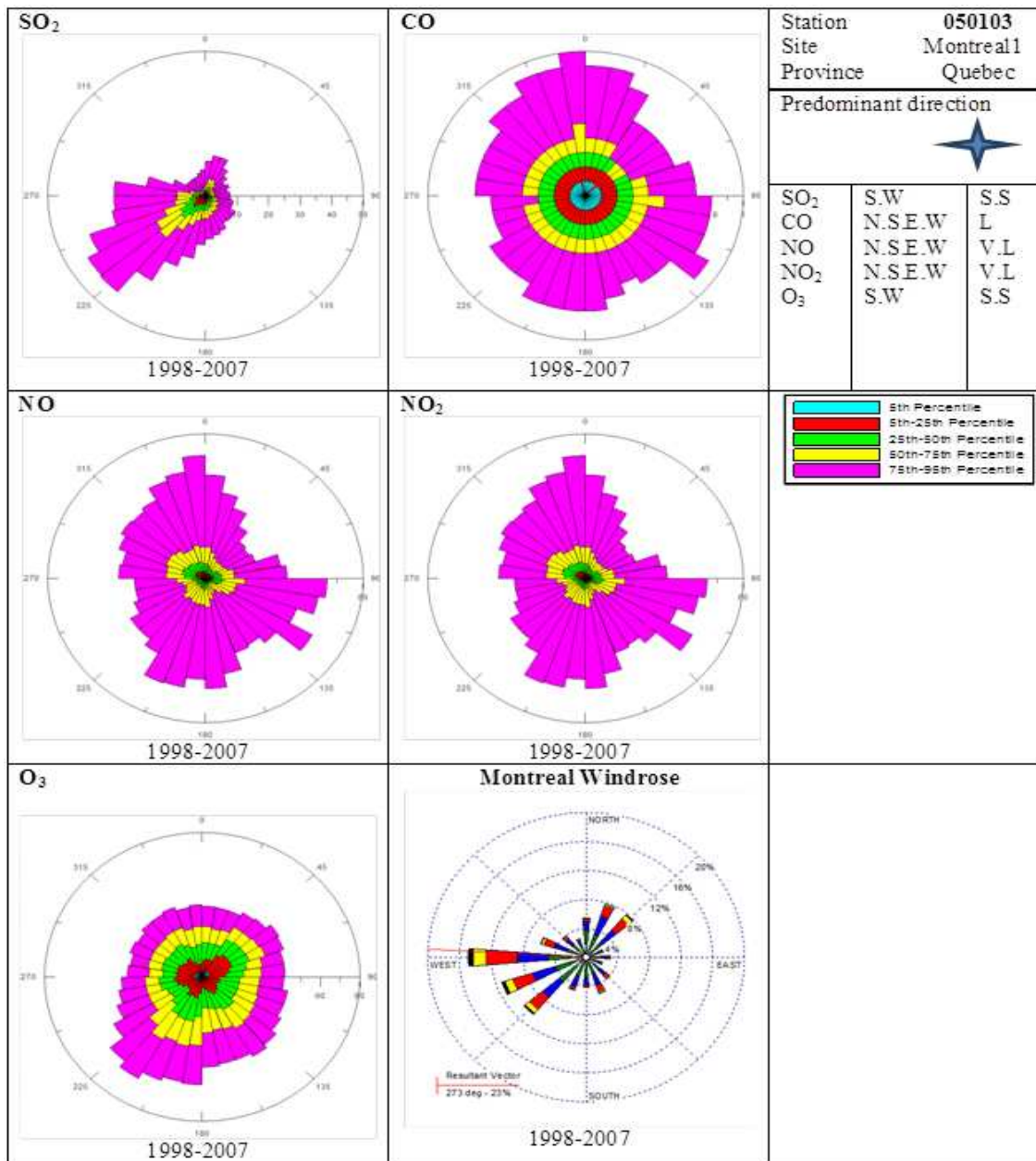S.S: Source specific
L: Local
V.L: Very Local
R: Regional
