James Bay Air Quality Study: Phase I

Report on the Results of Field Monitoring in 2007

February 8th, 2008

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ACKNOWLEDGEMENTS

The James Bay Air Quality Study (JBAQS) was conducted by a team of researchers and specialists, including (in alphabetical order, * indicates primary researchers for field monitoring and report authorship):

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Steve Sakiyama	BC Ministry of Environment

We would also like to acknowledge the input of Dr. Michael Brauer (UBC), and Dr. Jeff Brook (Environment Canada), both of whom provided initial advice regarding the Ogawa samplers and the feasibility of their use for this study. Special thanks also to the James Bay residents who volunteered their yards for sampling sites and those who helped deliver flyers to recruit volunteers. Ministry of Environment staff, particularly Warren McCormick, Mark Graham, John Sutherland and Ruth-Ann Devos provided equipment, expertise and data in support of this study.

Funding for the project was provided by Health Canada (Border Air Quality Study), the BC Ministry of Environment, the Clean Air Research Fund, the Greater Victoria Harbour Authority, and the MITACS (Mathematics of Information Technology and Complex Systems) internship program.

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SUMMARY

The objective of the James Bay Air Quality Study (JBAQS) was to establish general levels of pollutants in outdoor air in the James Bay area of Victoria BC. James Bay is a predominantly residential neighbourhood in the City of Victoria, with a population of just over 11,000 as of 2001. One third of this population is aged 65 years or older. Interestingly, over 77 percent of residences are apartment buildings (50 percent are five storeys or less, 27 percent are more than five storeys). In Victoria, only 64 percent of residences are apartments. Just over 36 percent of working James Bay residents walk to work, and another 14 percent cycle or take the bus. In Victoria, 25 percent of employed people walk to work and just over 21 percent cycle or take the bus to work.[1] The main sources of air pollution in the area include light duty and heavy duty vehicle traffic, helicopters, floatplanes, and marine vessels such as cruise ships, the passenger ferries MV Coho and Victoria Clipper, commercial fishing and whale watching boats, and recreation motorboats.

This report presents results of air quality field monitoring conducted in 2007 in the James Bay area of Victoria. The monitoring represents Phase 1 of the project; in Phase 2, a detailed pollutant dispersion model including all emission sources and meteorological data will produce estimates of short term (1-hour and 24-hour average) pollutant levels in the study area. A variety of sampling equipment was used to measure nitric oxide (NO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), fine particulate matter ($PM_{2.5}$) and contributing sources, and volatile organic compounds (VOCs), specifically benzene, toluene, ethylbenzene/xylene (referred to collectively as BTEX) and naphthalene. Supporting data, including traffic counts, wind speed and direction, precipitation, and cruise ship schedules were collected or acquired to aid in the interpretation of the field monitoring results.

The monitoring program was designed to take advantage of readily available and relatively inexpensive monitoring equipment, which limited where sampling occurred and over what time periods. In the absence of equipment capable of continuously monitoring hourly or daily levels over long periods of time (i.e., several months at least), which would have been useful for establishing trends over time, the focus of this study was to identify the general range of pollutant levels in the James Bay area. Most sites were therefore sampled in only one of three sampling periods between May and September 2007. In addition to establishing general pollutant levels, the monitoring was designed to explore whether the contributions of cruise ship emissions could be observed in the measured levels. While the study is meant to include all sources, most are relatively constant over time with the exception of cruise ships and their associated traffic. This provided an opportunity to sample on days with and without cruise ships present. This was not the case for any other source.

[1] The statistics on James Bay and Victoria are from the 2001 Canadian Census, as presented in the Neighbourhood Profiles available on the City of Victoria website: http://www.victoria.ca/residents/profiles.shtml

Limitations of the field monitoring are important to consider with respect to the results presented in this report. These include the capabilities of the equipment and the sampling strategy:

- A spot monitoring approach was adopted for the field study, meaning that continuous monitoring of pollutants at a specific site or sites over the duration of Phase 1 (May to September 2007), was not conducted. The results presented in this report therefore may not have captured the entire range of pollutant levels that existed in the study area. For NO, NO_2, SO_2 and $PM_{2.5}$, data from continuous monitoring stations operated by the BC Ministry of Environment near the study area (Topaz station and Royal Roads University station) are provided in order to aid in the assessment of how much the ranges differ from those measured during the field monitoring.

- For NO, NO_2 and SO_2, only relatively long-term measurements (i.e., 14 day averages) were possible; for $PM_{2.5}$ composition, including absorbance and metals, three-day average measurements were taken; for $PM_{2.5}$ mass, five minute averages were measured; and, for BTEX and naphthalene, continuous measures were captured and averaged over approximately one minute. In the case of NO, NO_2, SO_2, and $PM_{2.5}$ composition, the relatively long duration of the sampling time precludes any identification of hourly or daily variations in levels of these pollutants.

- Monitoring equipment was located at easily accessible outdoor sites in all cases. For two of the three sampling periods, sites were visited a minimum of twelve times to exchange samplers in order to measure pollutant levels on days with cruise ships in port and on days without. The logistics associated with sampler exchange excluded sites that required access through private residences. For $PM_{2.5}$ mass and composition, sampling equipment required outdoor power and a secure site, so locations were limited to residential yards with secure fencing or hedges, offered by volunteers. For these reasons, the spatial pattern of the sampling may not have been optimal. Maps of all sampled sites are included in this report to aid in the assessment of sample representativeness.

- The influence of cruise ship emissions and related traffic on levels of NO, NO_2 and SO_2, as well as $PM_{2.5}$ composition (absorbance, vanadium and nickel) was explored by taking measurements on days with cruise ships in port and on days without cruise ships in port. In all cases, the equipment used was capable only of providing average levels over the duration of the sampling period which, in the case of days with cruise ships in port, included many hours when cruise ships were not actually present. This means that the chances of measuring a difference due to cruise ship presence are diminished. For these reasons, it is important to consider the pollutant levels measured on days with cruise ships and days without cruise ships as averages over the

entire sampling period, not an indication of levels for any shorter time periods. The number of hours in which cruise ships were actually present for all samples are provided for reference. Analyses of hourly levels in 2006 at monitoring sites operated by the BC Ministry of Environment are also included to provide additional information on shorter-term trends that may be associated with the presence of cruise ships. Data from these stations for 2007 were not available in time to include in this report, but would reasonably be expected to show similar hourly trends.

- Comparing pollutant levels measured in different time periods is complicated by the fact that some influential factors may not be consistent, for example wind speed and direction or precipitation levels. While comparisons are made in this report between days with cruise ships present and days without cruise ships present, these should not be considered definitive proof of differences. Windroses and precipitation data are provided for all sampling periods to aid in the assessment of possible effects of differing conditions.

- Current air quality guidelines are provided when time periods are comparable to samples taken for this study, but it should be noted that standards are subject to change and should not be used to infer the absence of health risks.

- There may be other pollutants of interest that were not measured in this study.

Although the field monitoring study has limitations, it is important to note that this is only one part of a two phase study that will, when completed, provide significant information on both short-term episodic and long-term air quality in the study area. The monitoring equipment and procedures followed are well established and recognized to produce scientifically sound data. The field monitoring results also provide a valuable dataset that can be used to calibrate the pollutant dispersion model and validate its results.

In general, it was observed that winds came predominantly from the south and southwest for most sampling periods, as measured at the end of the Ogden Point breakwater. This would tend to transport emissions from cruise ships and helicopters more often to the western portions of the study area, and toward Topaz station (Figure 1). Emissions may be transported in different directions, however, and remain more concentrated when conditions are calm. The planned pollutant dispersion modelling in Phase 2 of this study should provide an indication of where emissions travel and their concentrations under different wind conditions. It was also observed that average monthly precipitation was higher in June, July and August of 2007 in comparison with 2006, although it is not possible to conclude whether this effectively reduced pollutant levels significantly in 2007.

The following summarizes conclusions specific to various pollutants, as drawn from the monitoring results. Full details are provided in each section and in the Appendices of this

report. Figure 1 shows the study area and sampling sites. Table 1 provides a summary of the sampling conducted.

Figure 1. Study area and field monitoring sites

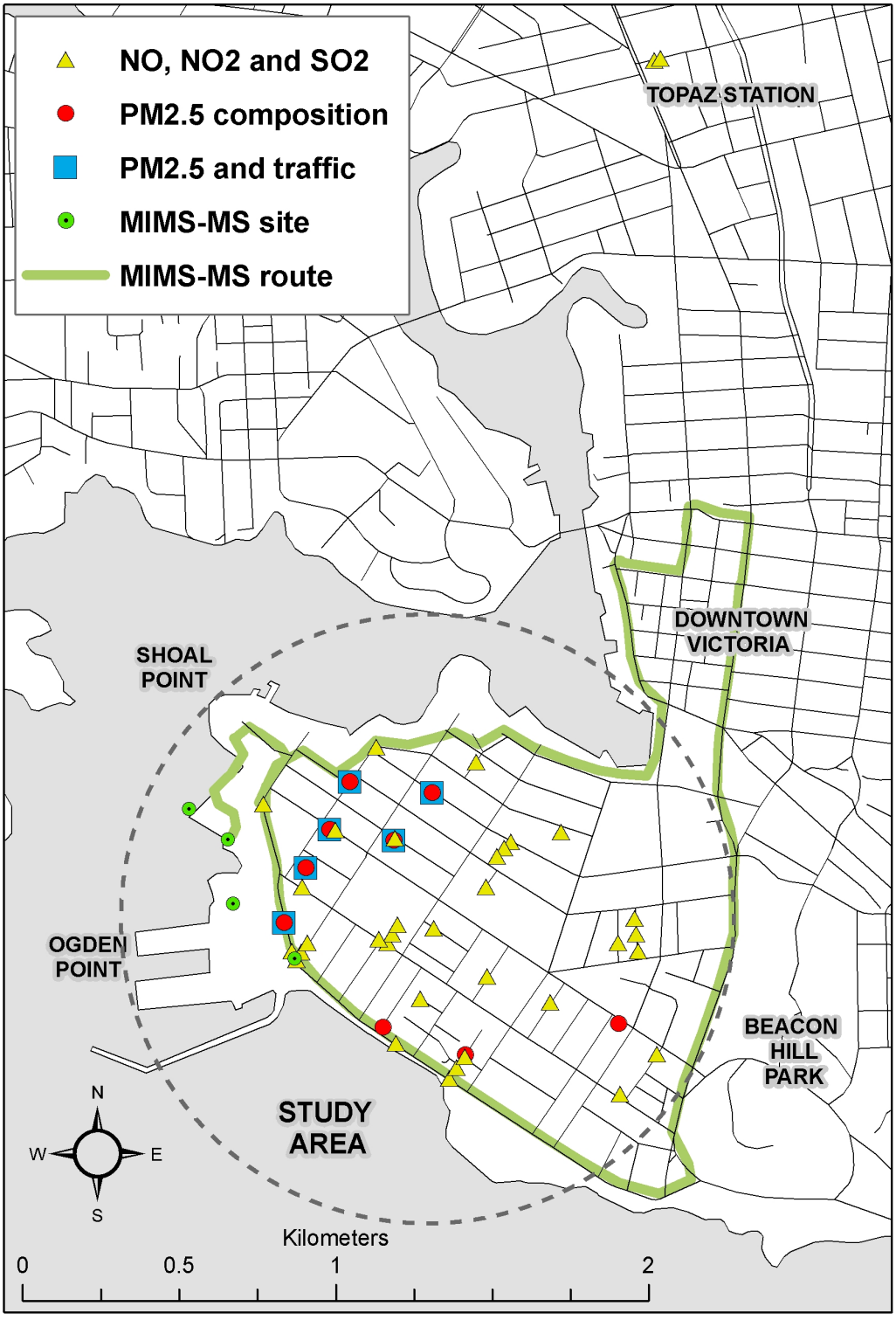


Table 1. Sample summary

Pollutant	Equipment	Duration	Dates	Total Sites	Notes
Nitric Oxide, Nitrogen Dioxide, Sulfur Dioxide	Ogawa passive samplers	long-term – 14 consecutive days	May -June	15	Five transects (3 samplers each) to investigate gradient with distance from traffic.
		long-term – 14 non-consecutive days over two months	June – July	11	Paired samplers: one set exposed on days with cruise ships present; one set exposed on days without cruise ships present.
			Aug - September	9	
$PM_{2.5}$	Radiance Research M903 nephelometers (light scatter)	short-term – 5 minute averages for 6 consecutive days	June	3	Included three days with cruise ships present and three days without for each sampling period.
			July	3	
$PM_{2.5}$ composition (metals and absorbance)	Partisol samplers (filters)	medium-term – two or three consecutive days	June	3	Two filters used at each site, one for consecutive days without cruise ships, one for consecutive days with cruise ships.
			July	3	
			Aug	2	
Traffic	Counting equipment	short-term – 15 minute averages for 6 consecutive days	June	3	Included three days with cruise ships present and three days without for each sampling period.
			July	3	
VOCs (BTEX and naphthalene	MIMS-MS	very short term – 1 minute averages	July	various	
			August	various	

Nitric oxide (NO):

- NO was measured in three sampling periods, the first on 14 consecutive days in May, the second and third on 14 nonconsecutive days in June-July and August-September respectively. Measured levels are therefore considered to indicate long-term averages.
- In general, NO levels averaged from 3.1µg/m^3 to 52 µg/m^3 per hour of sampler exposure.
- The highest average levels of NO were measured at locations on high traffic streets.
- There are no short-term (hourly or daily) or long-term (annual) air quality guidelines or standards for outdoor NO.
- Average levels of NO measured in the James Bay area are similar to average levels measured in other areas, and appear to be most affected by local traffic and meteorology.
- There is an indication in one sampling period that NO was higher on days when cruise ships were present. In the other sampling period, when wind directions were not as favourable, differences were not seen. Notably, cruise ships were present only for approximately 30 percent of the total exposure time for the samplers used on days with cruise ships, so differences would be minimized.
- There is no distinct spatial pattern of either higher than average or lower than average levels of NO, with the exception of two site where traffic is heavy on most days. These sites are higher than average on days without and days with cruise ships in port, but highest above average on days when cruise ships area present.
- There was no evidence of NO specifically from cruise ships reaching either the Topaz station or the Royal Roads University monitoring stations[2] in 2006. This is reasonable, as NO is highly reactive and easily converted to NO_2 and would be expected to decrease with distance from the source. Daily NO patterns at these stations are most affected by local vehicle traffic.

Nitrogen dioxide (NO_2):

- NO_2 was measured in three sampling periods, the first on 14 consecutive days in May, the second and third on 14 nonconsecutive days in June-July and August-September respectively. Measured levels are therefore considered to indicate long-term averages.
- In general, NO_2 levels ranged from 4.4 µg/m^3 to 23.7 µg/m^3 per hour of sampler exposure.
- The highest levels of NO_2 were measured near busy roads and at Topaz Station.
- Measured levels of NO_2 were roughly 25 to 30 percent of the current ambient air quality standards (annual average hourly maximum desirable is 60 µg/m^3; the maximum acceptable is 100 µg/m^3).

[2] These stations are maintained and operated by the BC Ministry of Environment, not by the study team researchers.

- Average levels of NO_2 measured in the James Bay area are similar to average levels measured in other areas, and appear to be most affected by nearby traffic and meteorology.
- NO_2 was higher on days when cruise ships were present in one of the two sampling periods that differentiated between days with and days without cruise ships in port. In the other sampling period, when wind directions were not as favourable, differences were not seen. Notably, cruise ships were present only for approximately 30 percent of the total exposure time for the samplers used on days with cruise ships, so differences would be minimized.
- Although there were more sites with higher than average levels of NO_2 when cruise ships were in port, there is no consistent pattern in terms of where the higher or lower than average sites are located in the study area. Two sites where traffic is heaviest are above average regardless of the presence of absence of cruise ships.
- Data from the Topaz station in 2006 suggests there may be short term (i.e., hourly) fluctuations in NO_2 associated with cruise ship emissions that are important to investigate.

Sulfur dioxide (SO_2):

- SO_2 was measured in three sampling periods, the first on 14 consecutive days in May, the second and third on 14 nonconsecutive days in June-July and August-September respectively. Measured levels are therefore considered to indicate long-term averages.
- In general, SO_2 levels ranged from less than 1 µg/m3 to 5.2 $\mu g/m^3$ per hour of sampler exposure in two sampling periods. Results from a third sampling period appear to be anomalous, and are likely the result of sampler problems.
- Measured levels of average SO_2 were below the BC air quality objectives (annual average hourly of 25 to 50 $\mu g/m^3$).
- Data from the Topaz station in 2006 suggests there may be short term (i.e., hourly) fluctuations in SO_2 associated with cruise ship emissions that are important to investigate.

Fine particulates ($PM_{2.5}$) mass:

- $PM_{2.5}$ mass was measured in two sampling periods, the first on six consecutive days in June/July, and the second on six consecutive days in July/August. Five-minute averages were measured and are presented in this report in several ways. Twenty-four hour averages are presented for each day sampled to aid the comparison with current standards. Graphs are also provided which show approximate 1-hour averages for the entire sampling periods and 5 minute averages for selected events associated with cruise ship activity. These results identify short-term variations in $PM_{2.5}$ levels.
- 24-hour average $PM_{2.5}$ levels ranged from 1.3 to 6.5 µg/m3. These levels are well below the current Canada Wide Standard for $PM_{2.5}$. Fifteen minute averages ranged from 1.3 to 17 µg/m3.

- There is no indication that 24-hour average $PM_{2.5}$ levels are consistently higher on days with cruise ships present in the study area. While the highest 24-hour average $PM_{2.5}$ levels in the study area were measured on days when cruise ships were in port, $PM_{2.5}$ levels at Topaz and Royal Roads University stations, which are not expected to be affected by cruise ship and related traffic emissions, are similar to or higher than levels measured in the study area, regardless of the presence of absence of cruise ships in port. This suggests regional trends in $PM_{2.5}$ levels are more important than immediate sources, at least for 24-hour average levels.
- The influence of cruise ship-related activity can be seen in the five-minute average $PM_{2.5}$ levels, with short term peaks in the range of 10 to 17 $\mu g/m^3$ coinciding with cruise ship arrivals and departures on some days.
- Traffic contributes significantly to $PM_{2.5}$ in the area, and is often responsible for short term peaks during morning commute times. $PM_{2.5}$ does not diminish quickly with distance from roads, but contributes to area-wide levels in the James Bay neighbourhood.
- Short tem levels (15 second averages) of $PM_{2.5}$ associated with winter residential wood burning range from less than 5 $\mu g/m^3$ to 25 $\mu g/m^3$.
- There was no evidence that $PM_{2.5}$ associated with the presence of cruise ships and associated traffic is reaching either the Topaz or Royal Road University monitoring stations in 2006.

Fine particulates ($PM_{2.5}$) composition:

- $PM_{2.5}$ composition was measured in three sampling periods, the first on two sets of three consecutive days in June/July, the second on two sets of three consecutive days in July/August, and the third on two sets of two consecutive days in September. The results therefore represent two or three-day averages.
- Absorbance levels of the $PM_{2.5}$ suggested diesel emissions were slightly higher on days with no cruise ships (weekdays) in two sampling periods. This suggests that weekday traffic, which would include more frequent buses, may be a more significant source of diesel emissions in the study area. In one study period, absorbance was higher on days with cruise ships (generally weekends) than on days without, when all sampled sites were downwind of the Ogden Point Terminal, suggesting that diesel emissions from the terminal area influenced the results. This suggests that sources other than cruise ships and their related traffic can have an equal or potentially greater influence on $PM_{2.5}$ composition depending on meteorological conditions.
- The influence of cruise ship emissions can be detected in the levels of vanadium and nickel present in the $PM_{2.5}$, indicating that cruise ship related emissions contribute to $PM_{2.5}$ in the area. Levels of vanadium and nickel measured in the James Bay area were consistent with levels measured at Topaz station and in the Pacific Northwest.

Volatile organic compounds (VOCs):

- Measurements conducted for this study are limited, and it is not possible to establish whether the levels observed are typical.
- Although conditions were generally unfavourable, distinct emissions events were measured with the MIMS-MS/MS.
- The concentrations of benzene, toluene, ethylbenzene/xylenes, and naphthalene in the James Bay area were low relative to concentrations measured in traffic in downtown Victoria and while at a gas station.
- The levels of benzene and toluene reported are likely too high, due to a methodological bias in the sampling equipment, and should be considered as a maximum level.
- There are no directly comparable air quality standards and guidelines for these VOCs.

This report provides results of the first phase of a two phase project. The following recommendations are based on the project results at the completion of this first phase, and on consultation with the project advisors:

1. The field monitoring was limited to measuring relatively long-term average pollutant levels for NO, NO_2 and SO_2. Analysis of data from Topaz station suggests there may be short-term peaks in NO_2 and SO_2 related to cruise ship activity. The Phase 2 pollutant dispersion modelling should include these pollutants and provide estimates of 1-hour, 24-hour, and seasonal average levels.

2. The field monitoring was limited to measuring pollutant levels near ground level. The Phase 2 pollutant dispersion modelling should include estimates of 1-hour, 24-hour, and seasonal average pollutant levels at varying elevations above ground level, with a focus on residential apartment buildings in the study area.