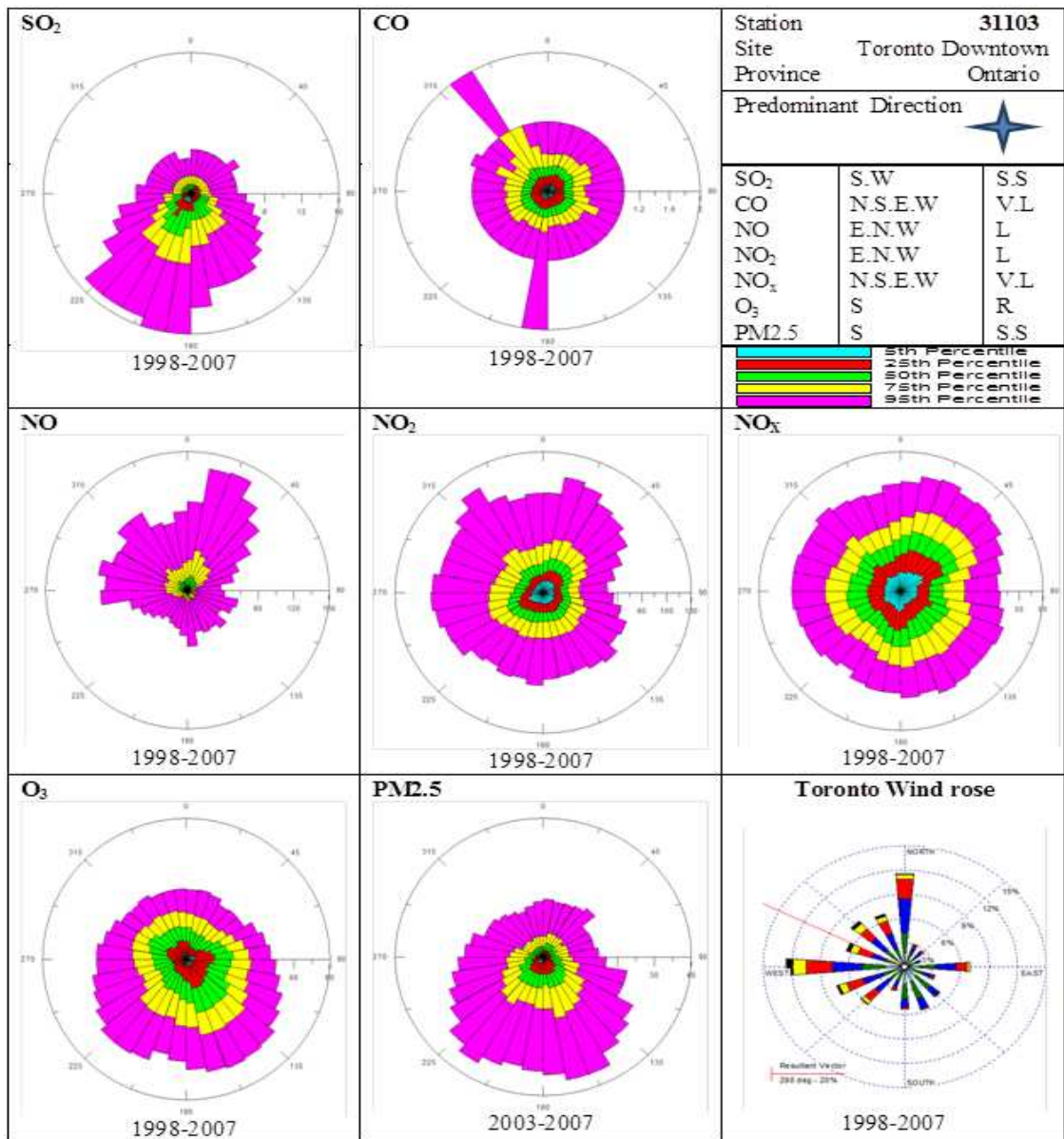
Fig G-3: Toronto Downtown (31103) Wind and Pollution Rose Plots

S.S: Source specific
L: Local
V.L: Very Local
R: Regional
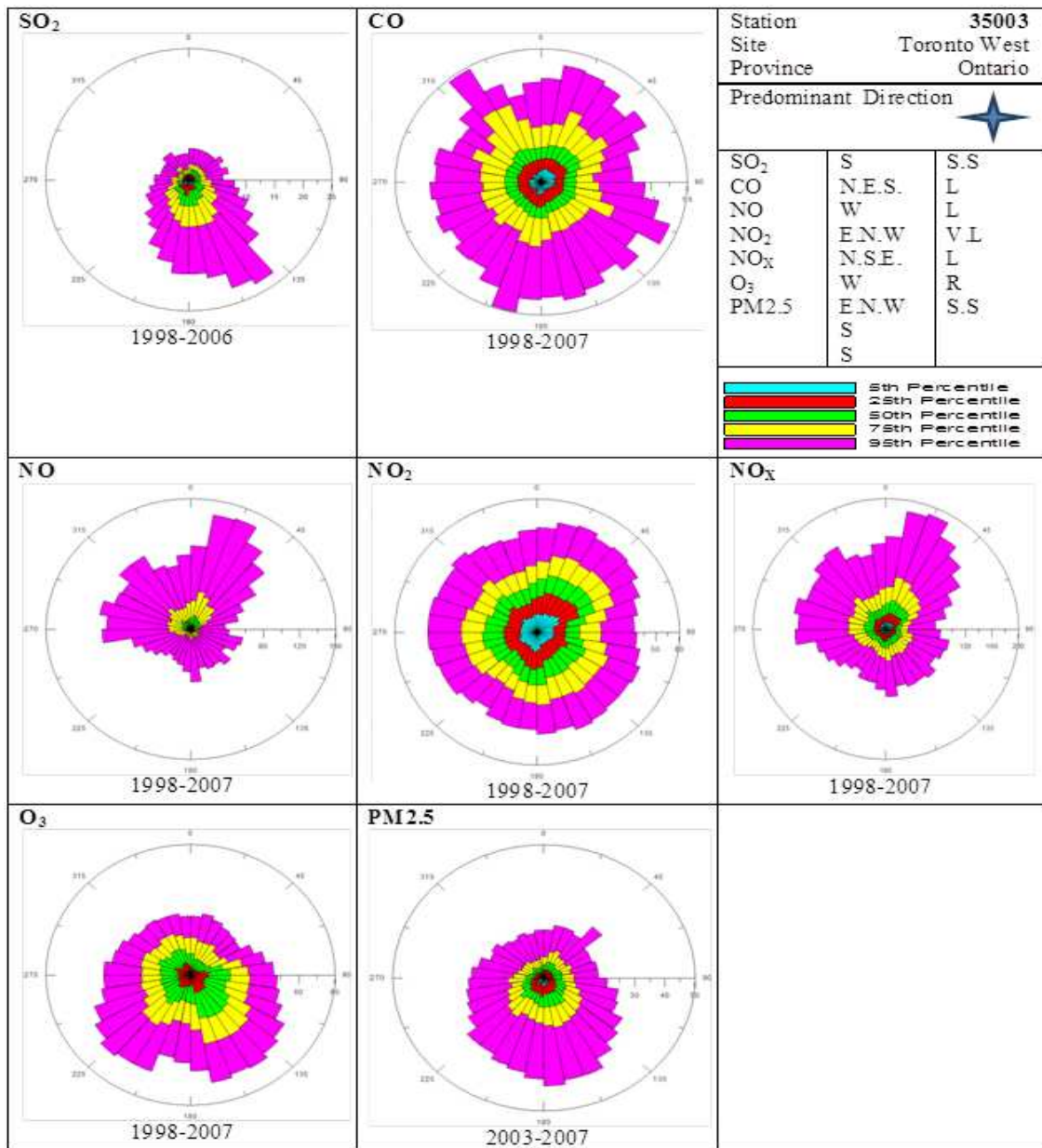
Fig G-4: Toronto West (35003) Wind and Pollution Rose Plots