3. Typical levels of VOCs (BTEX and naphthalene) were not established by the field monitoring, and will not be estimated in the pollutant dispersion model due to the difficulties of accurately modelling the complex behaviour of these pollutants in the atmosphere. Data on VOCs remains a significant gap at this time and should be the subject of additional study.

4. Together, the two phases of this study will provide a reasonable characterization of the typical short- and long-term levels of NO, NO_2, SO_2 and $PM_{2.5}$ in the study area. It is recommended that these reports be provided to an appropriate expert for the purpose of conducting a comprehensive health risk assessment.

PROJECT BACKGROUND AND REPORT STRUCTURE

In 2006, researchers at the University of Victoria's Spatial Sciences Research Lab (SSRL) were approached by staff of the Population Health Surveillance Unit of the Vancouver Island Health Authority (VIHA) with a request to help initiate a study on the air quality in the James Bay neighbourhood of Victoria. This was prompted in part by a request from the James Bay Neighbourhood Association (JBNA) to VIHA to investigate air quality and possible health risks in their residential area. James Bay is a predominantly residential neighbourhood in the City of Victoria, with a population of just over 11,000 as of 2001. One third of this population is aged 65 years or older. Over 77 percent of residences are apartment buildings (50 percent are five storeys or less, 27 percent are more than five storeys) compared to a city-wide average of 64 percent. Just over 36 percent of working James Bay residents walk to work, and another 14 percent cycle or take the bus. In Victoria, 25 percent of employed people walk to work and just over 21 percent cycle or take the bus to work.[3]

No air quality measurements were available to indicate the spatial or temporal variation of various pollutants in the James Bay neighbourhood. This lack of information created significant uncertainty about the air quality in the area in terms of actual levels of pollutants and the relative magnitude that different sources contribute to these levels.

Representatives of the study team attended a meeting of the James Bay Neighbourhood Association in May 2007, where residents expressed an interest in understanding both short-term (several hours) and long-term (weeks to months) impacts on air quality in the neighbourhood, with specific sources of concern being car and bus traffic, marine vessels, float planes and helicopters. These sources typically emit nitrogen oxides, sulfur dioxide, fine particulate matter, and volatile organic compounds.

The James Bay Air Quality Study (JBAQS) was designed to address the complexities of the pollution sources in the vicinity, with the objective of maximizing the utility of data collected with relatively simple monitoring equipment. Two phases were developed: firstly, field monitoring to establish existing levels of nitrogen dioxide, sulfur dioxide, fine particulates, metals, volatile organic carbons, as well as traffic volume in selected locations; and secondly, dispersion modelling with all emission sources characterized.

[3] The statistics on James Bay and Victoria are from the 2001 Canadian Census, as presented in the Neighbourhood Profiles available on the City of Victoria website: http://www.victoria.ca/residents/profiles.shtml

This report presents results based on the field monitoring conducted by the research team between May and September of 2007, for:

- Nitric oxide (NO)
- Nitrogen dioxide (NO_2)
- Sulfur dioxide (SO_2)
- Fine particulate matter ($PM_{2.5}$)
- Volatile organic compounds

Other data collected for this project to aid in the interpretation of the monitored results include:

- Traffic volume
- $PM_{2.5}$ composition

Additional data collected by other parties were also used to aid in the interpretation of the monitored results, including:

- NO, NO_2, SO_2 and $PM_{2.5}$ levels at fixed-site monitors operated by the BC Ministry of Environment at Royal Roads University and at Topaz Avenue (Figure 2).

- Wind speed and direction from fixed-site monitor operated by the Greater Victoria Harbour Authority at the end of the Ogden Point breakwater (Figure 2).

- Precipitation data from fixed-site monitor at the James Bay Community School operated as part of the UVIC School-based Weather Station Network[4] (Figure 2) and from the Victoria Airport.

This report also makes use of windroses to graphically show wind speed and direction for sampling durations. Appendix A includes an example of a windrose and instructions on interpretation, and wind speed conversions from knots (used in this report) to kilometers/hour and meters/second.

The remainder of this report is presented as follows:

- A description of the monitoring study design, the equipment used, and the limitations of the study are presented (Methodology section).

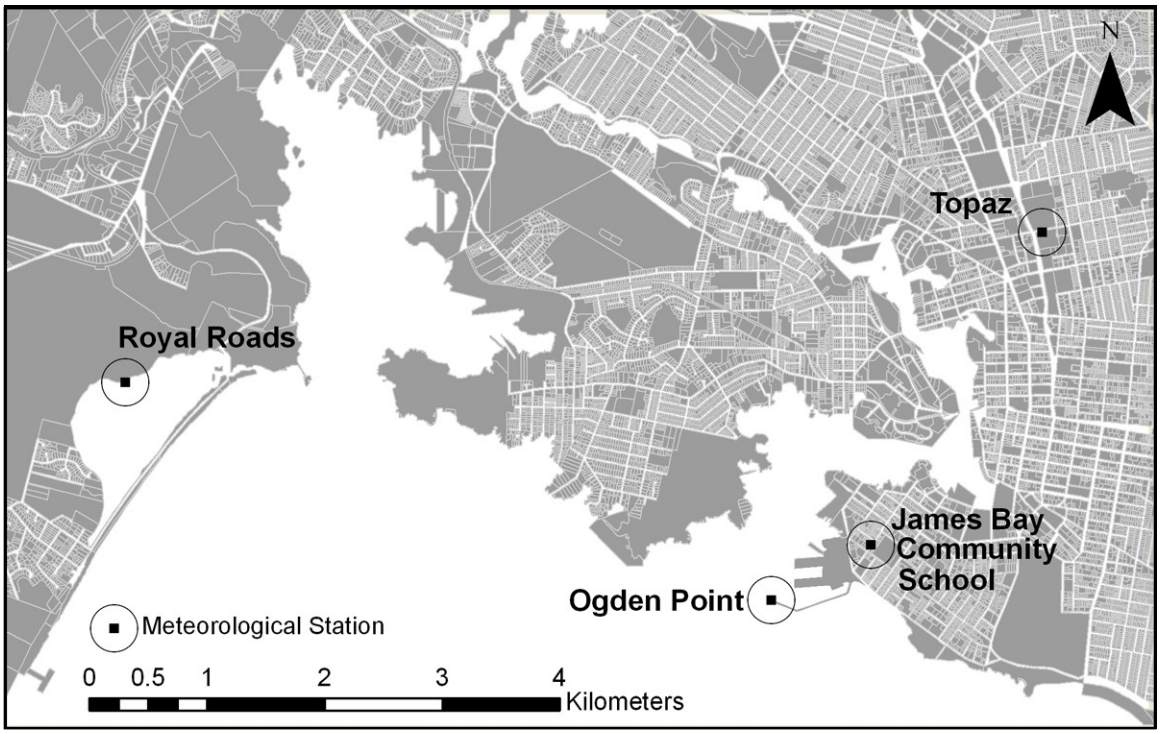
[4] Weaver, A.J., and E.C. Wiebe, 2006: Micrometeorological network in Greater Victoria schools: www.victoriaweather.ca. CMOS Bulletin, 34(4), 184-190.

- The monitoring results for each pollutant are presented in separate sections, each including supporting data and a discussion of the results (Sections for NO, NO_2, SO_2, $PM_{2.5}$, $PM_{2.5}$ composition, and VOCs).

- Next steps and recommendations are provided following the monitoring results.

- Appendices containing detailed information on the equipment used and quality control procedures employed for the monitoring study, and in some cases, detailed data are included following the main body of the report.

Figure 2. Locations of meteorological stations



METHODOLOGY

Sources of pollutants in the study area vary widely. The Ogden Point Terminal primarily serves cruise ships which emit a range of air pollutants when approaching and leaving the docks, and while in port. Associated with the cruise ships is bus and taxi traffic transporting passengers to and from tourist destinations in the region. The local roads, particularly Dallas Road, are frequently used by both tourists unrelated to the cruise ships as well as residents of the region. Near the Ogden Point terminal are the Coast Guard docks which serve their marine vessels. Other large marine vessels which regularly pass close by the Ogden Point terminal include the Coho ferry and the Victoria Clipper. Commercial fishing and whale watching boats contribute to pollution levels, as do recreational motorboats. Local air traffic includes numerous daily arrivals and departures of helicopters immediately to the north of the terminal and float planes from the Inner Harbour. There is little industrial development in the James Bay area, with the exception of activities typical of marine vessel servicing and repair at the Coast Guard facilities, and the Imperial Oil Terminal, located across the harbour in Esquimalt approximately one kilometre east of the Ogden Point terminal. Depending on the pollutant, natural sources may also contribute to local air quality, as can long-range transport of pollutants from other areas.

In the absence of equipment capable of measuring hourly changes in pollutant levels for long periods of time (i.e., many months), a 'spot' monitoring approach was adopted for this study in order to make use of the relatively inexpensive equipment available to the study team. Rather than maintaining equipment at a very few sites for long periods, the study team chose to monitor as many sites as possible, for shorter periods (three days to two months). This limits the results of this study to characterizing general pollutant levels between May and September 2007, with no information available on seasonal trends.

Availability of equipment and costs also limited which pollutants were measured in this study. The following list provides details on the air quality monitoring equipment used and pollutants measured:

- A total of 92 Ogawa samplers were used, each capable of measuring nitric oxide (NO), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) over 14 day intervals. These samplers were located at easily accessible outdoor sites and mounted on telephone, power, or light poles approximately 2 metres above the ground.

- Three Partisol filter samplers were available and were used to collect fine particulates ($PM_{2.5}$) over either three or two day intervals. The fine particulates collected on each filter were subsequently weighed, the absorbance measured (an indicator of heavy duty vehicle traffic). Filters were

then subject to analysis for the presence of metals, particularly vanadium (V) and nickel (Ni), which are indicators of emissions from ocean-going vessels, such as cruise ships[5]. These samplers required power and were located in volunteers' residential yards with secure fencing or hedges.

- Three Radiance Research nephelometers were available and were used to measure average light scatter, which can be converted to a measure of $PM_{2.5}$ mass, for five minute intervals. These samplers also required power and were located at the same sites as the Partisol samplers.

- A single mobile mass spectrometer (MIMS-MS) was available twice during the sampling season, each time for three days. This system was used to measure levels of benzene, toluene, ethylbenzene/xylene (BTEX) and naphthalene every minute. Various sites and one transect were monitored using this equipment.

Given the relatively short sampling times, the monitoring plan for each pollutant was designed primarily to support the pollutant dispersion modelling in Phase 2, to establish general levels of the measured pollutants between May and September 2007, and also to explore the potential effects of different sources on local air quality. The following provides a general description of the monitoring plans for each pollutant.

NO, NO_2 and SO_2 were measured with Ogawa samplers. Each sampler can measure all three pollutants at the same time, and can be exposed for up to 14 days, with sampler sensitivity being highest when exposed for this entire duration.[6] Two sampling designs were used for these pollutants:

1) Ogawa samplers were used to explore the change in pollutant levels with distance from roadways. In May/June, at each of five sites in the study area, three samplers (one at curbside, one approximately 10 metres from the curb, and one approximately 20 metres from the curb) were exposed for a total of 14 consecutive days. These results provide general pollutant levels, and will aid in calibrating the pollutant dispersion model.

2) Ogawa samplers were used to explore the influence of cruise ships and associated traffic on pollutant levels during two sampling periods, one in June/July and one in

[5] Hopke PK, Hwang I, Kim E, and Lee JH 2006. Analyses of PM-related Measurements for the Impacts of Ships. Final report to the Air Resources Board Contract 04-326.

[6] Sampler sensitivity refers to the minimum level of pollution that can be measured by the Ogawa sampler. When exposed for very short time (i.e., several hour or days), pollution levels must be relatively high to register. The sampler can detect lower levels of pollution when exposed for longer periods, up to 14 day, at which time the sampler becomes saturated.

August/September. This was accomplished by using paired samplers at a variety of sites, with one sampler exposed on days when cruise ships were in port, and the other sampler exposed only on days when cruise ships were not in port. Samplers were exposed therefore for several days per week, requiring approximately six to eight weeks of time to accumulate a total of 14 days of exposure and approximately 12 visits to each site to exchange samplers on days with and without cruise ships in port.

Regardless of whether a cruise ship-related impact is observed, these results provide general pollutant levels, and can be used to cross-check the pollutant dispersion model results.

$PM_{2.5}$ was measured in each of two sampling periods (June/July and July/August), using an instrument 'cluster', consisting of a Radiance Research nephelometer, a Partisol filter sampler, and a traffic counting tube to investigate the contribution of traffic and cruise ship-related emissions. The nephelometers measured light scatter on a 5 minute interval, and given that traffic is recognized as a significant source of $PM_{2.5}$, traffic counting tubes[7] capable of measuring traffic volume in 15 minute increments were employed to aid in the interpretation of variations in $PM_{2.5}$ levels. The nephelometers and traffic counting equipment were run continuously for six consecutive days, three when cruise ships were in port, and three when no cruise ships were in port. These results identify hourly and daily average levels of $PM_{2.5}$. The Partisol filter samplers draw air continuously through the filter, so $PM_{2.5}$ is accumulated for the entire period of exposure. For this study, separate filters were used for the three days with cruise ships and the three days without, providing only a three-day average measure. In a third sampling period (September), only the three Partisol filter samplers were employed, as the nephelometers needed to be calibrated, and this could not be completed within the time remaining for the field monitoring. The results of the Partisol filter analysis provide an indication of which sources are impacting $PM_{2.5}$ composition under different conditions.

Volatile organic compounds, specifically benzene, toluene, ethylbezene/xylene (BTEX) and naphthalene were monitored continuously during two sampling periods (July and August) by researchers from the Applied Environmental Research Lab at Malaspina University-College, using a mobile mass spectrometer (MIMS-MS).This monitor is capable of continuously and concurrently measuring very low levels of a wide range of chemicals associated with fuel combustion. The monitoring was planned to focus on capturing specific source plumes (cruise ships, helicopters, floatplanes, bus traffic, general traffic) in July, and then conducting mobile monitoring throughout the study area in August in order to explore whether the influence of each source could be identified in different parts of James Bay. Unfortunately, as access to the equipment was limited, monitoring occurred under adverse weather conditions, so few useful data were collected.

[7] Traffic counting equipment was provided and operated by TransTech: http://www.transtechdata.ca/

Appendices B, C, D and E provide technical details about the samplers and equipment, quality control procedures, and the exact times and dates of the sampling.

In addition, there was some interest among the project partners in comparing precipitation trends for the last several years. Recognizing that precipitation can diminish levels of airborne pollutants, the question arose as to whether 2007 was typical in terms of precipitation levels. A precipitation trend analysis is provided in Appendix F, and suggests that in 2007, precipitation (measured at the James Bay Elementary School) was lower in May and the first half of June, but higher in the latter half of June through to the end of August, in comparison with 2006 at the same site. In both years, precipitation between May and September was near or below the normal level based on 30 years of measurements at the Victoria Airport. It is conceivable that pollutant levels measured during the 2007 field monitoring were impacted by higher precipitation, but it is not possible to definitively measure this, as the effect would depend greatly on the timing of the precipitation. For example, a very heavy rain over a short period of time may diminish airborne pollutants in the relatively short-term, while the same amount of precipitation over many days may be less effective in reducing pollutants by a significant degree.

Results provided in this report should be viewed in the context of the following limitations:

- Continuous monitoring of pollutants at a specific site or sites over the duration of Phase 1 (May to September 2007), was not conducted. The results presented in this report therefore may not have captured the entire range of pollutant levels that existed in the study area. For NO, NO_2, SO_2 and $PM_{2.5}$, data from continuous monitoring stations operated by the BC Ministry of Environment near the study area (Topaz station and Royal Roads University station) are provided in order to aid in the assessment of how much the ranges differed from those measured during the field monitoring.

- For NO, NO_2 and SO_2, only relatively long-term measurements (i.e., 14 day averages) were possible; for $PM_{2.5}$ composition, including absorbance and metals, three-day average measurements were taken; for $PM_{2.5}$ mass, five minute averages were measured; and, for BTEX and naphthalene, continuous measures were captured and averaged over approximately one minute. In the case of NO, NO_2, SO_2, and $PM_{2.5}$ composition, the relatively long duration of the sampling time precludes any identification of hourly or daily variations in levels of these pollutants.

- Monitoring equipment was located at easily accessible outdoor sites in all cases. For NO, NO_2 and SO_2, samplers were attached to telephone, power, or light poles

approximately 2 metres above the ground[8]. For two of the three sampling periods, sites were visited a minimum of twelve times to exchange samplers in order to measure pollutant levels on days with cruise ships in port and on days without. The logistics associated with sampler exchange excluded sites that required access through private residences. For $PM_{2.5}$ mass and composition, sampling equipment required outdoor power and a secure site, so locations were limited to residential yards with secure fencing or hedges, offered by volunteers. For these reasons, the spatial pattern of the sampling may not have been optimal. Maps of all sampled sites are included in this report to aid in the assessment of sample representativeness.

- The influence of cruise ship emissions and related traffic on levels of NO, NO_2 and SO_2, as well as $PM_{2.5}$ composition (absorbance, vanadium and nickel) was explored by taking measurements on days with cruise ships in port and on days without cruise ships in port. In all cases, the equipment used was capable only of providing average levels over the duration of the sampling period which, in the case of days with cruise ships in port, included many hours when cruise ships were not actually present. This means that the chances of measuring a difference due to cruise ship presence are diminished. For NO, NO_2 and SO_2, it was not feasible to exchange samplers to capture only the hours with cruise ships in port. For example, assuming cruise ships are in port three days per week for approximately six hours per day, the samplers would have to be exchanged on 56 days to accumulate a total of 14 days of exposure. For these reasons, it is important to consider the pollutant levels measured on days with cruise ships and days without cruise ships as averages over the entire sampling period, not an indication of average levels for any shorter time periods. The number of hours in which cruise ships were present for all samples are provided for reference. Analyses of hourly levels in 2006 at monitoring sites operated by the BC Ministry of Environment are also included to provide additional information on shorter-term trends that may be associated with the presence of cruise ships. Data from these stations for 2007 were not available in time to include in this report, but would reasonably be expected to show similar hourly trends.

- Comparing pollutant levels measured in different time periods is complicated by the fact that factors influencing levels may not be consistent, for example source emission rates, wind speed and direction or precipitation levels. So, while comparisons are made in this report between days with cruise ships present and days without cruise ships present, these should not be considered definitive proof of differences. Windroses and precipitation data are provided for all sampling periods to aid in the assessment of possible effects of differing conditions.

[8] By special request, two samplers were located on the second and third floor balconies of a residential apartment building. The results from these two samplers are presented as an Appendix to this report.

- Current air quality guidelines are provided when time periods are comparable to samples taken for this study, but it should be noted that standards are subject to change and should not be used to infer the absence of health risks.

- There may be other pollutants of interest that were not measured in this study.

NITRIC OXIDE

What is nitric oxide?

Nitric oxide (NO) is a colorless, flammable and highly reactive gas. It is rapidly converted through oxidation to nitrogen dioxide (NO_2), and plays a role in the formation of ground-level ozone (O_3). Nitric oxide originates from both man-made and natural sources. In outdoor air, man-made sources include fossil fuel combustion for transportation, industry and electric power generation. Space heating may also contribute NO to the atmosphere.[9] Natural sources include forest fires, lightning, and soil microbes.[10]

What are the sources of nitric oxide in the James Bay neighbourhood?

The major sources of NO in the study area are passenger and heavy duty vehicles, and marine vessels including the MV Coho, the Victoria Clipper and commercial fishing boats, while float planes and helicopters are estimated to be very minor sources.[11] Cruise ships are also a major source. No significant industrial activities were identified as potential sources of NO in the study area or in the general region, other than marine vessel servicing and repair at the Coast Guard station. Natural sources are also expected to be negligible.

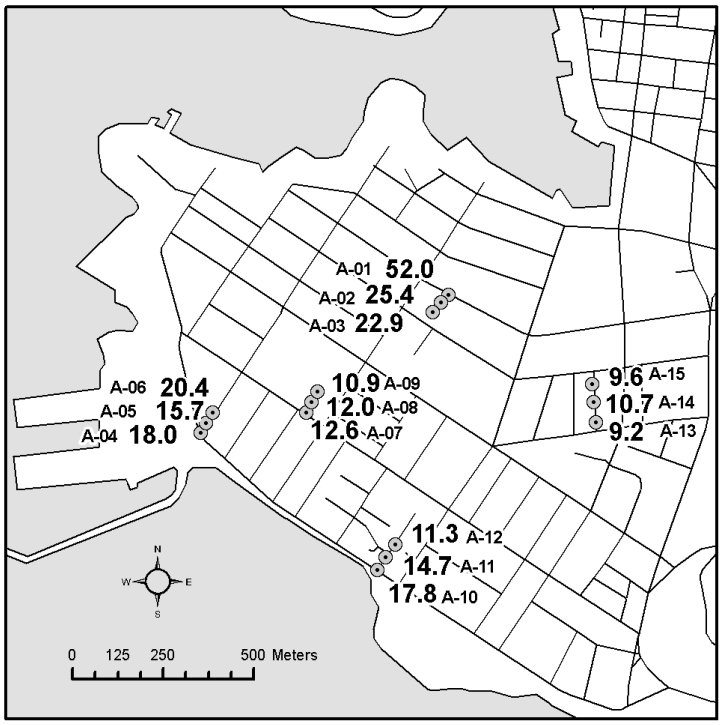
What are the results of the field monitoring?