S.S: Source specific
L: Local
V.L: Very Local
R: Regional
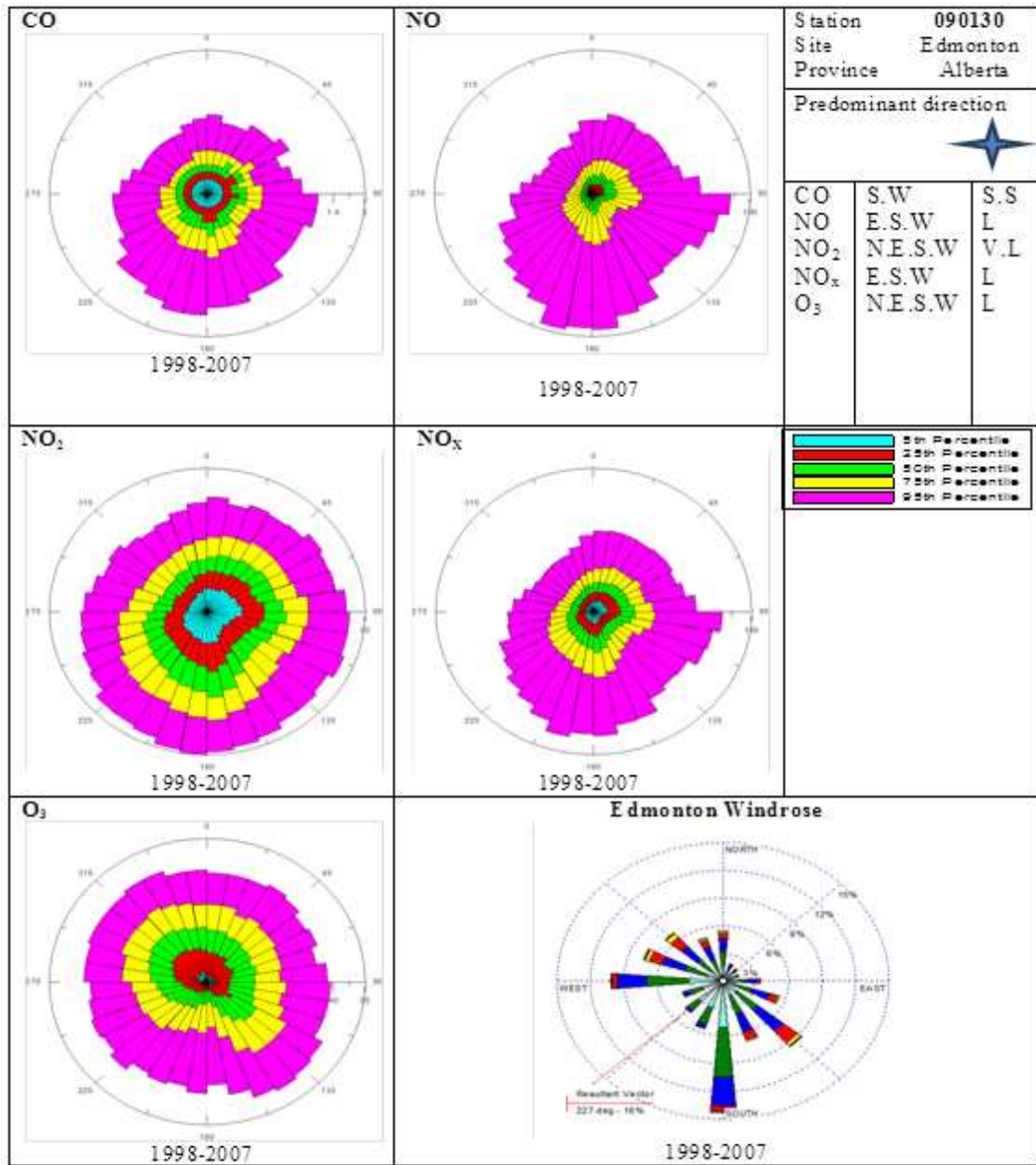
Fig G-5: Edmonton (090130) Wind