Figures 3 through 8 provide the sampling sites, monitoring results and supporting data on wind speed and direction, precipitation, and the numbers of hours in which cruise ships were present during each sampling period. By special request, two NO measurements were taken at the Shoal Point residences over August 8th to 22nd, 2007. As no other samples were taken for this same period, it is not possible to place the results in context with other parts of the study area, so results are provided in Appendix G.

[9] SENES Consultants Ltd. (2006). Capital Regional District Air Contaminant Emissions Inventory for 2004. Prepared for the Capital Regional District, Victoria, B.C.
[10] Environment Canada : http://www.ec.gc.ca/TOXICS/EN/detail.cfm?par_substanceID=216&par_actn=s1
[11] Tradewinds Scientific Ltd. (2000). Victoria Harbour Air Quality Impact Study, March 29, 2000. Prepared for Transport Canada Programs Branch, Vancouver, B.C. – although did not include cruise ships

Figure 3. Nitric oxide Sample A monitoring sites and results: May 22 to June 6, 2007 (consecutive 14 day exposure)

(a)



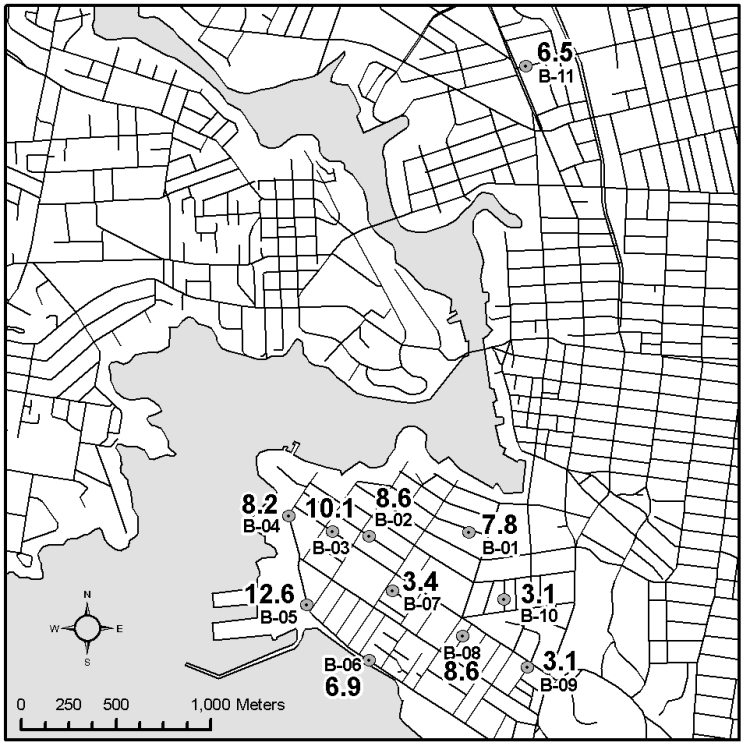
(b)

Site	14-day average hourly NO (µg/m^3)*	
	Actual	± 15%
A-01	52.0	44.2 – 59.8
A-02	25.4	21.6 – 29.2
A-03	22.9	19.5 – 26.3
A-04	18.0	15.3 – 20.3
A-05	15.7	13.3 – 18.1
A-06	20.4	17.3 – 23.5
A-07	12.6	10.7 – 14.5
A-08	12.0	10.2 – 13.8
A-09	10.9	9.3 – 12.5
A-10	17.8	15.1 – 20.5
A-11	14.7	12.5 – 16.9
A-12	11.3	9.6 – 13.0
A-13	9.2	7.8 – 10.6
A-14	10.7	9.1 – 12.3
A-15	9.6	8.2 – 11.0
Reference – Topaz Station**	8.9	
Reference – Royal Roads Station**	not available	

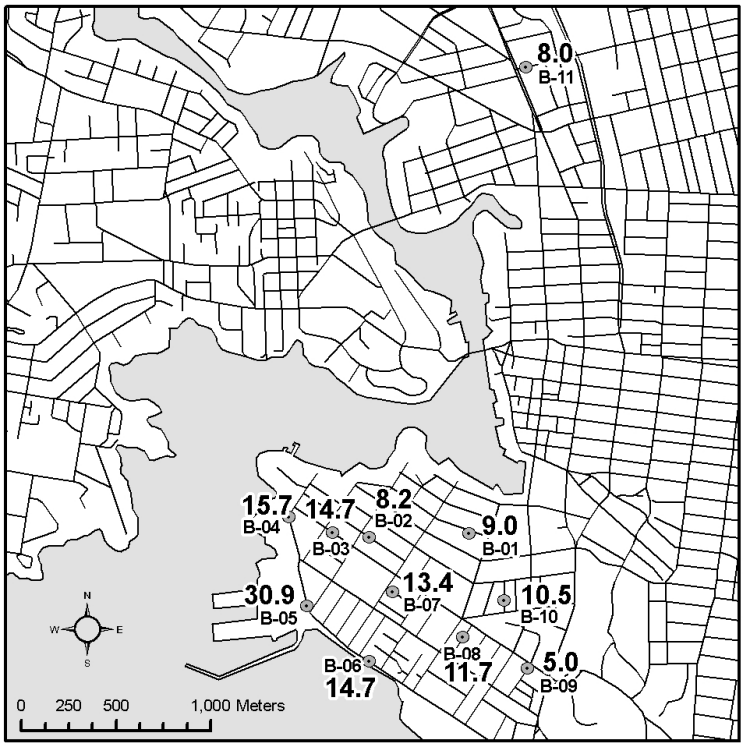
* Total NO measured was divided by the total hours exposed for each sampler.
** Average of all hourly measurements at MoE stations during sample exposure

Figure 4. Nitric oxide Sample B monitoring sites and results: June 15 to July 28, 2007 (non-consecutive exposures, totaling 14 days)

(a) Days with no cruise ships



(b) Days with cruise ships



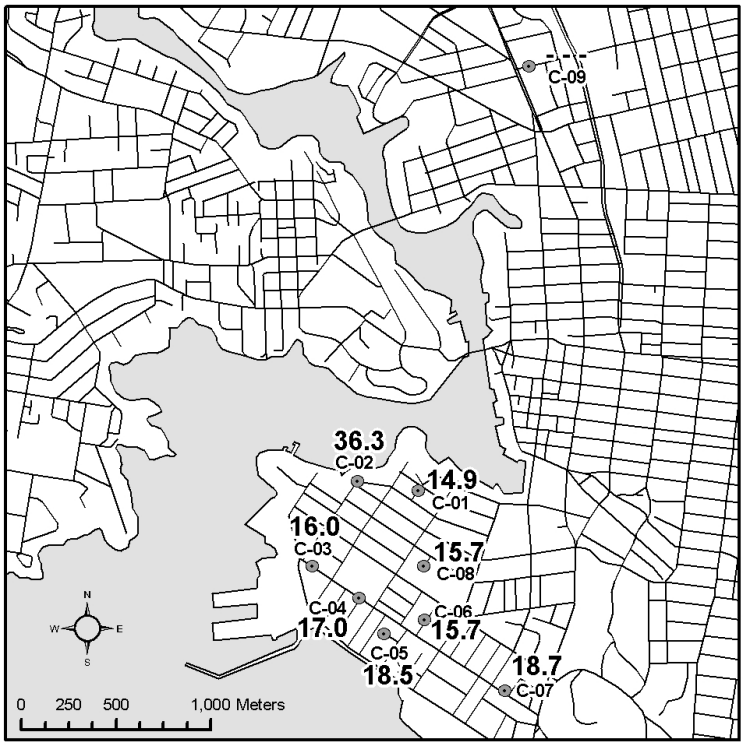
(c)

Site	14-day average hourly NO (µg/m^3)*			
	Days with no cruise ships		Days with cruise ships	
	Actual	+/- 10 %	Actual	+/- 10 %
B-01	7.8	7.0 – 8.6	9.0	8.1 – 9.9
B-02	8.6	7.7 – 9.5	8.2	7.4 – 9.0
B-03	10.1	9.1 – 11.1	**14.7**	13.2 – 16.2
B-04	8.2	7.4 – 9.0	**15.7**	14.1 – 17.3
B-05	12.6	11.3 – 13.9	**30.9**	27.8 – 34.0
B-06	6.9	6.2 – 7.6	**14.7**	13.2 – 16.2
B-07	3.4	3.1 – 3.7	**13.4**	12.1 – 14.7
B-08	8.6	7.7 – 9.5	**11.7**	10.5 – 12.9
B-09	3.1	2.8 – 3.4	**5.0**	4.5 – 5.5
B-10	3.1	2.8 – 3.4	**10.5**	9.5 – 11.6
B-11	6.5	5.9 – 7.2	8.0	7.2 – 8.8
Reference – Topaz Station**				
	9.1		6.8	
Reference – Royal Roads Station**				
	not available		not available	

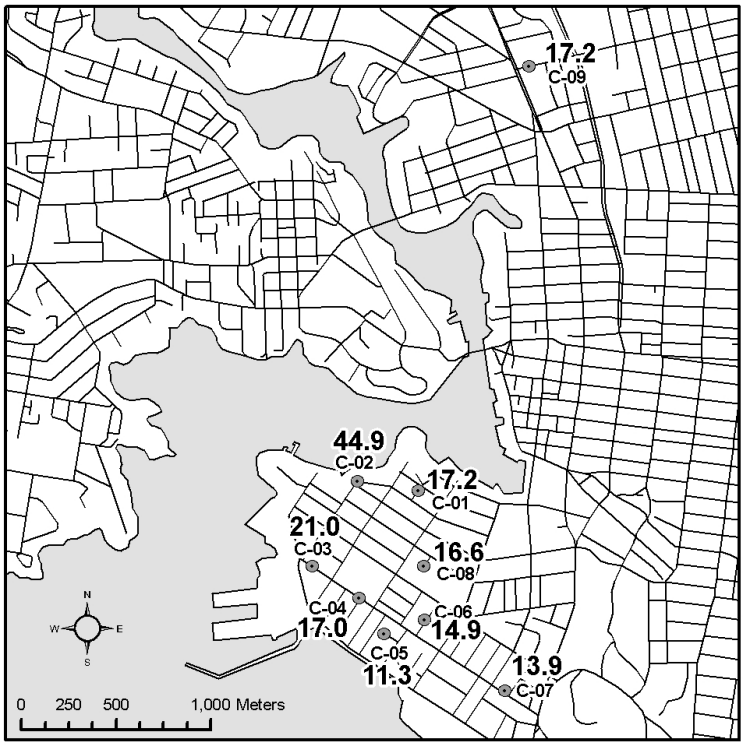
* Total NO measured was divided by the total hours exposed for each sampler.
** Average of all hourly measurements at MoE stations during sample exposure
Bold shows levels higher when +/- 10% range is considered

Figure 5. Nitric oxide Sample C monitoring sites and results: August 17 to September 23, 2007 (non-consecutive exposures, totaling 14 days)

(a) Days with no cruise ships



(b) Days with cruise ships



(c)

Site	14 day average hourly NO (µg/m^3)*			
	Days with no cruise ships		Days with cruise ships	
	Actual	+/- 10 %	Actual	+/- 10 %
C-01	14.9	13.4 – 16.4	17.2	15.5 – 18.9
C-02	36.3	32.7 – 39.9	**44.9**	40.4 – 49.4
C-03	16.0	14.4 – 17.6	**21.0**	18.9 – 23.1
C-04	17.0	15.3 – 18.7	17.0	15.3 – 18.7
C-05	**18.5**	16.7 – 20.4	11.3	10.2 – 12.4
C-06	15.7	14.1 – 17.3	14.9	13.4 – 16.4
C-07	**18.7**	16.8 – 20.6	13.9	12.5 – 15.3
C-08	15.7	14.3 – 17.3	16.6	14.9 – 18.3
C-09	--		17.2	15.5 – 18.9
Reference – Topaz Station**	not available		not available	
Reference – Royal Roads Station**	not available		not available	

* Total NO measured was divided by the total hours exposed for each sampler.
** Average of all hourly measurements at MoE stations during sample exposure
Bold shows levels higher when +/- 10% range is considered

Figure 6. Windroses for sampling periods A, B and C (NO, NO_2 and SO_2)

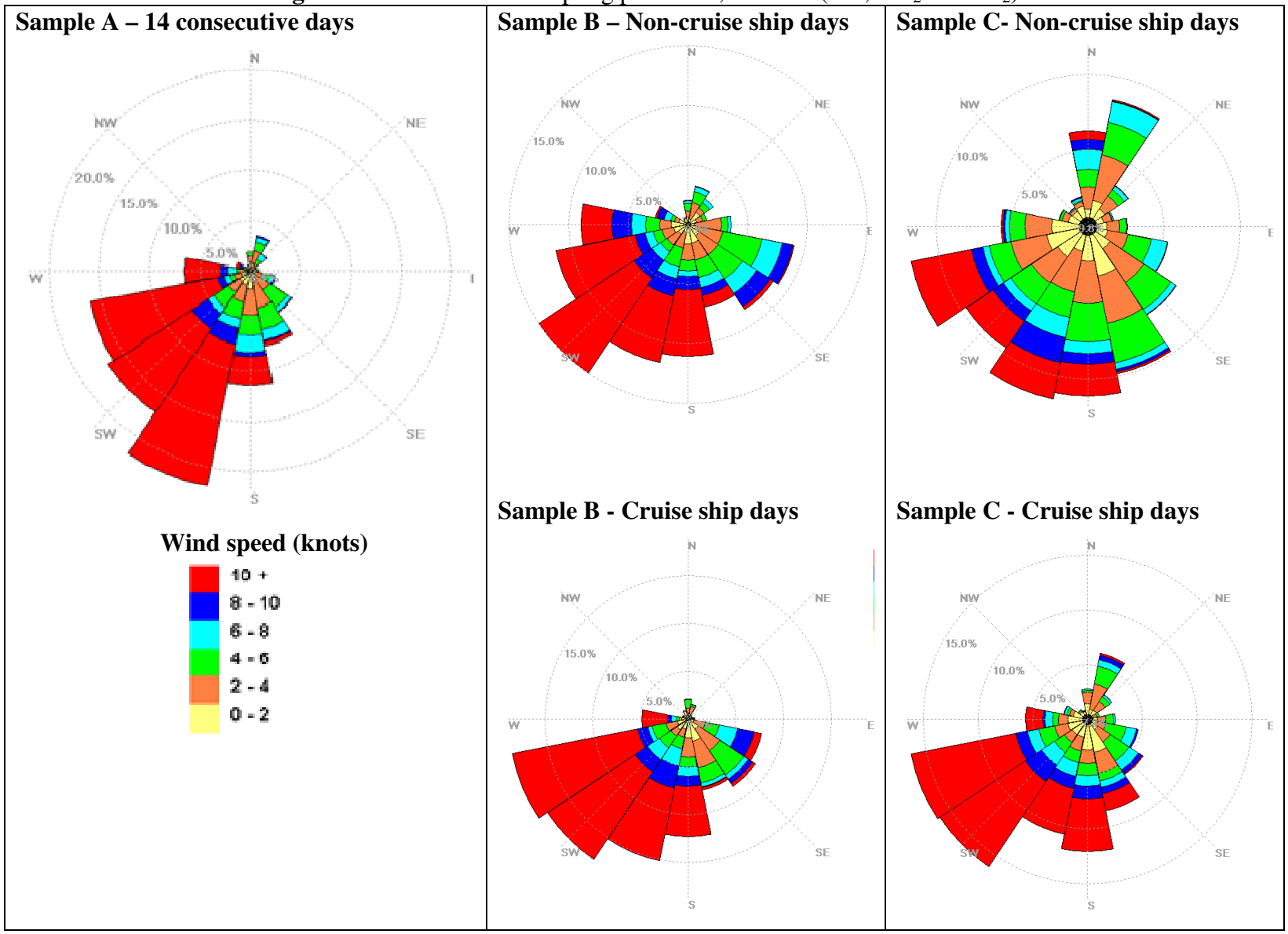


Figure 7. Precipitation for sampling periods A, B and C (NO, NO_2 and SO_2)

Date	Time	Precipitation (mm)	Notes
Sample A			
June 6th	9am to – 3pm	1.02	No cruise ships
Sample B			
Non-cruise day samplers			
June 21st	6:30am – 9pm	3.30	1 cruise ship 6pm – midnight
July 17th	7:30am – 3:30pm	6.86	No cruise ships present
Cruise day samplers			
June 15th	8:15am – 10am	0.51	2 cruise ships 6/7pm – midnight
June 22nd	3:46am – 4am	0.25	2 cruise ships 6/7pm – midnight
June 23rd	2:37am – 3am	0.25	3 cruise ships 5/6pm – midnight
June 28th	3:00pm – 7:15pm	4.32	1 cruise ship 7am – 2pm 1 cruise ship 6pm - midnight
June 29th	2pm – 3:30pm	1.27	2 cruise ships 6/7pm – midnight
July 20th	10am – 4:30pm	1.78	2 cruise ships 6/7pm – midnight
July 21st	1:45am – 11pm	3.05	3 cruise ships 5/6pm – midnight
July 22nd	3:30am – 11pm	4.06	1 cruise ship noon – 7pm
Sample C			
Non-cruise day samplers			
August 20th	8am – 9:30am	0.25	No cruise ships
August 21st	3am – 7am	3.81	No cruise ships
September 3rd	5pm – 8:30pm	1.27	No cruise ships
September 4th	2am – 3:30am	0.51	No cruise ships
September 20th	8am – 9:30am	0.51	No cruise ships*
Cruise day samplers			
August 16th	5pm – midnight	1.02	1 cruise ship 6pm – midnight
August 18th	4pm – 4:30pm	0.25	3 cruise ships 5/6pm - midnight
August 31st	1pm – 4pm	1.02	2 cruise ships 6/7 - midnight
September 16th	10am – 5pm	6.10	1 cruise ship 8am – 5pm
September 21st	4am – 6pm	1.02	2 cruise ships 6/7pm - midnight
September 22nd	2pm – 4pm	0.51	2 cruise ships 7/8 am – 4/5pm 3 cruse ships 5/6pm - midnight

* sampler only open until 1pm, cruise ships arrived at 6pm

Figure 8. Presence of cruise ships during sampling periods A, B and C (NO, NO_2 and SO_2)

Sample A:

Total sample hours: 336

	No ships	**1 ship**	**2 ships**	**3 ships**
Hours	291	23	10	12
Percent of total sample hours	87	7	3	4

Sample B:

Non-cruise day samplers - total sample hours: 336

	No ships	**1 ship**	**2 ships**	**3 ships**
Hours	318	18	--	--
Percent of total sample hours	95	5	--	--

Cruise day samplers - total sample hours: 336

	No ships	**1 ship**	**2 ships**	**3 ships**
Hours	237	22	35	42
Percent of total sample hours	71	6	10	13

Sample C:

Non-cruise day samplers - total sample hours: 336

	No ships	**1 ship**	**2 ships**	**3 ships**
Hours	319	17	--	--
Percent of total sample hours	95	5	--	--

Cruise day ship samplers - total sample hours: 336

	No ships	**1 ship**	**2 ships**	**3 ships**
Hours	232	36	32	36
Percent of total sample hours	69	11	9	11

What are the limitations of the monitoring equipment and sampling design?

The Ogawa samplers used measure total nitrogen oxides (NO_x) and NO_2. The NO level is then calculated by subtracting the measured NO_2 level from the measured NO_x level. The samplers are capable of measuring levels of NO_x and NO_2 as low as 1 $\mu g/m^3$ when exposed for 168 hours or more. Samplers were exposed for 336 hours for this study.

The samplers are not suitable for measuring short-term fluctuations in NO under normal outdoor conditions, such as might occur over several hours. Due to logistics, the samplers used to monitor days with cruise ships present were exposed for many hours in which no cruise ships were present (approximately 70 percent of total exposure time).This would reduce the overall impact of short-term high levels of cruise ship related emissions on the measured levels. The results represent average levels over the exposure period, and should not be used to infer short-term levels of NO.

Based on duplicate samples made in as part of the field monitoring, the precision of the results is estimated to be +/- 10%.

How do we interpret the monitoring results?

In general, average NO levels ranged from 3.1 $\mu g/m^3$ to 52 $\mu g/m^3$ per hour of sampler exposure.

The highest average level (52 $\mu g/m^3$) was measured at the curbside on Superior Street in May (Site A-01, Figure 3a). This street has a high volume of car and bus traffic. This high level is not likely associated with cruise ship-related traffic, as Superior Street is not a designated route for buses serving the cruise ships. This high level is also not likely associated with cruise ship emissions, as other sites closer to the terminal measured lower, instead of higher levels of NO when cruise ships were present.