and pollution rose plots
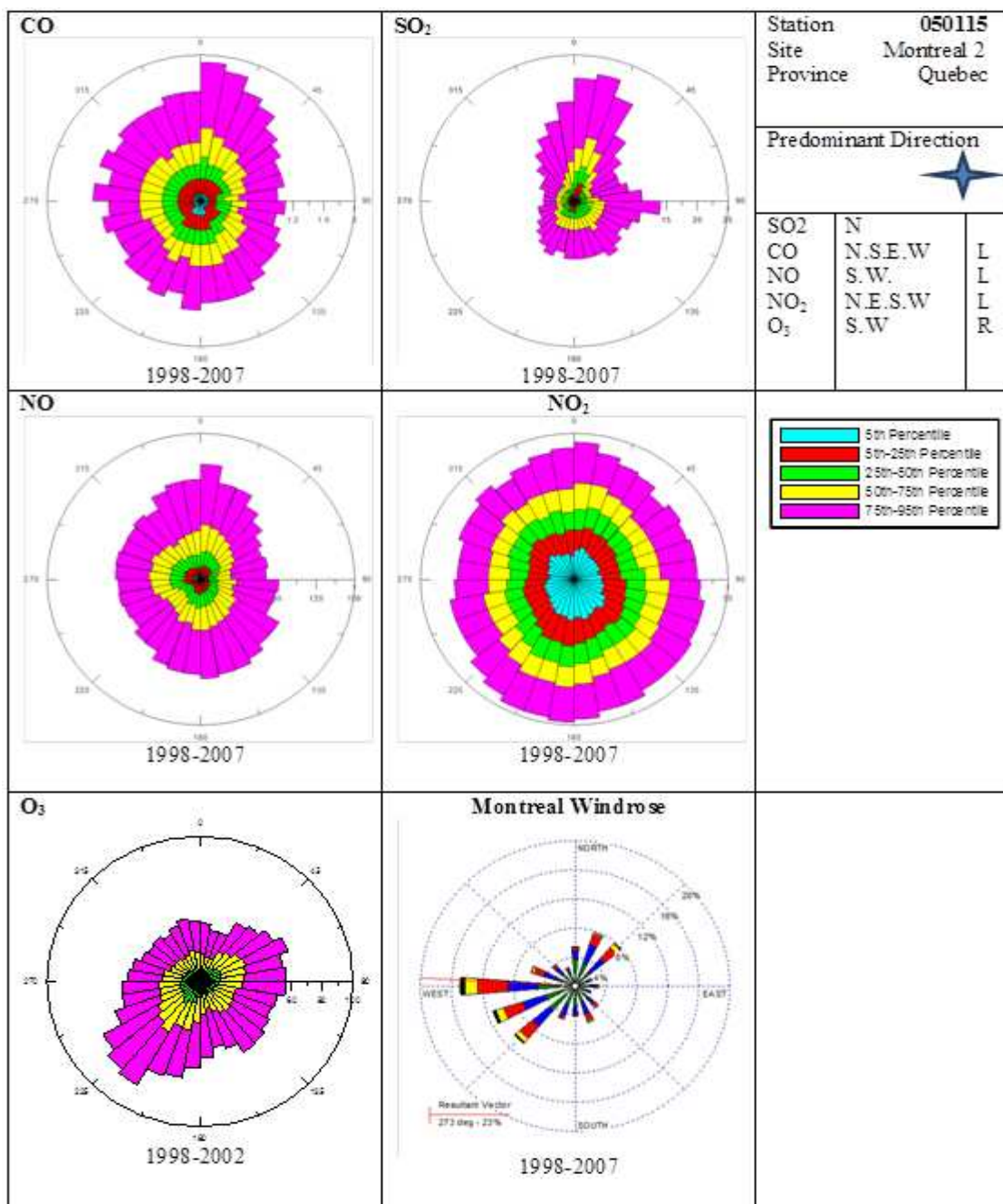
S.S: Source specific
L: Local
V.L: Very Local
R: Regional

Fig G-6: Calgary (090227) Wind and Pollution Rose Plots

S.S: Source specific
L: Local
V.L: Very Local
R: Regional

Fig G-7: Montreal 1 (050130) Wind and Pollution Rose Plots

S.S: Source specific
R: Regional
L: Local
V.L: Very Local

Fig G-8: Montreal 2 (050115) Wind and Pollution Rose Plots

S.S: Source specific
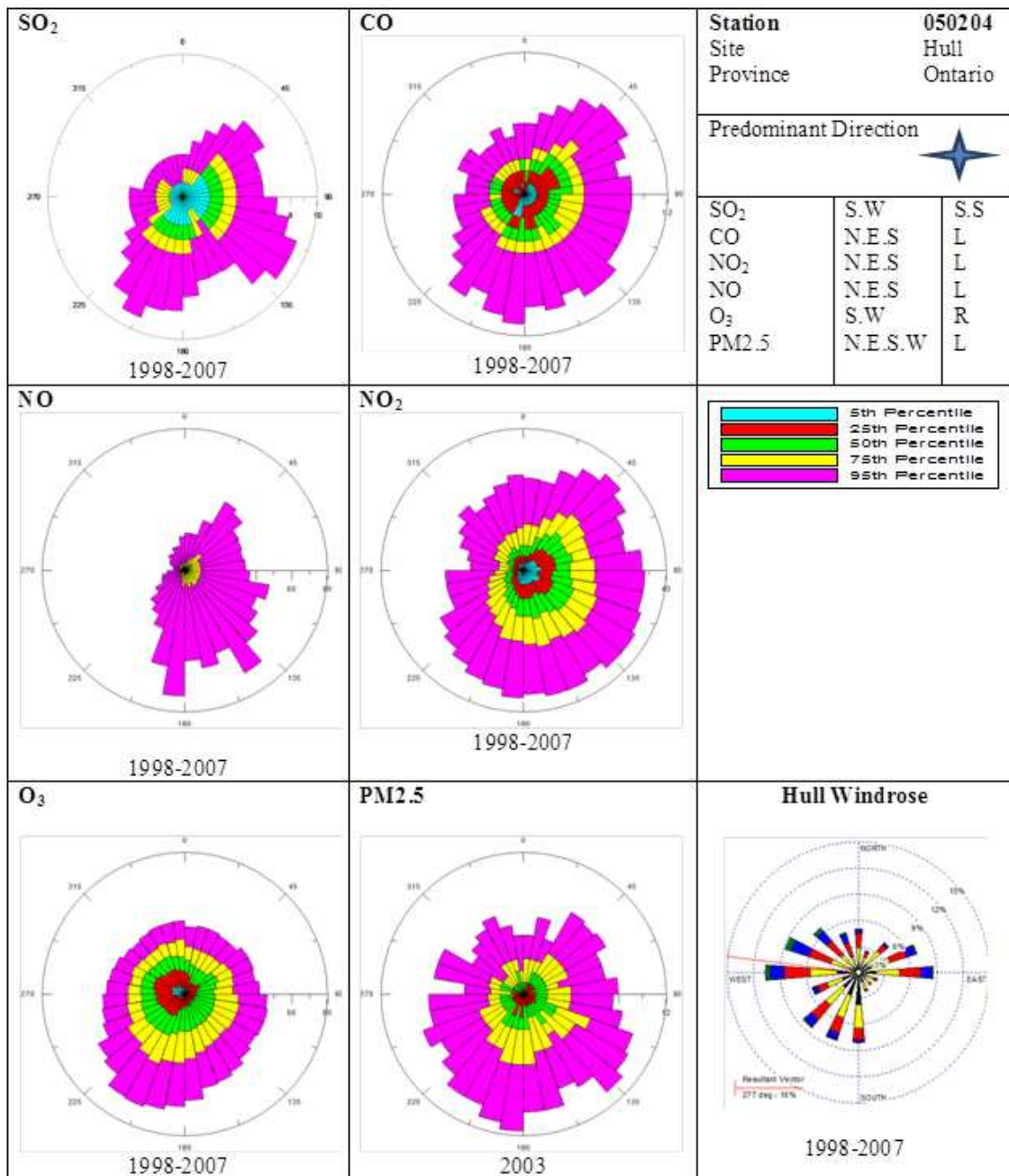L: Local
V.L: Very Local
R: Regional

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Fig G-9: Hull (050204) Wind and Pollution Rose Plots.