The second highest average level (44.9 $\mu g/m^3$) was measured during monitoring in August/September, at the intersection of Superior and St Lawrence Streets (Site C-02, Figure 5a), by the sampler exposed on days when cruise ships were present. This location is influenced by high car and transit bus volumes, and is on the designated route for buses serving the cruise ships.

The third highest average level (30.9 $\mu g/m^3$) was measured during monitoring in June/July, at the intersection of Montreal Street and Dallas Road (Site B-05, Figure 4a), by the sampler exposed when cruise ships were present. This location is influenced by high car and transit bus volumes, and is on the designated route for buses serving the cruise ships.

Levels of NO were higher on days with cruise ships present compared to levels on days without cruise ships present during the June/July sampling period, at eight of the eleven sites. At the remaining three, levels were similar regardless of cruise ships being present. During the August/September sampling period, NO levels were slightly higher overall, but no consistent trend of higher NO levels on days with cruise ships present was observed in the results. In fact, NO was higher on days without cruise ships present at two sites during the August/September sampling period.

It is unlikely that differences in traffic patterns between weekdays (most non-cruise ship days) and weekends (most cruise ship days) account for differences in NO levels in the results from the June/July monitoring. If higher traffic volume on weekends was a consistent and important source of NO, we would also expect to see higher levels of NO on cruise ship days in the results from the August/September monitoring. These were not observed.

Differences in wind speed and direction may have influenced the results of the June/July sampling compared to the August/September sampling:

- During the June/July sampling, the windroses for days with cruise ships and days without (Figure 6) suggest wind speeds and directions were relatively similar for both sample sets.
- During the August/September sampling, the windrose for the days with cruise ships (Figure 6) shows a higher percentage of winds of 10 or more knots/hour (approximately 30% from south and west directions) compared to the windrose for days without cruise ships (approximately 15% coming from south and west directions).
- Wind speeds were generally higher during the June/July sampling period than in the August/September sampling period.

Wind speed and direction may have been more favourable for the detection of the impact of cruise ship related emissions of NO in the June/July sampling period, as conditions were similar. In contrast, calmer winds on non-cruise days in the August/September sampling period may have resulted in higher local levels of NO, thereby diminishing the chance of seeing a difference due solely to the presence or absence of cruise ships.

During both the June/July and August/September sampling periods, rain occurred on two days when cruise ships were present. This could decrease levels of NO in the air, which may have lessened the chances of detecting differences associated with cruise ship presence.

Comparisons of all NO levels measured in cruise days with all levels measured on days without cruise ships are provided in Figures 9 and 10. Figure 9 shows all measures taken

on days without cruise ships, expressed as a ratio of the average of all measures in the same sampling period. Figure 10 shows the same for all measures taken on days without cruise ships in port. The use of ratios allows for an assessment of where levels tended to be higher or lower than average, regardless of different sampling periods and weather conditions.

In general, there are two sites which are much higher than average regardless of the presence of absence of cruise ships. These sites are on Dallas Road near the Ogden Point Terminal and on Superior at St. Lawrence. Both of these sites have heavy traffic on most days. On days with cruise ships present, these sites were the highest above average. Otherwise, no distinct pattern in higher than or lower than average levels is apparent.

Figure 9. Map showing sites with higher or lower than average levels of NO on days without cruise ships in port, Samples B and C combined

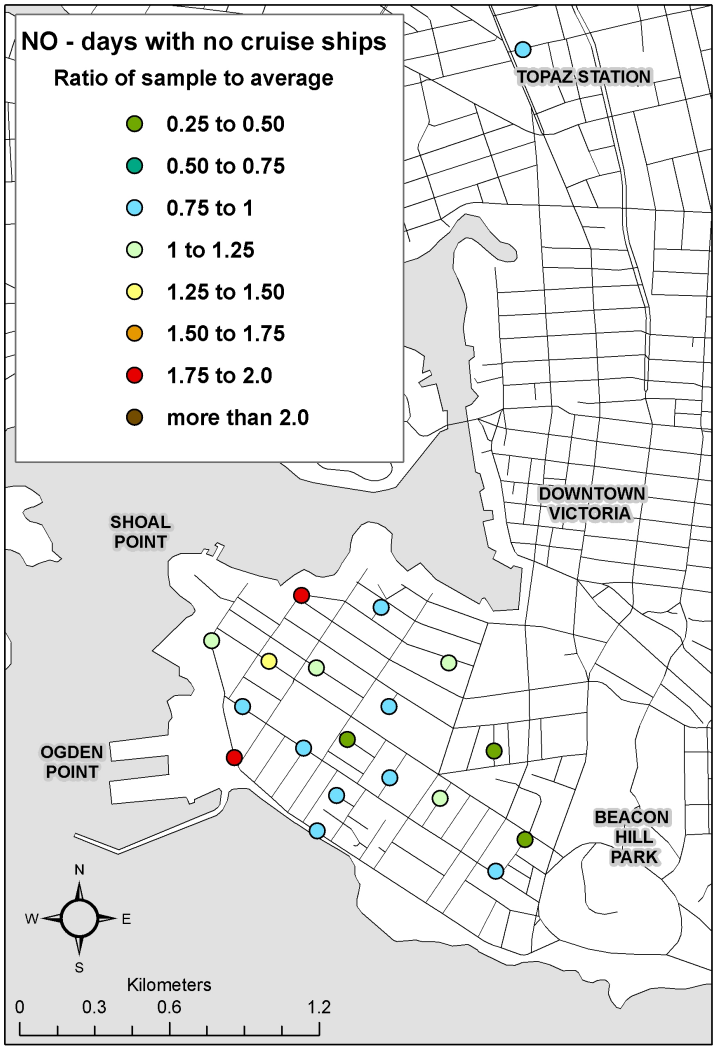
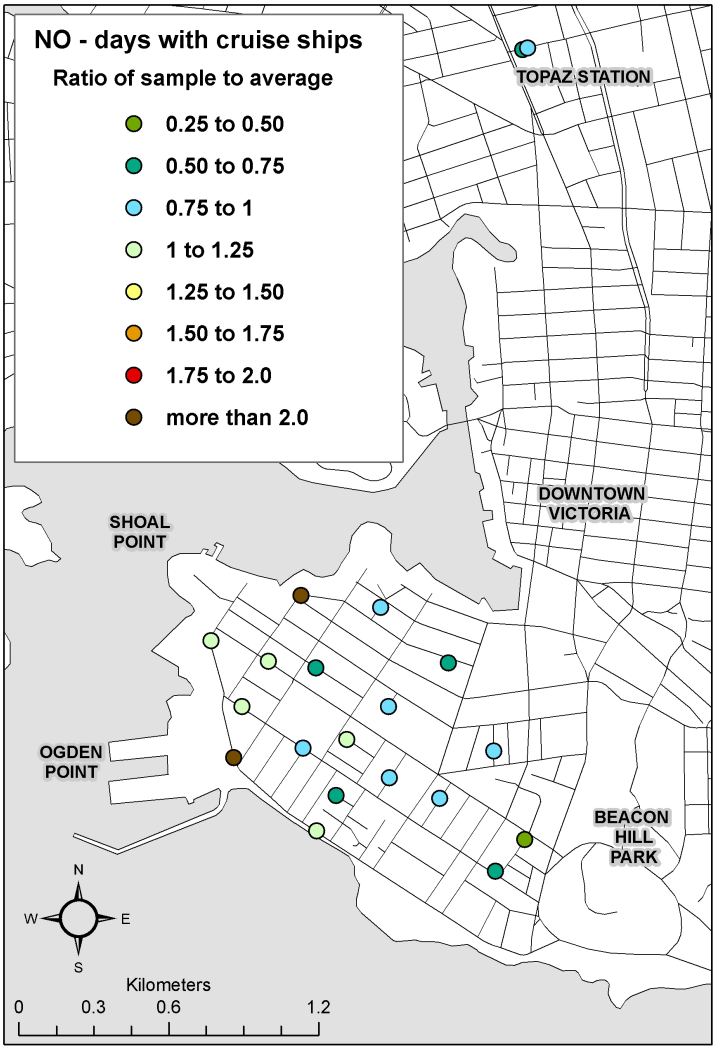


Figure 10. Map showing sites with higher or lower than average levels of NO on days with cruise ships in port, Samples B and C combined



How do these levels compare to those measured at other times or locations?

NO was measured at 42 locations in the CRD for an unrelated study conducted by UVIC researchers[12]. Samplers were exposed on 14 consecutive days between June 22 and July 6, 2006. Results are presented in Figure 11 and 12. In general, NO levels ranged from approximately 4 to 52 µg/m^3, with the highest levels observed nearest to heavily travelled roads, followed by locations in and near the downtown core, including James Bay.

[12] Poplawski, K., Gould, T., Setton, E., Allen, R., Su, J., Larson, T., Henderson, S., Brauer, M., Hystad, P., Lightowlers, C., Keller, P., Cohen, M., Silva, C. and Buzelli, M. (In Press). Intercity transferability of land use regression models for estimating ambient concentrations of nitrogen dioxide. Submitted to: *Journal of Exposure Science and Environmental Epidemiology.*

Figure 11. NO measured at locations in the CRD from June 22 to July 6, 2006 (consecutive 14-day exposure)

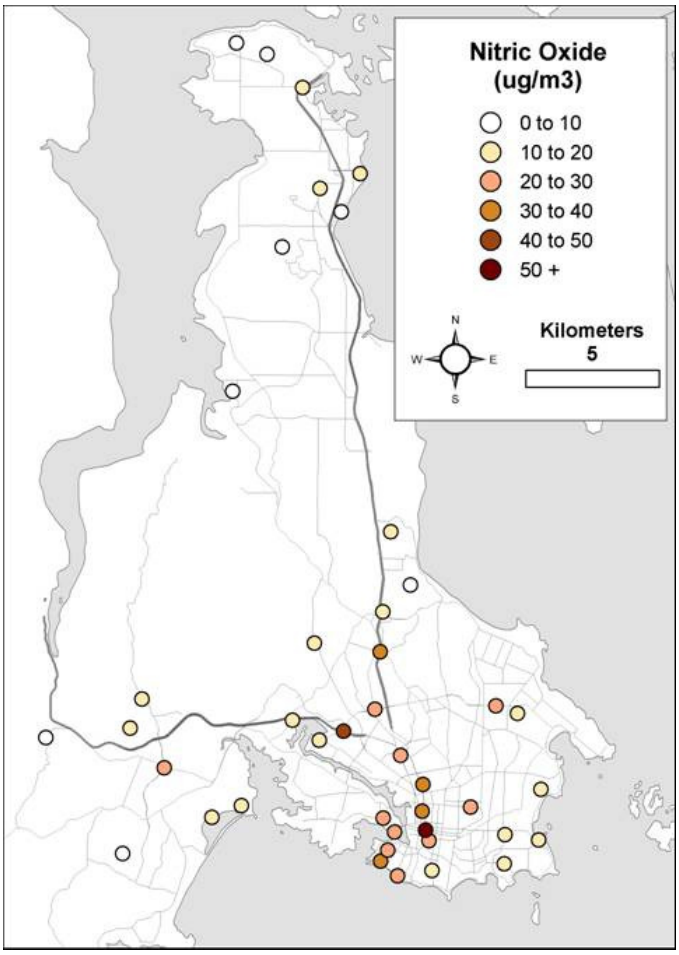
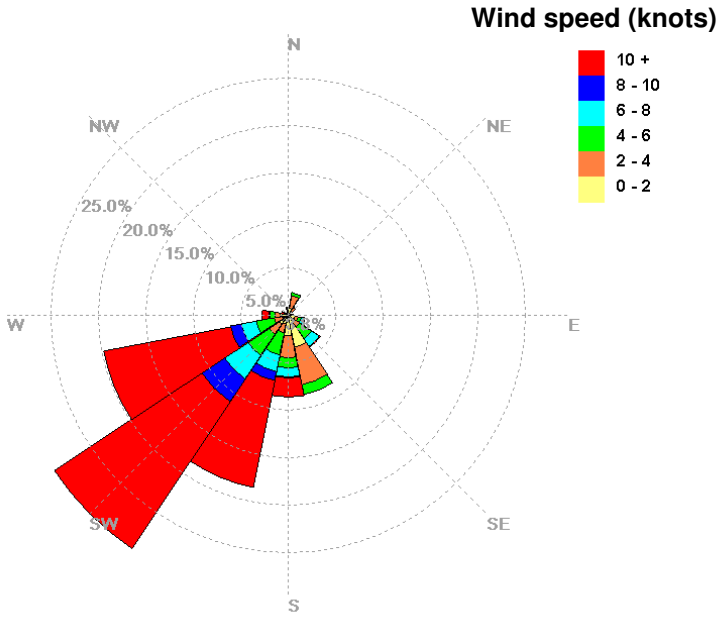


Figure 12. Windrose, precipitation and presence of cruise ships for CRD NO sample in 2006

(a) Windrose



(b) Precipitation (James Bay Community School site):

Time	Precipitation (mm)	Notes
June 22 – July 6, 2006	none recorded	

(c) Cruise Ship Presence:

2006 CRD Sample - total sample hours: 336

	No ships	**1 ship**	**2 ships**	**3 ships**
Hours	200	91	15	30
Percent of total sample hours	60	27	4	9

An analysis of the daily pattern of NO levels was conducted using 2006 data for Topaz station and Royal Roads University station. For each station, data were sorted into three groups – days with cruise ships present, days without cruise ships present but during the cruise season (May – October) and off season days (January – April and November – December). The average level for 1am , 2am, 3am, and so on for each group was then calculated and graphed to show the average daily pattern for each group, as shown in Figures 13 and 14.

At both Topaz and Royal Roads University stations, the same daily pattern is evident. NO levels peak between 8am and 9am, associated with morning weekday traffic. Decreases in traffic after the morning rush hour, in conjunction with increased solar heating and therefore more atmospheric mixing, contribute to lower levels throughout the day. Slight increases in late evening are associated with residential heating in part.[13]
At the Topaz Avenue station (Figure 13), where traffic is much heavier, average hourly levels range from between 4 and 48 $\mu g/m^3$. At the Royal Roads University station (Figure 14), where traffic is very low, average hourly levels range from between 1 and 10 $\mu g/m^3$.

Morning peak levels in NO are highest on days without cruise ships between May and October inclusive. Days without cruise ships present tend to be weekdays, with high morning traffic. Days with cruise ships are more often weekends, with lower morning traffic. Off-season levels are generally lower due to cooler temperatures.

These levels cannot be compared directly to the 2007 field data, as the averaging periods are different. The graphs do show, however, that at these two stations in 2006, NO levels were generally unaffected by the presence or absence of cruise ships.

[13] SENES Consultants Ltd., 2006. Air Quality in the Capital Regional District 2005. Prepared for the Capital Regional District Environmental Services Department, Victoria, BC.

Figure 13. Average diurnal pattern of NO at Topaz Station, 2006 on days with cruise ships, days without, and off season

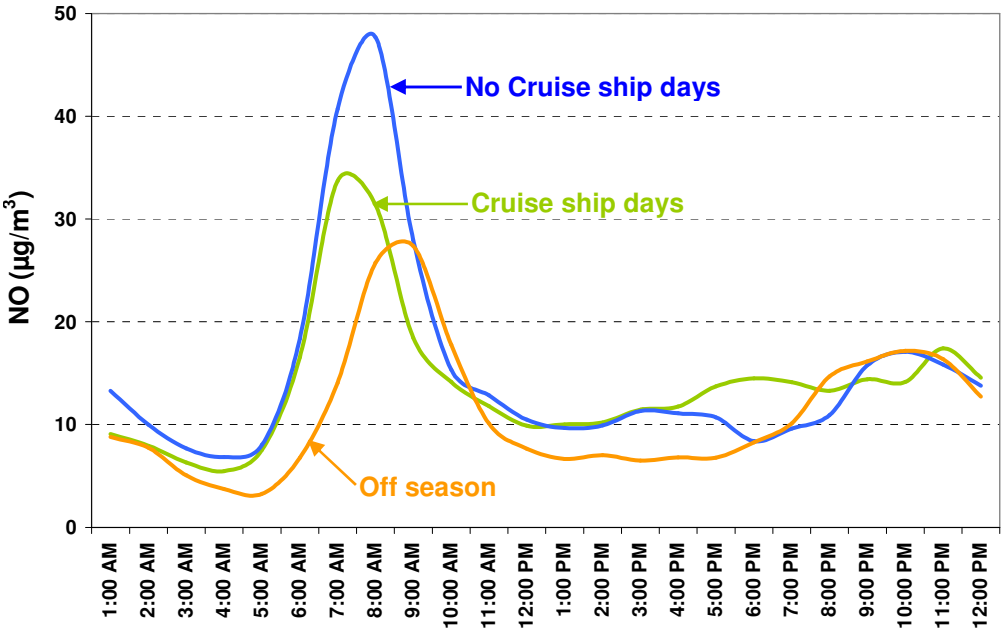
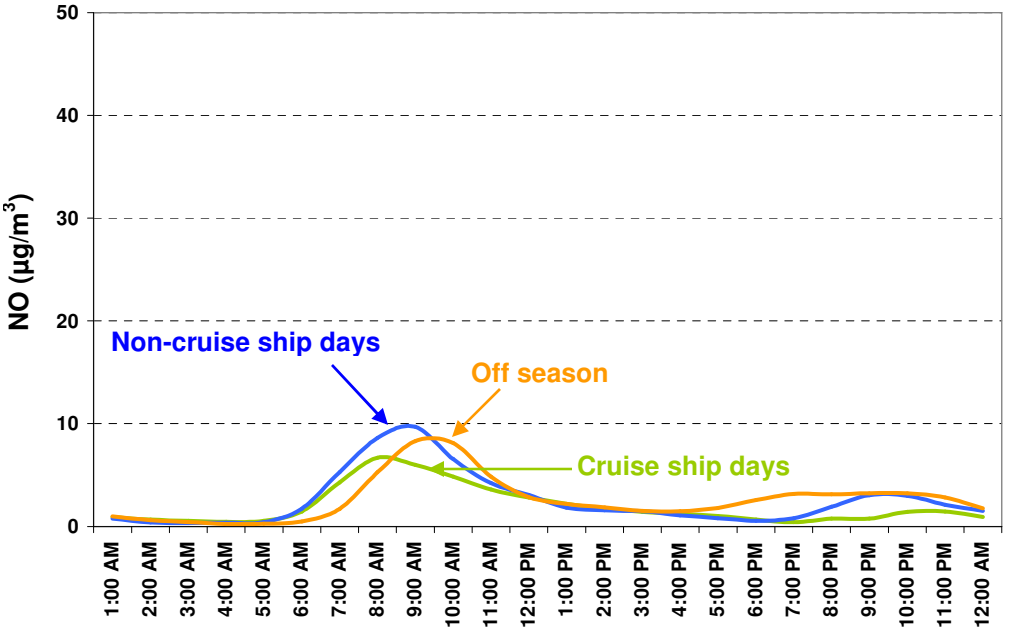


Figure 14. Average diurnal pattern of NO at Royal Roads University Station, 2006 on days with cruise ships, days without, and off season



How do these levels compare to air quality standards or guidelines?

There are no short-term (hourly or daily) or long-term (annual) air quality guidelines or standards for outdoor NO.

Conclusions about nitric oxide

In general, average NO levels ranged from 3.1µg/m^3 to 52 µg/m^3 per hour of sampler exposure.

The highest average levels of NO were measured at locations on busy streets.

There are no short-term (hourly or daily) or long-term (annual) air quality guidelines or standards for outdoor NO.

Average levels of NO measured in the James Bay area are similar to average levels measured in other areas, and appear to be most affected by local traffic and meteorology.

There is an indication in one sampling period that NO was higher on days when cruise ships were present. In the other sampling period, when wind directions were not as favourable, differences were not seen. Notably, cruise ships were present only for approximately 30 percent of the total exposure time for the samplers used on days with cruise ships, so differences would be minimized.

There is no distinct spatial pattern of either higher than average or lower than average levels of NO, with the exception of two site where traffic is heavy on most days. These sites are higher than average on days without and days with cruise ships in port, but highest above average on days when cruise ships are present.

There is no evidence of NO specifically from cruise ships reaching either the Topaz station or the Royal Roads University station. This is reasonable, as NO is highly reactive and easily converted to NO_2 and would be expected to decrease with distance from the source. Daily NO patterns at these stations are most affected by local vehicle traffic.

NITROGEN DIOXIDE

What is nitrogen dioxide?

Nitrogen dioxide (NO_2) is a red-orange gas, not flammable, and a strong oxidizing agent. It is produced by high-temperature combustion of fossil fuels and the conversion of NO. It has the same outdoor sources as NO: high-temperature combustion of fossil fuel for transportation, industry and electric power generation and space heating, and occurs naturally due to forest fires, lightening and soil microbes.

What are the sources of nitrogen dioxide in the James Bay neighbourhood?

Similar to NO, the major sources of NO_2 in the study area are passenger and heavy duty vehicles and marine vessels, including the MV COHO, the Victoria Clipper and commercial fishing boats. Float planes and helicopters are estimated to be very minor sources.[14] Cruise ships are also a major source. No significant industrial activities were identified as potential sources of NO_2 in the study area or in the general region. Natural sources and space heating are expected to be negligible.