S.S: Source specific
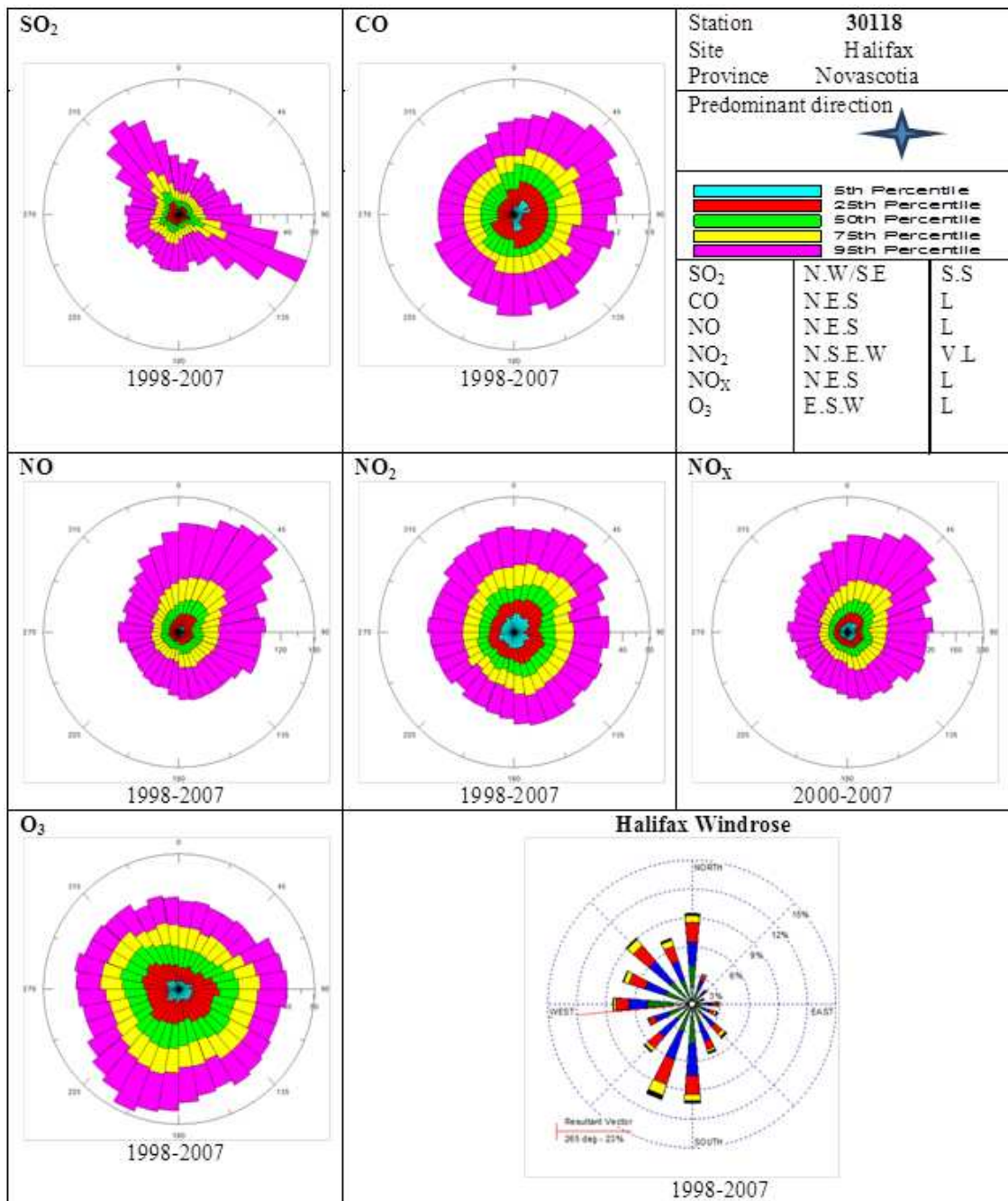L: Local
V.L: Very Local
R: Regional