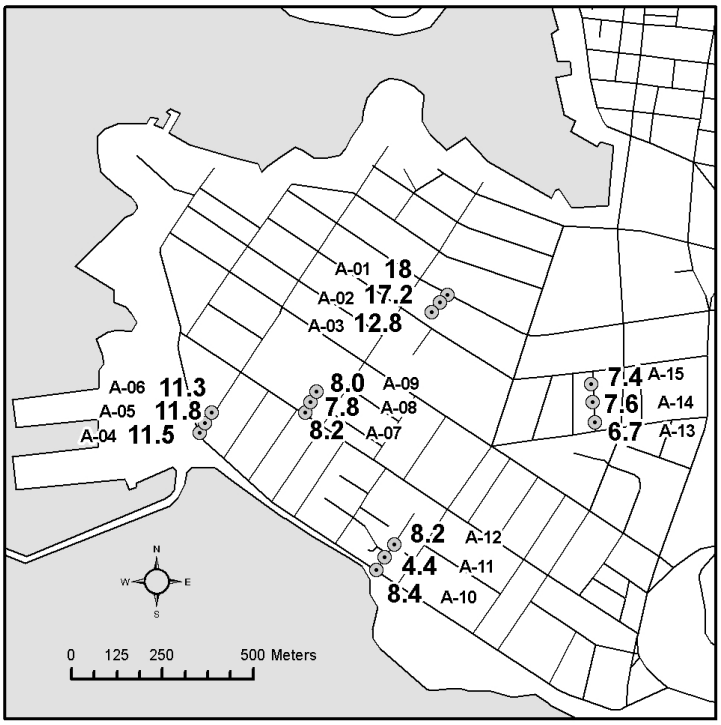
What are the results of the field monitoring?

Figures 15, 16 and 17 provide the sampling sites and monitoring results. See previous Figures 6, 7 and 8 for windroses, precipitation and presence of cruise ships during sampling periods. By special request, two NO_2 measurements were taken at the Shoal Point residences over August 8th to 22nd, 2007. As no other samples were taken for this same period, it is not possible to place the results in context with other parts of the study area, so results are provided in Appendix G.

[14] Tradewinds Scientific Ltd. (2000). Victoria Harbour Air Quality Impact Study, March 29, 2000. Prepared for Transport Canada Programs Branch, Vancouver, B.C.– although did not include cruise ships

Figure 15. Nitrogen dioxide Sample A monitoring sites and results: May 22 to June 6, 2007 (consecutive 14 day exposure)

(a)



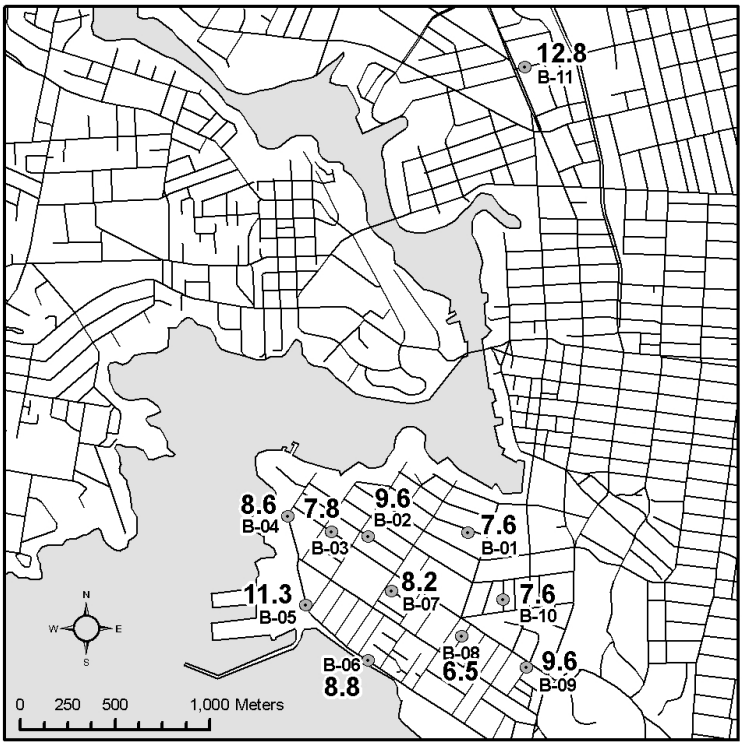
(b)

Site	14-day average hourly NO_2 (µg/m^3)*	
	Actual	± 15%
A-01	18.0	15.3 – 20.7
A-02	17.2	14.6 – 19.8
A-03	12.8	10.9 – 14.7
A-04	11.5	9.8 – 13.2
A-05	11.8	10.0 – 13.6
A-06	11.3	9.6 – 13.0
A-07	8.2	7.0 – 9.4
A-08	7.8	6.6 – 15.0
A-09	8.0	6.8 – 9.2
A-10	8.4	7.1 – 9.7
A-11	4.4	3.7 – 5.1
A-12	8.2	7.0 – 9.4
A-13	6.7	5.7 – 7.7
A-14	7.6	6.5 – 8.7
A-15	7.4	6.3 – 8.5
Reference – Topaz Station**	21.1	
Reference – Royal Roads Station**	not available	

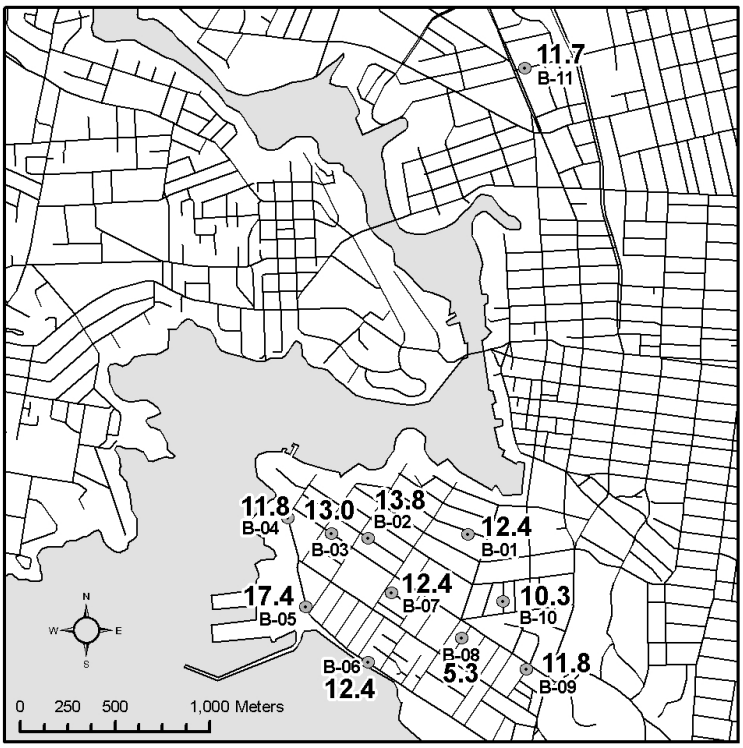
* Total NO_2 measured was divided by the total hours exposed for each sampler.
** Average of all hourly measurements at MoE stations during sample exposure

Figure 16. Nitrogen dioxide Sample B monitoring sites and results: June 15 to July 28, 2007 (non-consecutive exposures, totaling 14 days)

(a) Days with no cruise ships



(b) Days with cruise ships



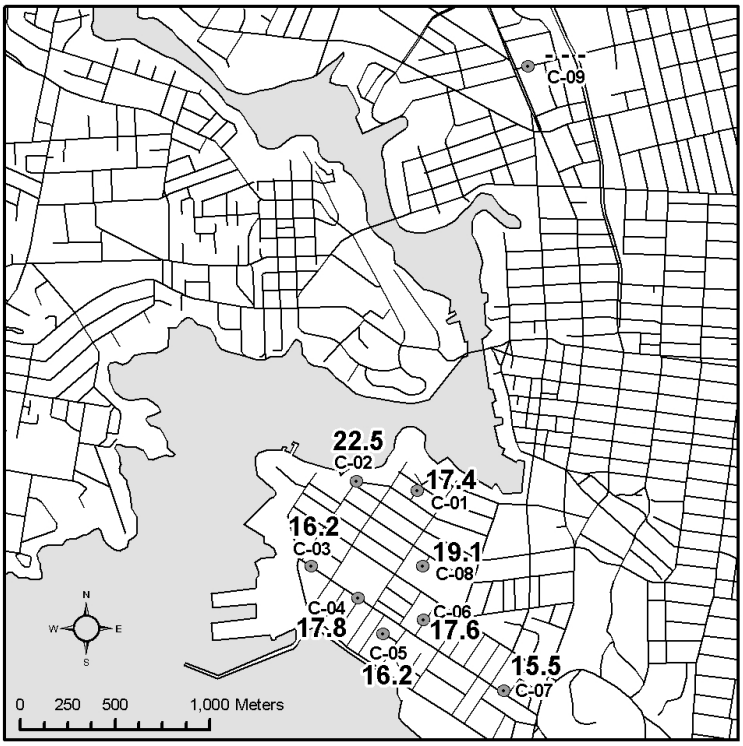
(c) Sample B monitoring results for NO_2

Site	14-day average hourly NO_2 ($\mu g/m^3$)*			
	Days with no cruise ships		Days with cruise ships	
	Actual	+/- 10 %	Actual	+/- 10 %
B-01	7.6	6.8 – 8.4	**12.4**	11.2 – 13.6
B-02	9.6	8.6 – 10.6	**13.8**	12.4 – 15.2
B-03	7.8	7.0 – 8.6	**13.0**	11.7 – 14.3
B-04	8.6	7.7 – 9.5	**11.8**	10.6 – 13.0
B-05	11.3	10.2 – 12.4	**17.4**	15. 7 – 19.1
B-06	8.8	7.9 – 9.7	**12.4**	11.2 – 13.6
B-07	8.2	7.4 – 9.0	**12.4**	11.2 – 13.6
B-08	**6.5**	5.9 – 7.2	5.3	4.8 – 5.8
B-09	9.6	8.6 – 10.6	11.8	10.6 – 13.0
B-10	7.6	6.8 – 8.4	**10.3**	9.3 – 11.3
B-11	12.8	11.5 – 14.1	11.7	10.5 – 12.9
Reference – Topaz Station**				
	19.8		19.5	
Reference – Royal Roads Station**				
	not available		not available	

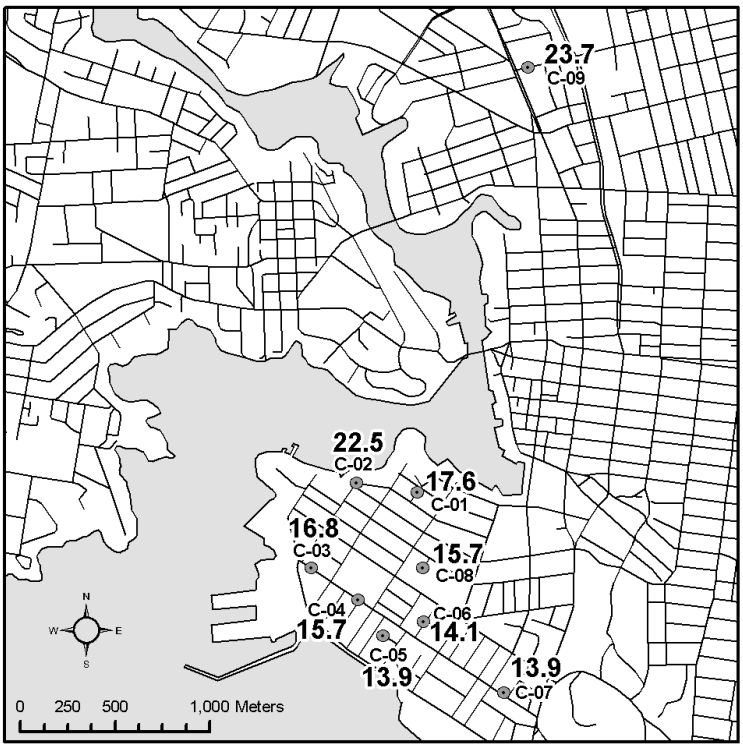
* Total NO_2 measured was divided by the total hours exposed for each sampler.
** Average of all hourly measurements at MoE stations during sample exposure
Bold shows levels higher when +/- 10% range is considered

Figure 17. Nitrogen dioxide Sample C monitoring sites and results: August 17 to September 23, 2007 (non-consecutive exposures, totaling 14 days)

(a) Days with no cruise ships



(b) Days with cruise ships



(c) Sample C monitoring results for NO_2

Site	14 day average hourly NO_2 ($\mu g/m^3$)*			
	Days with no cruise ships		Days with cruise ships	
	Actual	+/- 10 %	Actual	+/- 10 %
C-01	17.4	15.7 – 19.1	17.6	15.8 – 19.4
C-02	22.5	20.3 – 24.8	22.5	20.3 – 24.8
C-03	16.2	14.6 – 17.8	16.8	15.1 – 18.5
C-04	17.8	16.0 – 19.6	15.7	14.1 – 17.8
C-05	16.2	14.6 – 17.8	13.9	12.5 – 15.3
C-06	**17.6**	15.8 – 19.4	14.1	12.7 – 15.5
C-07	15.5	14.0 – 17.1	13.9	12.5 – 15.3
C-08	19.1	17.2 – 21.0	15.7	14.1 – 17.8
C-09	--		23.7	21.3 – 26.1
Reference – Topaz Station**				
	not available		not available	
Reference – Royal Roads Station**				
	not available		not available	

* Total NO_2 measured was divided by the total hours exposed for each sampler.
** Average of all hourly measurements at MoE stations during sample exposure
Bold shows levels higher when +/- 10% range is considered

What are the limitations of the monitoring equipment and sampling design?

The samplers are capable of measuring levels of NO_2 as low as 1 $\mu g/m^3$ when exposed for 168 hours or more. Samplers were exposed for 336 hours for this study.

The samplers are not suitable for measuring short-term fluctuations in NO_2 under normal outdoor conditions, such as might occur over several hours. Due to logistics, the samplers used to monitor days with cruise ships present were exposed for many hours in which no cruise ships were present (approximately 70 percent of total exposure time).This would reduce the overall impact of short-term high levels of cruise ship related emissions on the measured levels. The results represent average levels over the exposure period, and should not be used to infer short-term levels of NO_2.

Based on duplicate samples made in as part of the field monitoring, the precision of the results is estimated to be +/- 15%.

How do we interpret the monitoring results?

In general, average NO_2 levels ranged from 4.4 $\mu g/m^3$ to 23.7 $\mu g/m^3$ per hour of sample exposure.

The highest average level (23.7 $\mu g/m^3$) was measured at Topaz Station (Site C-09, Figure 17b) during the August/September sampling period, on days when cruise ships were present.

The second highest average level (22.5 $\mu g/m^3$) was measured at the intersection of Superior Street and St. Lawrence Street during the August/September sampling period (Site C-02, Figures 17a and 17b), and was the same on days with cruise ships and without cruise ships. This site is influenced by heavy traffic and is on the designated route for buses serving the cruise ships. Wind direction is also predominantly from the Ogden Point terminal toward this site.

The third highest average level (19.1 $\mu g/m^3$) was measured at Michigan Street, just east of Oswego Street, during the August/September sampling period on days with no cruise ships in port (Site C-08, Figure 17a). Michigan Street has moderate traffic volume.

During the June/July sampling period, the highest level of NO_2 (17.4 $\mu g/m^3$) was measured at the intersection of Montreal Street and Dallas Road, immediately opposite the main vehicle exit of the Ogden Point terminal (Site B-05, Figure 16b).

Similar to NO, levels of NO_2 were higher on days with cruise ships present compared to levels on days without cruise ships present during the June/July sampling period, at eight of the eleven sites. During the August/September sampling period, NO_2 levels were slightly higher overall in comparison to the June/July sampling period, but were similar at each site regardless of the presence or absence of cruise ships.

It is unlikely that differences in traffic patterns between weekdays (most non-cruise ship days) and weekends (most cruise ship days) account for differences in NO_2 levels in the results from the June/July monitoring. If higher traffic volume on weekends was a consistent and important source of NO_2, we would also expect to see higher levels of NO_2 on cruise ship days in the results from the August/September monitoring. These were not observed.

Differences in wind speed and direction may have influenced the results of the June/July sampling compared to the August/September sampling:

- During the June/July sampling, the windroses for days with cruise ships and days without (Figure 6) suggest wind speeds and directions were relatively similar for both sample sets.
- During the August/September sampling, the windrose for the days with cruise ships (Figure 6) shows a higher percentage of winds of 10 or more knots/hour (approximately 30% from south and west directions) compared to the windrose for days without cruise ships (approximately 15% coming from south and west directions).
- Wind speeds were generally higher during the June/July sampling period than in the August/September sampling period.

Wind speed and direction may have been more favourable for the detection of the impact of cruise ship related emissions of NO_2 in the June/July sampling period, as conditions were similar. In contrast, calmer winds on non-cruise days in the August/September sampling period may have resulted in higher local levels of NO_2, thereby diminishing the chance of seeing a difference due solely to the presence or absence of cruise ships.

During both the June/July and August/September sampling periods, rain occurred on two days when cruise ships were present. This would tend to decrease levels of NO_2 in the air, and diminish the chances of detecting differences associated with cruise ship presence.

Comparisons of all NO_2 levels measured in cruise days with all levels measured on days without cruise ships are provided in Figures 18 and 19. Figure 18 shows all measures taken on days without cruise ships, expressed as a ratio of the average of all measures in the same sampling period. Figure 19 shows the same for all measures taken on days without cruise ships in port. The use of ratios allows for an assessment of where levels tended to be higher or lower than average, regardless of different sampling periods and weather conditions.

In general, there are more sites (9 in total) with higher than average levels on days when cruise ships were present in comparison to days without cruise ships (6 in total). As with NO, the two sites most above average are at Dallas Road near the Ogden Point Terminal and at Superior and St. Lawrence, regardless of the presence or absence of cruise ships. There is no clear pattern of higher or lower than average levels in the study area.

Figure 18. Map showing sites with higher or lower than average levels of NO_2 on days without cruise ships in port, Samples B and C combined

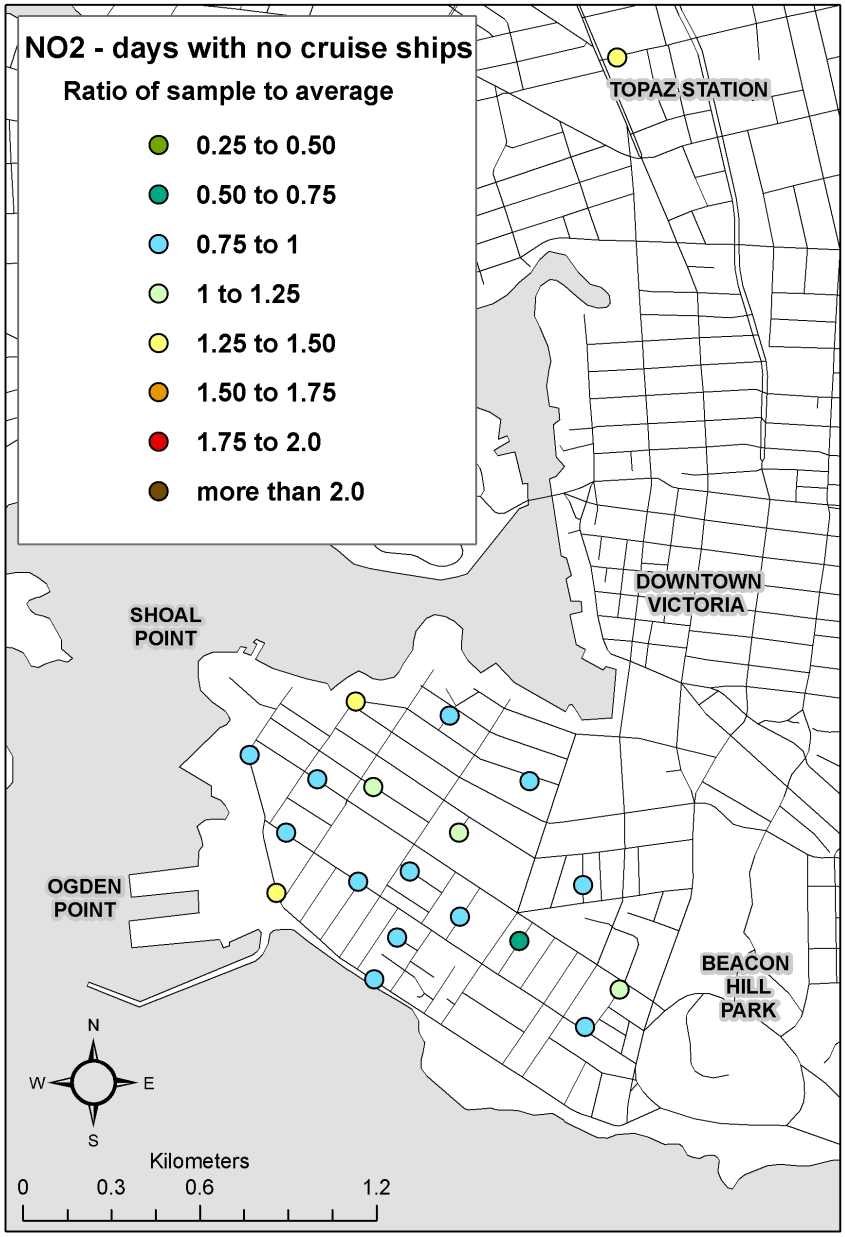
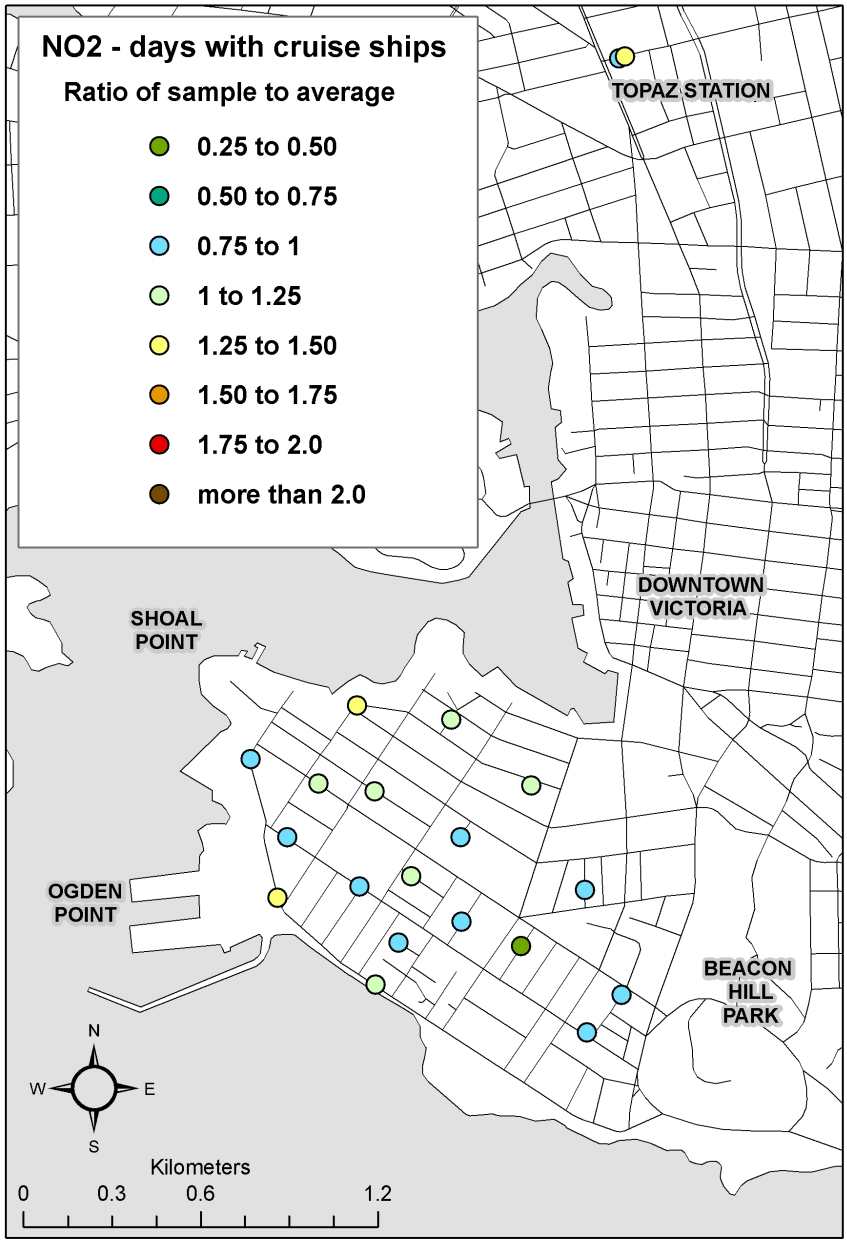


Figure 19. Map showing sites with higher or lower than average levels of NO_2 on days with cruise ships in port, Samples B and C combined



How do these levels compare to those measured at other times or locations?

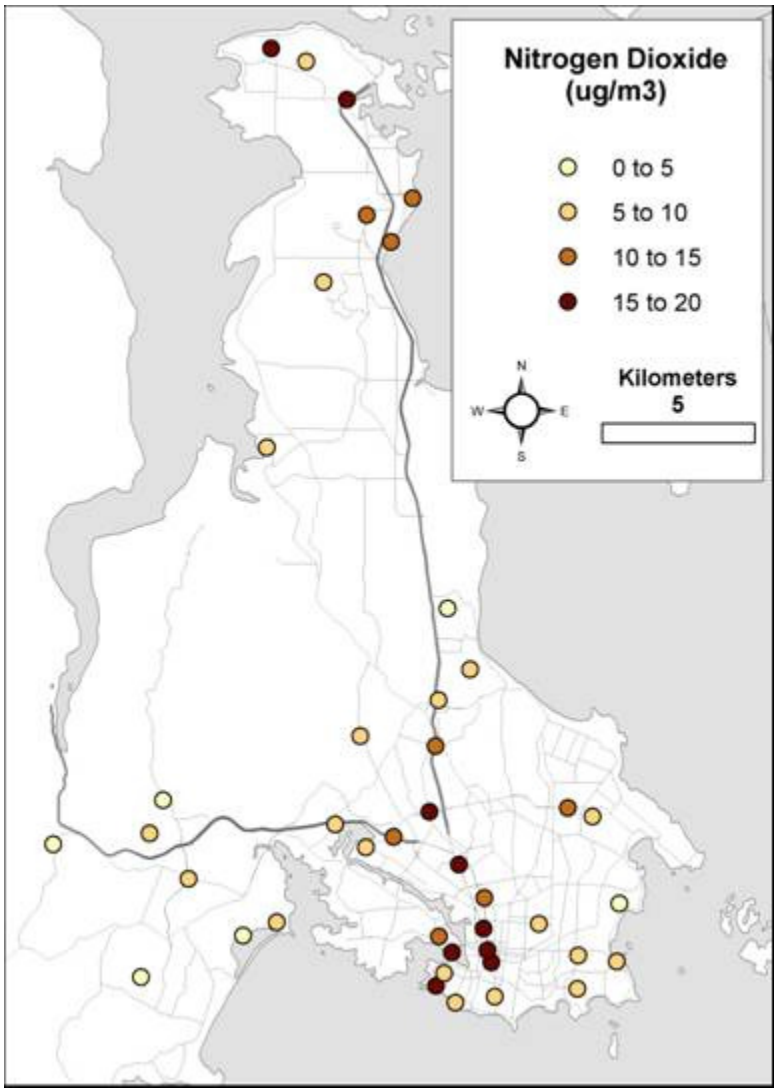
NO_2 was measured at 42 locations in the CRD for an unrelated study conducted by UVIC researchers[15]. Samplers were exposed on 14 consecutive days between June 22 and July

[15] Poplawski, K., Gould, T., Setton, E., Allen, R., Su, J., Larson, T., Henderson, S., Brauer, M., Hystad, P., Lightowlers, C., Keller, P., Cohen, M., Silva, C. and Buzelli, M. (In Press). Intercity transferability of land use regression models for estimating ambient concentrations of nitrogen dioxide. Submitted to: *Journal of Exposure Science and Environmental Epidemiology.*

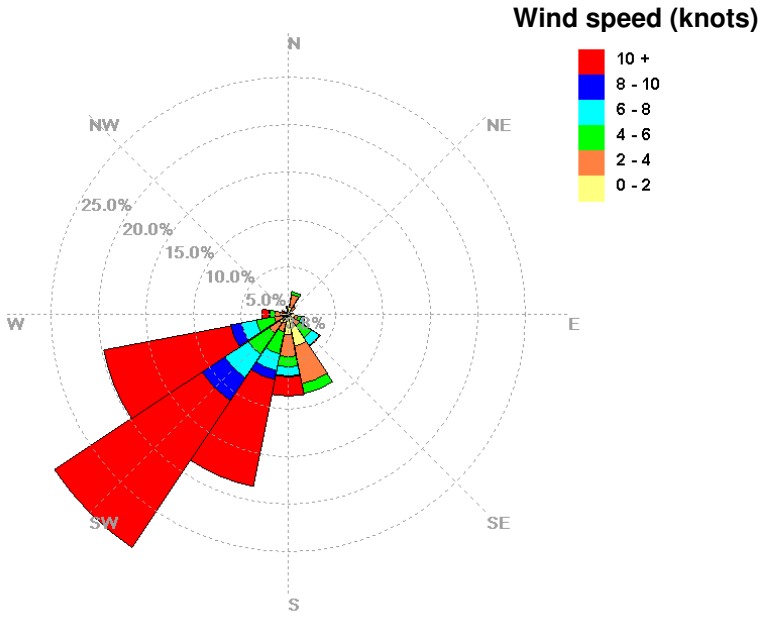
6, 2006. Results are displayed in Figure 20. In general, NO_2 levels ranged from approximately 1 to 20 µg/m^3, with the highest levels occurring on heavily travelled roads in the downtown core and along the Pat Bay Highway. Sites on less-travelled residential roads were lower, including those in James Bay.

Figure 20. NO_2 measured at locations in the CRD from June 22 to July 6, 2006 (consecutive 14-day exposure)

(a) Measured levels



(b) Windrose for June 22 to July 6, 2006 (Ogden Point Station):



(c) Precipitation for June 22 to July 6, 2006 (James Bay Community School site):

Date	**Time**	**Precipitation (mm)**	**Notes**
June 22 – July 6, 2006		none recorded	

(d) Cruise Ship Presence for June 22 to July 6, 2006:

2006 CRD Sample - total sample hours: 336

	No ships	**1 ship**	**2 ships**	**3 ships**
Hours	200	91	15	30
Percent of total sample hours	60	27	4	9

An analysis of the daily pattern of NO_2 levels was conducted using 2006 data for Topaz station and Royal Roads University station. For each station, data were sorted into three groups – days with cruise ships present, days without cruise ships present but during the cruise season (May – October) and off season days (January – April and November – December). The average level for 1am , 2am, 3am, and so on for each group was then calculated and graphed to show the average daily pattern for each group, as shown in Figures 21 and 22.

At both Topaz and Royal Roads stations, the same daily pattern is evident. NO_2 levels peak between 8am and 9am and again between 9pm and 10pm.

At the Topaz Avenue station (Figure 21), average hourly levels range from between 14 and almost 40 $\mu g/m^3$. On days with cruise ships present, NO_2 is up to 35 percent higher between 5pm and 11pm on days with cruise ships present, suggesting that NO_2 related to cruise ships emissions may be reaching this monitoring site. The highest hourly level measured at the Topaz Station on days when cruise ships were present was 97.5 $\mu g/m^3$ and occurred on May 4th, 2006 between 9pm and 10pm when one cruise ship was present; however, on this day, winds were predominantly from the north and northeast and it is unlikely that this maximum is due to cruise ship emissions. The second highest hourly level recorded was 93.7 $\mu g/m^3$, on September 2nd, 2006, when three cruise ships were in port and winds were coming from the terminal toward Topaz station, suggesting that this short-term peak may be associated with cruise ship emissions.

At the Royal Roads station (Figure 22), average hourly levels range from between 6 and 14 $\mu g/m^3$. There is no substantial difference in the pattern and levels seen on days with cruise ships present and days without, suggesting that cruise ship emissions do not reach this monitoring station.

These levels cannot be compared directly to the 2007 field data, as the averaging periods are different; however, this analysis suggests that there may be short term (i.e., hourly) fluctuations in NO_2 associated with cruise ship emissions that are important to investigate.

Figure 21. Average diurnal pattern of NO_2 at Topaz Station, 2006 on days with cruise ships, days without, and off season

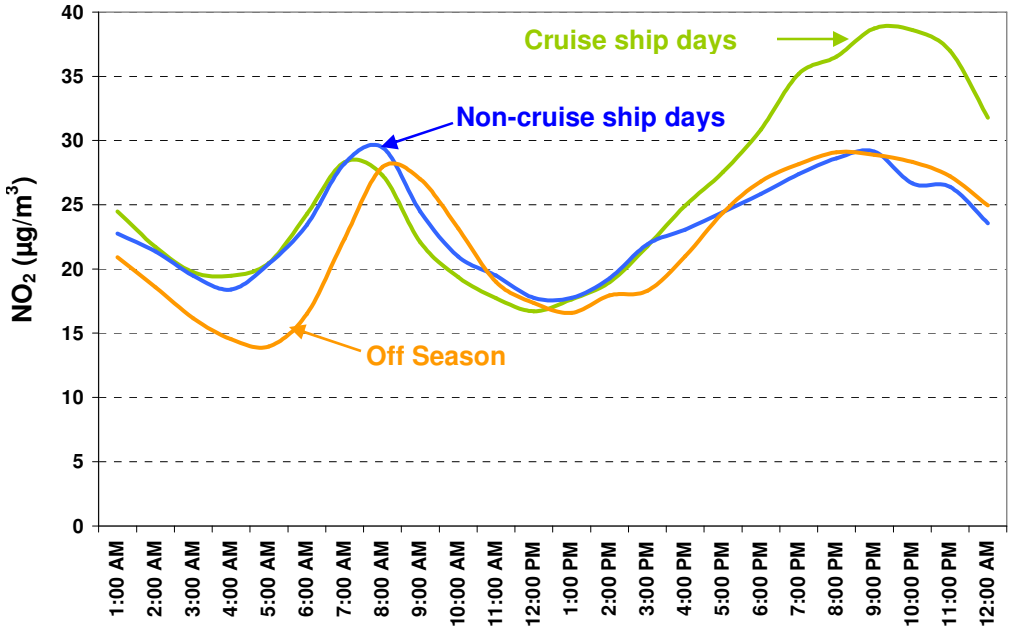
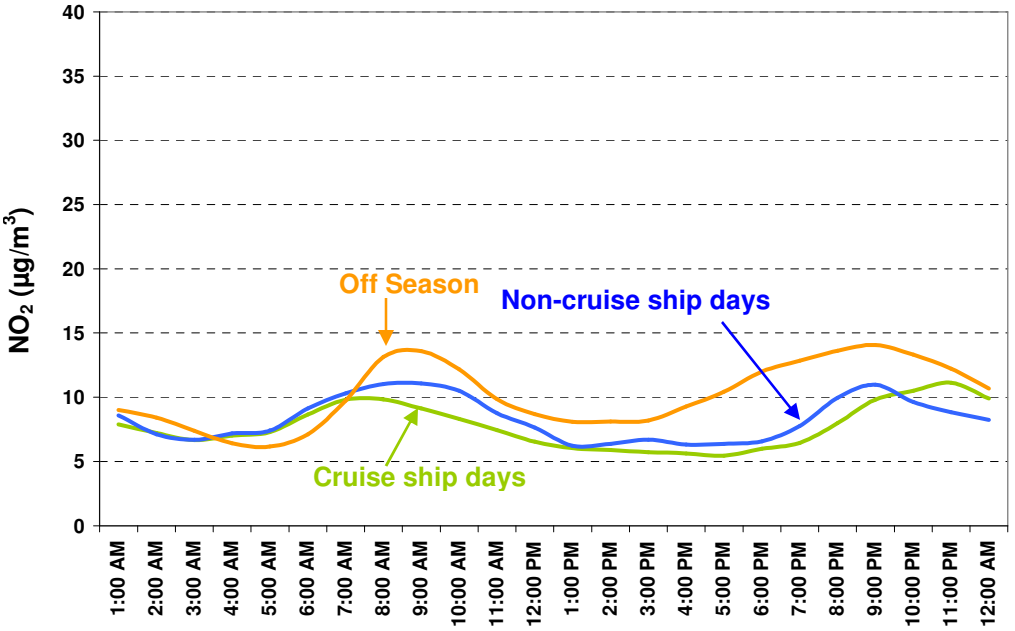


Figure 22. Average diurnal pattern of NO_2 at Royal Roads University Station, 2006 on days with cruise ships, days without, and off season



How do these levels compare to air quality standards or guidelines?

The current Canadian air quality objectives for NO_2 are:

Averaging period	Maximum desirable ($\mu g/m^3$)	Maximum acceptable ($\mu g/m^3$)	Maximum tolerable ($\mu g/m^3$)
1-hour	--	400	1000
24-hour	--	200	300
Annual mean	60	100	--

The NO_2 levels measured in the James Bay neighbourhood are most comparable to the annual mean, although based on 14 non-consecutive days of exposure. The highest average level of NO_2 measured in the James Bay neighbourhood was 22.5 $\mu g/m^3$, compared to the annual maximum desirable level of 60 $\mu g/m^3$. Slightly higher levels were measured at Topaz Station – 23.7 $\mu g/m^3$.

The maximum 1-hour level measured at Topaz Station in 2006 was 97.5 $\mu g/m^3$, which is approximately 25 percent of the maximum acceptable 1-hour standard.

Conclusions about nitrogen dioxide

In general, average NO_2 levels ranged from 4.4 $\mu g/m^3$ to 23.7 $\mu g/m^3$.

The highest average levels of NO_2 were measured near high traffic roads and at Topaz Station.

Measured levels of long-term average NO_2 were roughly 25 to 30 percent of the current ambient air quality standards.

Average levels of NO_2 measured in the James Bay area are similar to average levels measured in other areas, and appear to be most affected by local traffic and meteorology.

There is an indication in one sampling period that NO_2 was higher on days when cruise ships were present. In the other sampling period, when wind directions were not as favourable, differences were not seen. Notably, cruise ships were present only for approximately 30 percent of the total exposure time for the samplers used on days with cruise ships, so differences would be minimized.

Although there were more sites with higher than average levels of NO_2 when cruise ships were in port, there is no consistent pattern in terms of where the higher or lower than

average sites are located in the study area. Two sites where traffic is heaviest are above average regardless of the presence of absence of cruise ships.

Data from the Topaz station suggests there may be short term (i.e., hourly) fluctuations in NO_2 associated with cruise ship emissions that are important to investigate. As emissions of NO from cruise ships are transported, conversion to NO_2 occurs, and so NO_2 levels may be higher as distance increase, at least until emissions are well dispersed.

SULFUR DIOXIDE

What is sulfur dioxide?

Sulfur dioxide (SO_2) is a colourless gas, and in outdoor air is due mainly to the combustion of sulfur-containing fuels, including coal, oil and vehicle fuels, and to industrial processes such as ore smelting and natural gas processing.[16] The amount of SO_2 produced depends on the sulfur content of the fuel used. Large coal-fired power plants and non-ferrous metal smelters can be large regional sources of SO_2.[17] Natural sources of SO_2 include volcanic activity, hotsprings, and the decay of vegetation on land or in the ocean.

What are the sources of sulfur dioxide in the James Bay neighbourhood?

SO_2 is produced mainly by marine vessels, specifically cruise ships which use heavy fuel oil, as well as the MV Coho and the Victoria Clipper[18] being the main sources. Commercial fishing boats may also produce SO_2[19], although these vessels use light fuel oil or lower sulfur diesel fuel (Table 2). All other sources together, including recreational motorboats, whale watching boats, float planes, helicopters, passenger and heavy duty vehicles are estimated to be responsible for 15 percent or less of the total emissions of SO_2.[20] No major industrial sources of SO_2 were identified in the region, and releases from space heating and natural sources are expected to be negligible[21].

Table 2. Sulfur content of fuel type for 2002 West Region[22]

Type of Fuel	Average Sulfur Content (%wt.)	Type of Fuel	Average Sulfur Content (%wt.)
Aviation Turbo Fuel	0.039	Low-Sulfur Diesel Fuel	0.025
Motor Gasoline	0.020	Heavy Fuel oil	0.247
Aviation Gasoline	0.007	Light Fuel oil	0.070
Kerosene/Stove oil	0.034	Heavy Fuel Oil	1.439

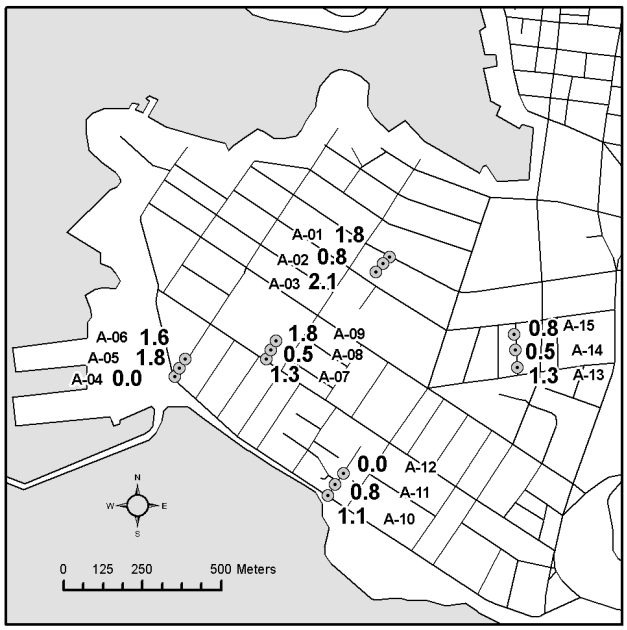
[16] Environment Canada : http://www.ec.gc.ca/TOXICS/EN/detail.cfm?par_substanceID=161&par_actn=s1
[17] Brauer M. 2002. Chapter 2: Sources, Emissions, Concentrations, Exposures and Doses, in A Citizen's Guide to Air Pollution. Second Edition, Suzuki Foundation,. Vancouver, BC.
[18] SENES Consultants Ltd. (2006). Capital Regional District Air Contaminant Emissions Inventory for 2004. Prepared for the Capital Regional District, Victoria, B.C
[19] Ibid
[20] Tradewinds Scientific Ltd. (2000). Victoria Harbour Air Quality Impact Study, March 29, 2000. Prepared for Transport Canada Programs Branch, Vancouver, B.C.
[21] SENES Consultants Ltd. (2006). Capital Regional District Air Contaminant Emissions Inventory for 2004. Prepared for the Capital Regional District, Victoria, B.C
[22] Environment Canada. (2002). Sulphur in Liquid Fuels. (http://www.ec.gc.ca/cleanair-airpur/CAOL/OGEB/fuels/reports/SulphurLiquid/2002SulphurLiquid_p4_e.cfm)

What are the results of the field monitoring?