Fig G-10: Halifax (30118) Wind and Pollution Rose Plots

 N.W/S.E: North West and South East
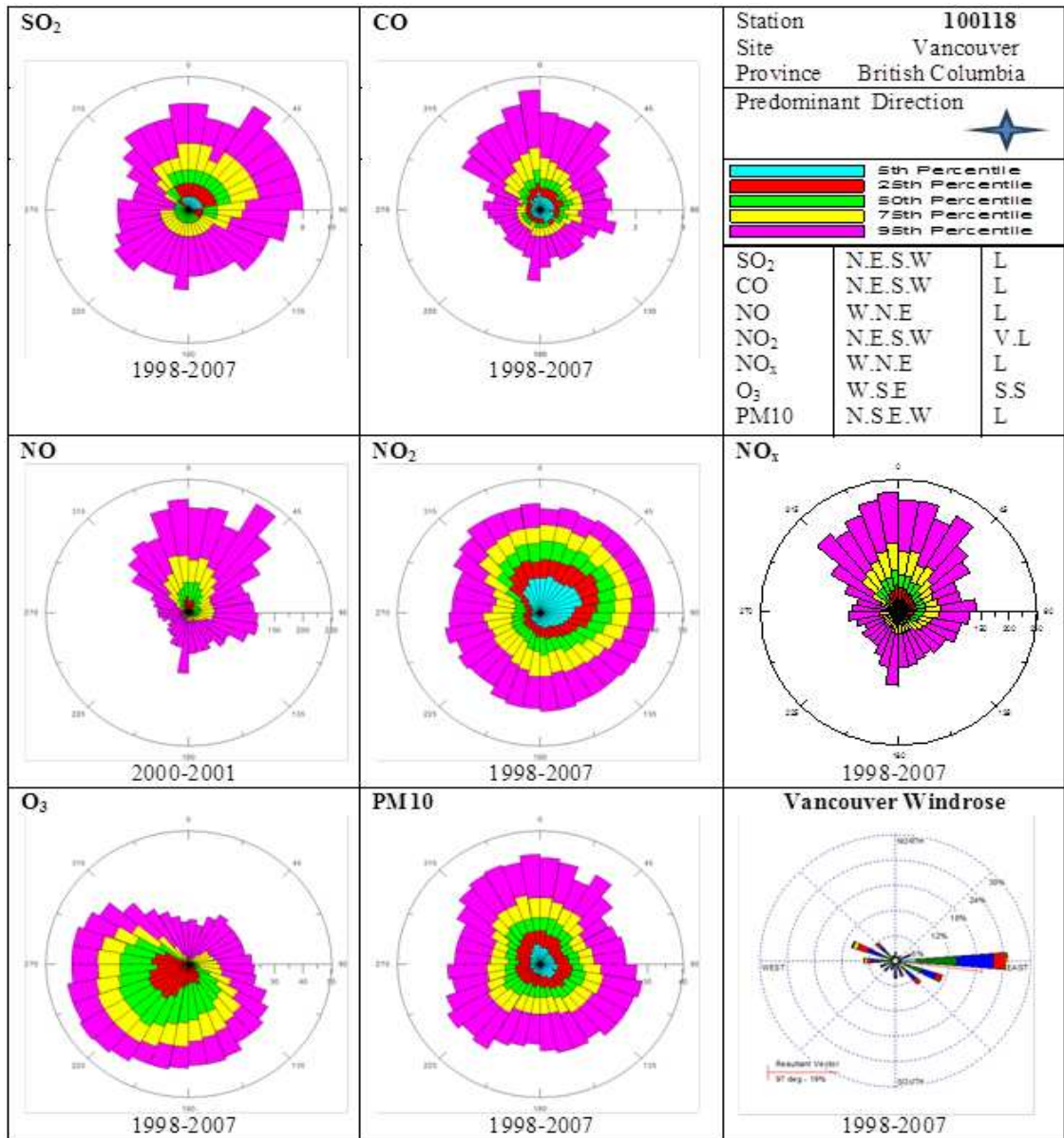L: Local
V.L: Very Local
R: Regional

Fig G-11: Vancouver (100118) Wind and Pollution Rose Plots

S.S: Source specific
L: Local
V.L: Very Local
R: Regional

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