Figures 23, 24 and 25 provide the sampling sites and monitoring results. See previous Figures 6, 7 and 8 for windroses, precipitation and presence of cruise ships during sampling periods. By special request, two SO_2 measurements were taken at the Shoal Point residences over August 8th to 22nd, 2007. Results are provided in Appendix G.

Figure 23. Sulfur dioxide Sample A monitoring sites and results: May 22 to June 6, 2007 (consecutive 14 day exposure)

(a)



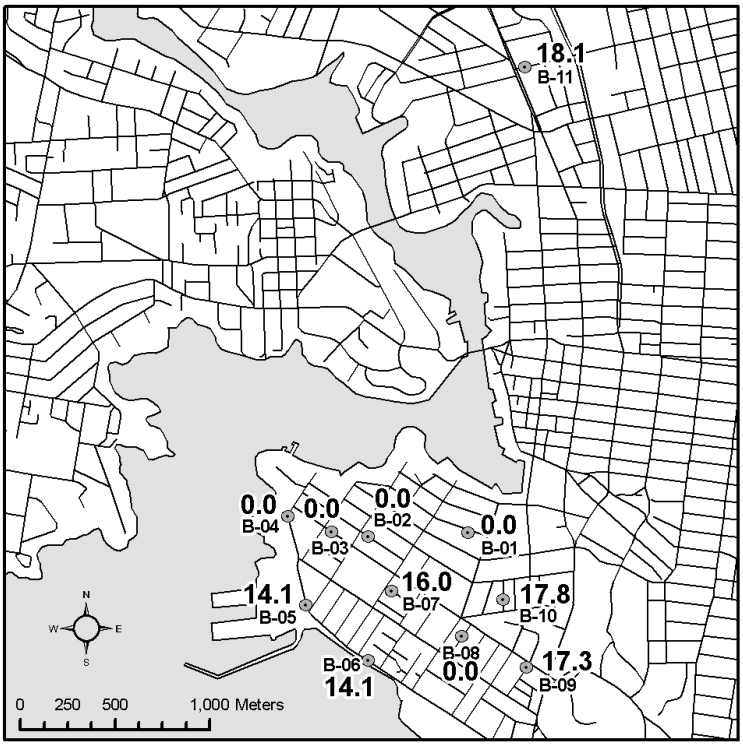
(b)

Site	14-day average hourly SO_2 (µg/m³)*	
	Actual	± 50%
A-01	1.8	0.9 – 2.7
A-02	0.8	0.4 – 1.2
A-03	2.1	1.1 – 3.2
A-04	0.0	--
A-05	1.8	0.9 – 2.7
A-06	1.6	0.8 – 2.4
A-07	1.3	0.7 – 2.0
A-08	0.5	0.3 – 0.8
A-09	1.8	0.9 – 2.7
A-10	1.1	0.6 – 1.7
A-11	0.8	0.4 – 1.2
A-12	0.0	--
A-13	1.3	0.7 – 2.0
A-14	0.5	0.3 – 0.8
A-15	0.8	0.4 – 1.2
Reference –Topaz Station**	5	

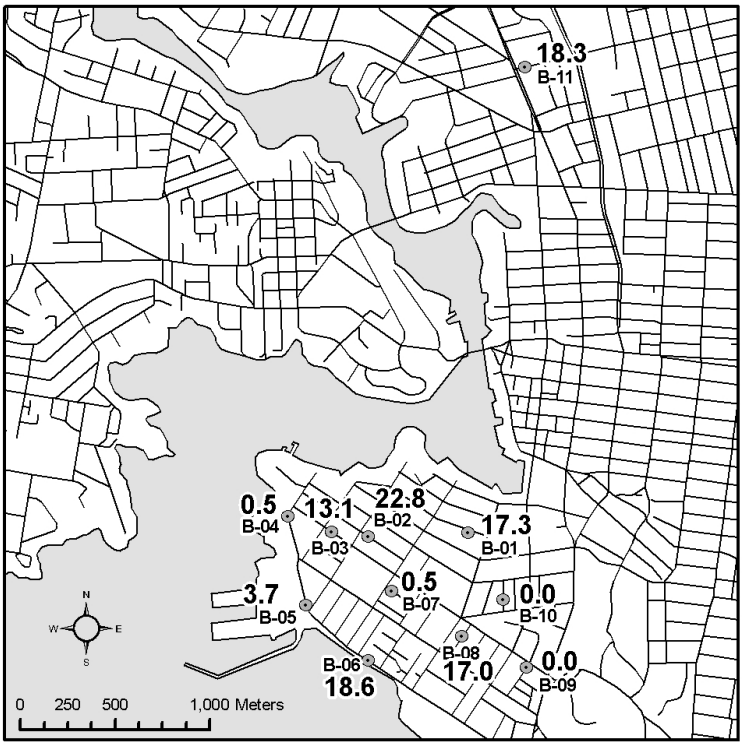
* Total SO_2 measured was divided by the total hours exposed for each sampler.
** Average of all hourly measurements at MoE stations during sample exposure

Figure 24. Sample B monitoring sites and results: June 15 to July 28, 2007 (non-consecutive exposures, totaling 14 days)

(a) Days with no cruise ships



(b) Days with cruise ships



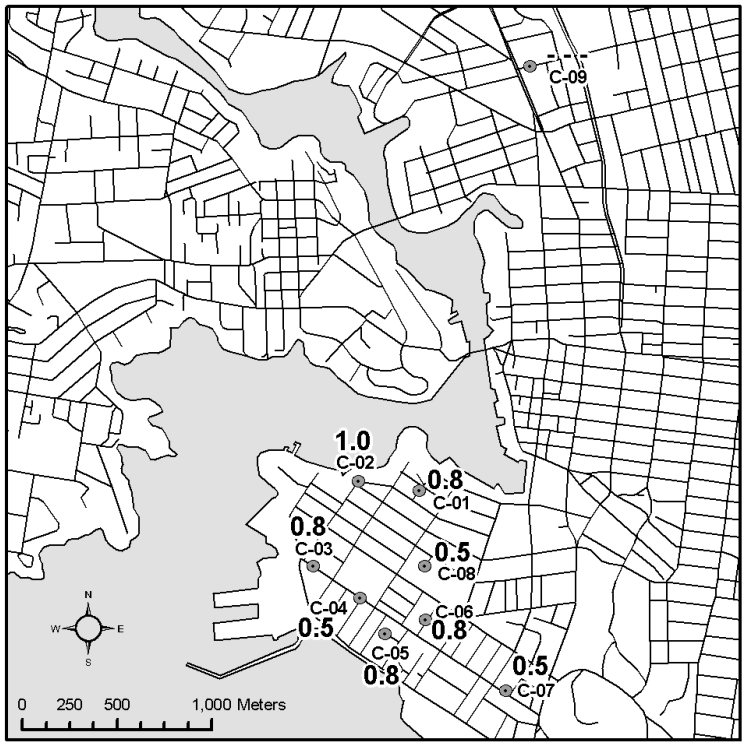
(c) Sample B monitoring results for SO_2

Site	14-day average hourly SO_2 ($\mu g/m^3$)*			
	Days with no cruise ships		Days with cruise ships	
	Actual	+/- 50 %	Actual	+/- 50 %
B-01	0.0	--	17.3	8.7 – 26.0
B-02	0.0	--	22.8	11.4 – 34.2
B-03	0.0	--	13.1	6.6 – 19.7
B-04	0.0	--	0.5	0.3 – 0.8
B-05	14.1	7.1 – 21.2	3.7	1.9 – 5.6
B-06	14.1	7.1 – 21.2	18.6	9.3 – 27.9
B-07	16.0	8.0 – 24.0	0.5	0.3 – 0.8
B-08	0.0	--	17.0	8.5 – 25.5
B-09	17.3	8.7 – 26.0	0.0	--
B-10	17.8	8.9 – 26.7	0.0	--
B-11	18.1	9.1 – 27.2	18.3	9.15 – 27.5
Reference – Topaz Station**				
	1.0		2.3	

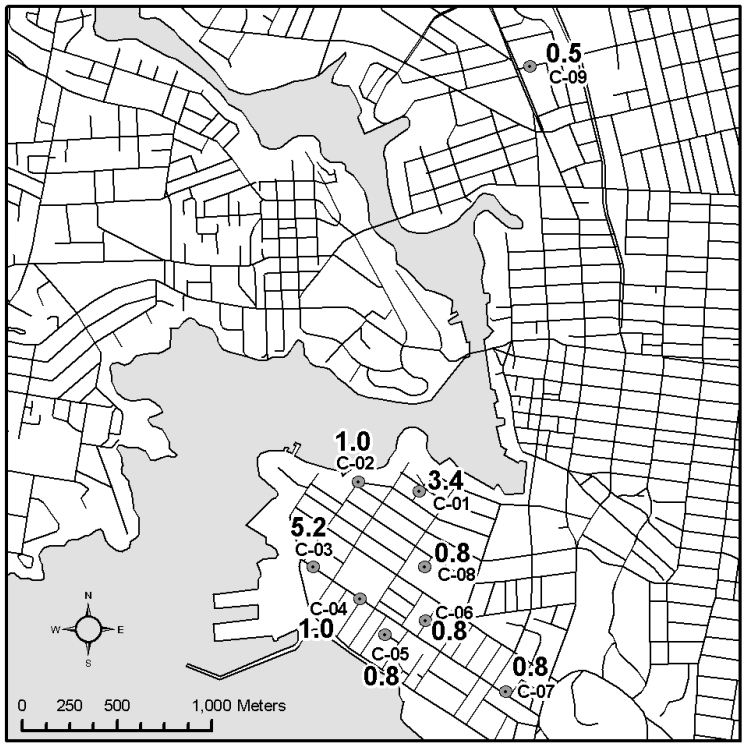
* Total SO_2 measured was divided by the total hours exposed for each sampler.
** Average of all hourly measurements at MoE station during sample exposure
Bold shows levels higher when +/- 50 % range is considered

Figure 25. Sulfur dioxide Sample C monitoring sites and results: August 17 to September 23, 2007
(non-consecutive exposures, totaling 14 days)

(a) Days with no cruise ships



(b) Days with cruise ships



(c) Sample C monitoring results for SO_2

Site	14 day average hourly SO_2 ($\mu g/m^3$)*			
	Days with no cruise ships		Days with cruise ships	
	Actual	+/- 50 %	Actual	+/- 50 %
C-01	0.8	0.4 – 1.2	3.4	1.7 – 5.1
C-02	1.0	0.5 – 1.5	1.0	0.5 – 1.5
C-03	0.8	0.4 – 1.2	5.2	2.6 – 7.8
C-04	0.5	0.3 – 0.8	1.0	0.5 – 1.5
C-05	0.8	0.4 – 1.2	0.8	0.4 – 1.2
C-06	0.8	0.4 – 1.2	0.8	0.4 – 1.2
C-07	0.5	0.3 – 0.8	0.8	0.4 – 1.2
C-08	0.5	0.3 – 0.8	0.8	0.4 – 1.2
C-09			0.5	0.3 – 0.8
Reference – Topaz Station**	not available		not available	

* Total SO_2 measured was divided by the total hours exposed for each sampler.
** Average of all hourly measurements at MoE station during sample exposure
Bold shows levels higher when +/- 50 % range is considered

What are the limitations of the monitoring equipment and sampling design?

The samplers are capable of measuring levels of SO_2 as low as 1 $\mu g/m^3$ when exposed for 168 hours or more. Samplers were exposed for 336 hours for this study.

The samplers are not suitable for measuring short-term fluctuations in SO_2 under normal outdoor conditions, such as might occur over several hours. Due to logistics, the samplers used to monitor days with cruise ships present were exposed for many hours in which no cruise ships were present (approximately 70 percent of total exposure time).This would reduce the overall impact of short-term high levels of cruise ship related emissions on the measured levels. The results represent average levels over the exposure period, and should not be used to infer short-term levels of SO_2.

Based on duplicate samples made in as part of the field monitoring in May and August/September, the precision of the results is estimated to be +/- 50%. This large range is attributed to the generally low levels of SO_2 measured, often at or near the detection limit of the samplers.

Results from the June/July sampling period are unusual. Many of the samplers measured no SO_2, while others measured much higher levels. There was no distinct spatial pattern to either the low or the high measurements, nor any association with the presence of cruise ships. The measurements from this sampling period should be considered with caution, and may be indicative of a sampler problem, rather than actual measured levels.

How do we interpret the monitoring results?

In the May and August/September sampling periods, average SO_2 levels ranged from 0 to 5.2 $\mu g/m^3$ per hour of sampler exposure.

Excluding the measurement made in July/August, the highest level measured was 5.2 $\mu g/m^3$, on Niagara Street between Montreal and St. Lawrence Streets (Site C-03, Figure 25a), by the sampler exposed on days with cruise ships in port in August/September. This site was the closest to the Ogden Point terminal in this sampling period.

The second highest level measured in the May and August/September sampling periods was 3.4 $\mu g/m^3$, on Pendray Street (Site C-01, Figure 25a), by the sampler exposed on days with cruise ships in port in August/September. This site was downwind of the Ogden Point terminal in this sampling period.

The third highest level measured in the May and August/September sampling periods was 2.1 $\mu g/m^3$, at Superior Street between Oswego and Menzies Streets (Site A-03, Figure 23a).

During the June/July sampling period, the three highest levels measured were 22.8, 18.6, and 18.3 $\mu g/m^3$, on days when cruise ships were present. Other sampling equipment measuring SO_2 at the Topaz station recorded an average of only 2.3 $\mu g/m^3$ during this same period on cruise ship days. These results are considered to be anomalous, and may indicate a problem with the samplers in the period.

How do these levels compare to those measured at other times or locations?

No other measures of SO_2 in the vicinity of the study area exist, other than those at Topaz Station.

An analysis of the daily pattern of SO_2 levels was conducted using 2006 data for Topaz station. No other monitoring station in the vicinity measured SO_2 for all of 2006. Data were sorted into three groups – days with cruise ships present, days without cruise ships present but during the cruise season (May – October) and off season days (January – April and November – December). The average level for 1am , 2am, 3am, and so on for

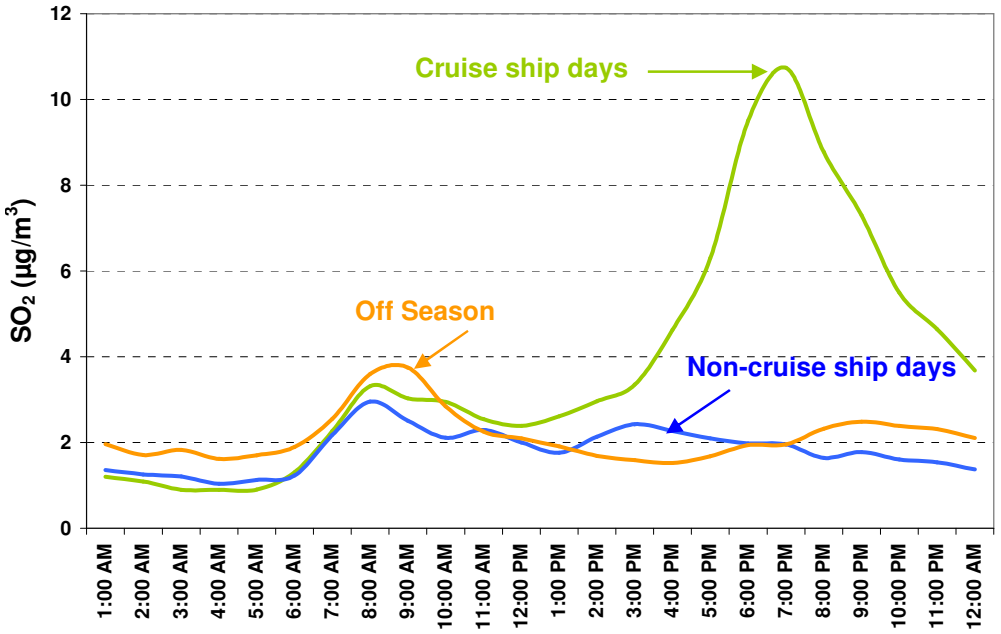
each group was then calculated and graphed to show the average daily pattern for each group, as shown in Figure 26.

The daily pattern on days without cruise ships and on off-season days is very similar, and levels are generally around 2 µg/m^3, although there is a small increase to between 3 and 4 µg/m^3 on average associated with morning commute traffic. The daily pattern on days with cruise ships present shows a marked peak, with levels beginning to rise around 4pm, peaking at 11 µg/m^3 around 8pm, and then declining to less than 4 µg/m^3 by midnight. This suggests that SO_2 associated with cruise ship arrivals is reaching the Topaz station.

The highest hourly level of SO_2 measured at Topaz Station in 2006 was 77 µg/m^3 and occurred twice, on June 24th at 8pm when three cruise ships were present, and on July 21st at 8pm when 2 cruise ships were present. In both cases, winds were coming from the terminal toward Topaz Station.

These levels cannot be compared directly to the 2007 field data, as the averaging periods are different; however, this analysis suggests that there may be short term (i.e., hourly) fluctuations in SO_2 that are important to investigate.

Figure 26. Average diurnal pattern of SO_2 at Topaz Station, 2006 on days with cruise ships, days without, and off season



How do these levels compare to air quality standards or guidelines?

The current Canadian air quality objectives for SO_2 are:

Averaging period	Maximum desirable ($\mu g/m^3$)	Maximum acceptable ($\mu g/m^3$)	Maximum tolerable ($\mu g/m^3$)
1-hour	450	900	--
24-hour	150	300	800
Annual mean	30	60	--

The current BC air quality objectives for SO_2 are:

Averaging period	Level A ($\mu g/m^3$)	Level B ($\mu g/m^3$)	Level C ($\mu g/m^3$)
1-hour	450	900	900 - 1300
3 hour	375	665	--
24-hour	160	260	360
Annual mean	25	50	80

The SO_2 levels measured in the James Bay neighbourhood are most comparable to the annual mean, although the exposures were for only 14 non-consecutive days. Assuming the highest average level of SO_2 measured in the James Bay neighbourhood was in fact 22.8 $\mu g/m^3$, this is less than the Canadian annual maximum desirable level of 30 $\mu g/m^3$ and maximum acceptable level of 60 $\mu g/m^3$. The analogous BC air quality objectives are 25 $\mu g/m^3$ and 50 $\mu g/m^3$ respectively.

Assuming that average levels are actually much lower (in the range of 1 to 5 µg/m3), which would be consistent with the sampling results from May and August/September, and with average SO_2 levels measured at Topaz station, SO_2 levels measured in the James Bay neighbourhood are well below the annual maximum desirable levels for both the Canadian and provincial objectives.

Conclusions about sulfur dioxide

No short-term measurements of SO_2 were made in the James Bay neighbourhood.

In general, average SO_2 levels ranged from less than 1 µg/m3 to 5.2 $\mu g/m^3$ in two sampling periods. Results from a third sampling period were anomalous, and are likely the result of sampler problems.

Measured levels of long-term average SO_2 were below the Canadian and BC annual maximum desirable air quality objectives.

Data from the Topaz station suggests there may be short term (i.e., hourly) fluctuations in SO_2 associated with cruise ship emissions that are important to investigate.

FINE PARTICULATES

What are fine particulates?

Fine particulates ($PM_{2.5}$) are airborne particles equal to or less than 2.5 micrometers in diameter (for reference, human hair is about 50 micrometers wide). They may be solid or liquid, and of varying chemical and physical composition.[23] $PM_{2.5}$ can remain suspended in the air for many days or weeks until finally settling on surfaces or removed by precipitation. Fossil fuel and wood combustion, along with industrial processes and activities release $PM_{2.5}$ into outdoor air. $PM_{2.5}$ can also be produced through chemical reactions in the air with sulfur dioxide (SO_2), nitric oxide and nitrogen dioxide (NO and NO_2) ammonia (NH_3) and volatile organic compounds (VOCs). [24] Other natural sources include dust storms, seaspray, and forest fires.

What are the sources of fine particulates in the James Bay neighbourhood?

There are a number of sources of $PM_{2.5}$ in the James Bay neighbourhood. Marine vessels, both large and small are estimated to produce the majority of $PM_{2.5}$, but emissions from passenger cars and heavy duty vehicles are also significant. Float planes and helicopters are estimated to be very small sources of $PM_{2.5}$.[25] During the heating season, wood burning for residential heating is a significant source of $PM_{2.5}$.[26] Cement manufacturing at a site approximately two kilometers north of the study area produces $PM_{2.5}$.[27] $PM_{2.5}$ can be transported over very long distances, and sources outside of the study area may also contribute to local levels.

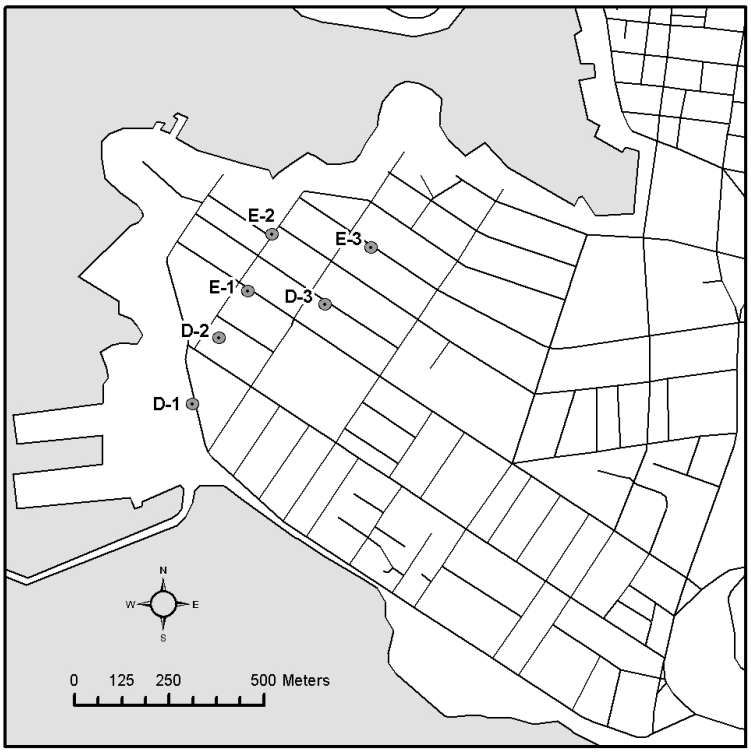
What are the results of the field monitoring?

Figures 27 through 31 provide the sampling sites, monitoring results and supporting data on wind speed and direction and precipitation during each sampling period.

[23] Brauer M. 2002. Chapter 2: Sources, Emissions, Concentrations, Exposures and Doses, in A Citizen's Guide to Air Pollution. Second Edition, Suzuki Foundation,. Vancouver, BC.
[24] Suzuki N. 2003. Particulate matter in BC: a report on PM10 and PM2.5 mass concentrations up to 2000. BC Ministry of Water, Land and Air Protection and the Pacific and Yukon region of Environment Canada. Victoria, BC.
[25] Tradewinds Scientific Ltd. (2000). Victoria Harbour Air Quality Impact Study, March 29, 2000. Prepared for Transport Canada Programs Branch, Vancouver, B.C.
[26] SENES Consultants Ltd. (2006). Capital Regional District Air Contaminant Emissions Inventory for 2005. Prepared for the Capital Regional District, Victoria, BC.
[27] National Pollutant Release Inventory : http://www.ec.gc.ca/pdb/npri/npri_online_data_e.cfm

Figure 27. $PM_{2.5}$ monitoring sites and results

(a) Sampling sites



(b) 24-hour average $PM_{2.5}$ levels (nephelometer): Sites D-1, D-2 and D-3

Date	**$PM_{2.5}$ (µg/m^3)**					**Notes**
	Site D-1	**Site D-2**	**Site D-3**	**Topaz***	**RRU***	
June 25th – 26th	--	1.7	2.1	1.9	1.3	Non-cruise ship day
June 26th – 27th	--	2.3	2.4	4.5	4.5	Non-cruise ship day
June 27th – 28th	--	2.4	2.4	3.1	3.5	Non-cruise ship day
June 28th – 29th	3.4	3.8	3.7	5.2	4.7	Cruise ship day
June 29th – 30th	2.2	2.2	1.7	2.5	2.3	Cruise ship day
June 30th – July 1st	3.9	4.5	4.1	4.4	4.5	Cruise ship day
July 1st – 2nd	1.9	--	--	3.0	2.9	Non-cruise ship day
July 2nd – 3rd	1.7	--	--	3.7	2.6	Non-cruise ship day
July 3rd – 4th	2.3	--	--	4.3	3.1	Non-cruise ship day

* Levels measured by MoE at their monitoring stations

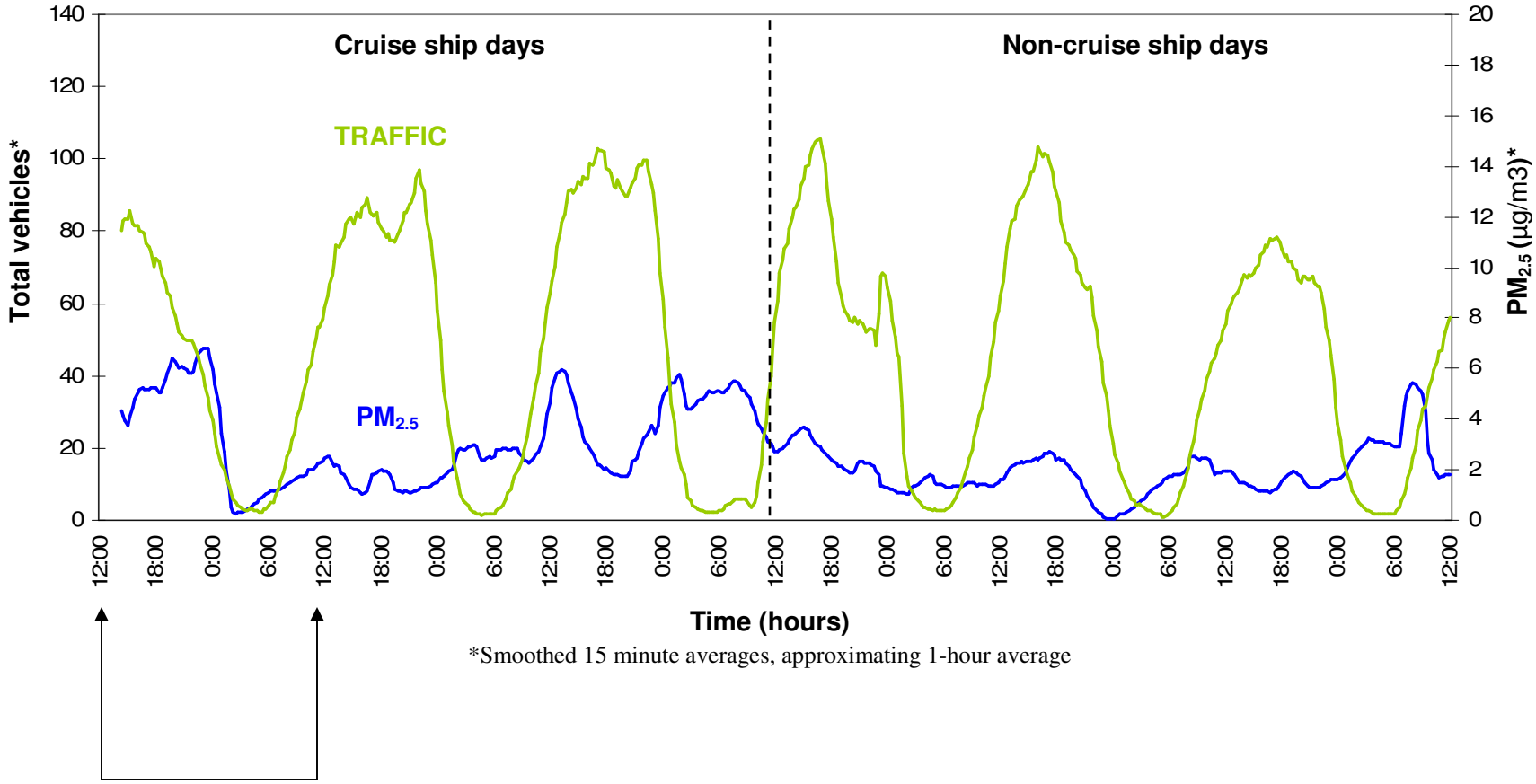
(c) 24-hour average $PM_{2.5}$ levels (nephelometer): Sites E-1, E-2 and E-3

Date	**$PM_{2.5}$ ($\mu g/m^3$)**					**Notes**
	Site E-1	**Site E-2**	**Site E-3**	**Topaz***	**RRU***	
July 30th – 31st	2.6	3.2	2.9	5.0	no	Non-cruise ship day
July 31st – Aug. 1st	3.1	3.8	3.5	5.8	data	Non-cruise ship day
August 1st – 2nd	2.5	2.9	2.8	6.7		Non-cruise ship day
August 2nd – 3rd	1.3	1.3	1.5	2.8	no	Cruise ship day
August 3rd – 4th	3.2	3.0	3.0	3.5	data	Cruise ship day
August 4th – 5th	5.4	6.5	5.3	6.6		Cruise ship day

* Levels measured by MoE at their monitoring stations

Figure 28. Smoothed 15 minute average $PM_{2.5}$ and traffic volume

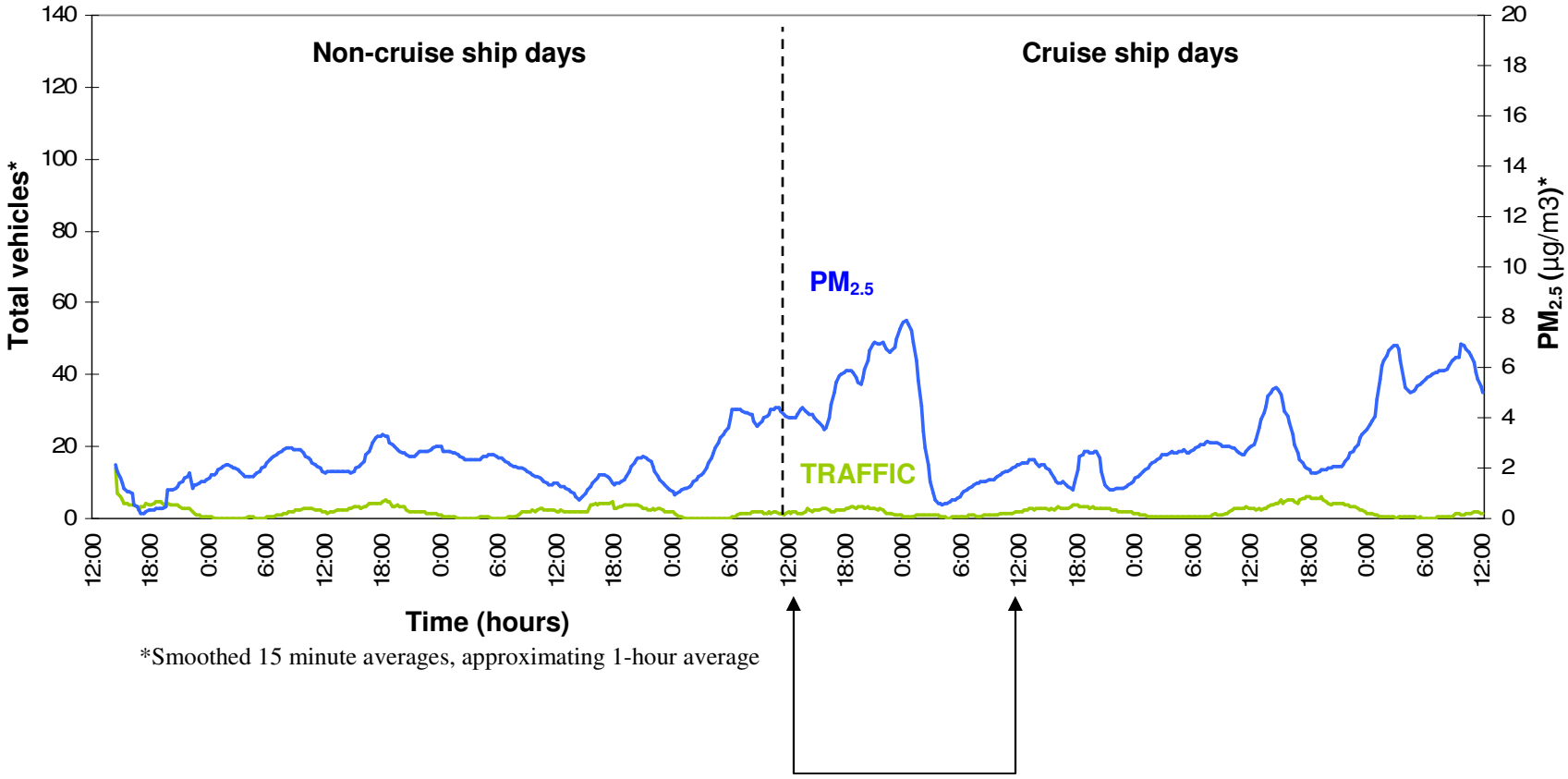
(a) $PM_{2.5}$ and traffic (nephelometer and traffic counters): Site D-1 June 28th to July 4th



*Smoothed 15 minute averages, approximating 1-hour average

See Figure 29 for details

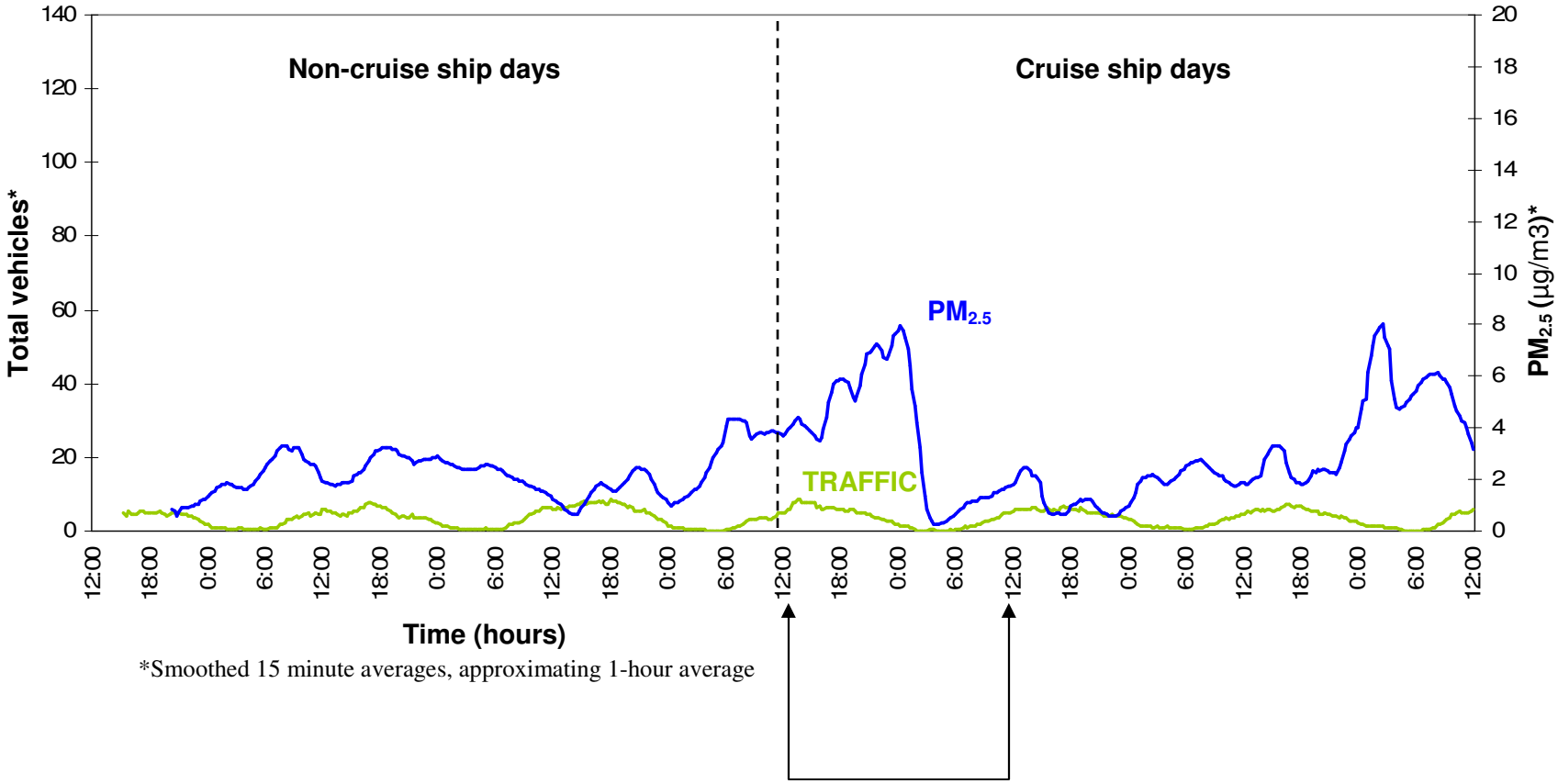
(b) $PM_{2.5}$ and traffic (nephelometer and traffic counters): Site D-2 June 25th to July 1st



*Smoothed 15 minute averages, approximating 1-hour average

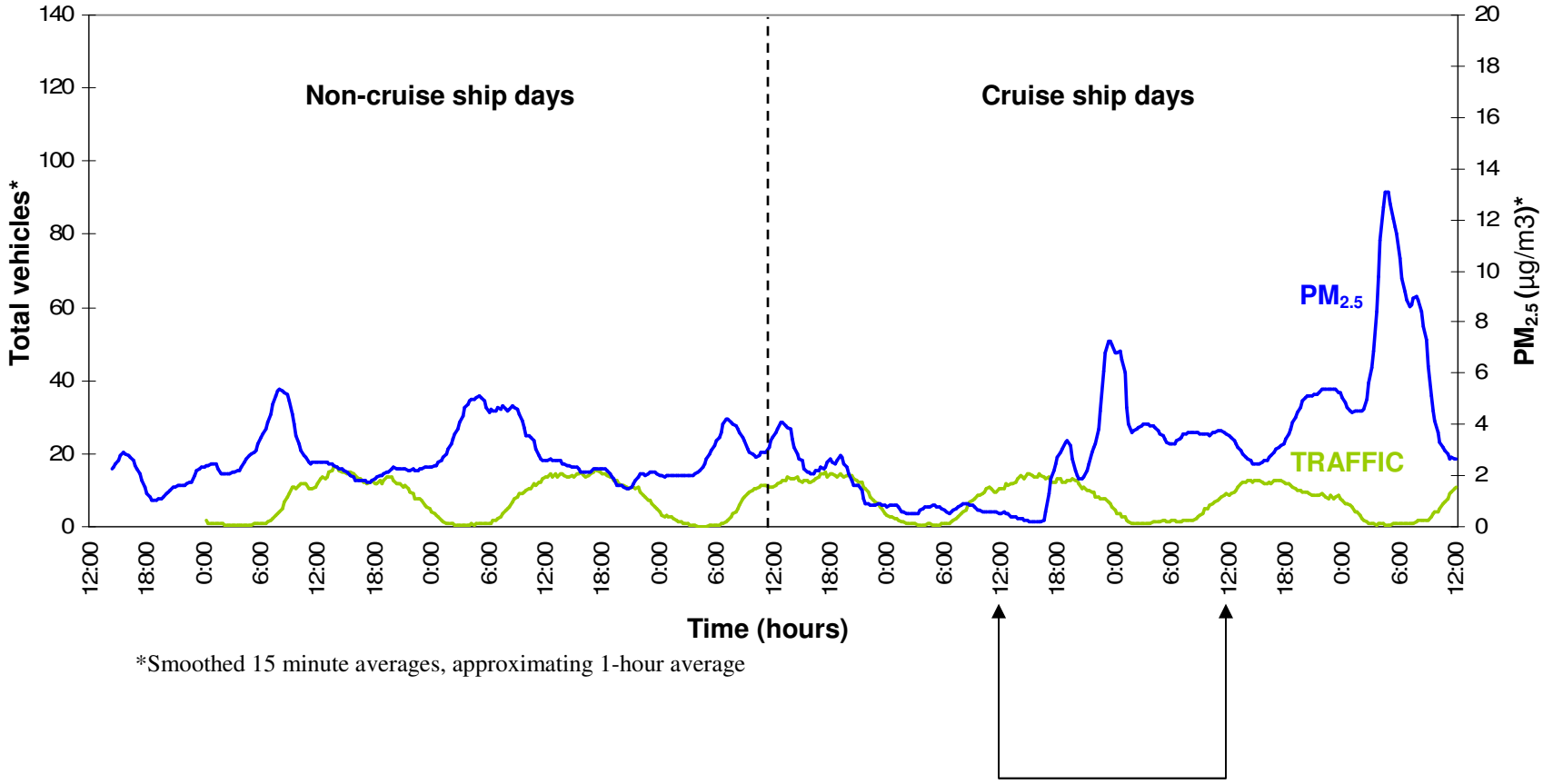
See Figure 29 for details

(c) $PM_{2.5}$ and traffic (nephelometer and traffic counters): Site D-3 June 25th to July 1st



See Figure 29 for details

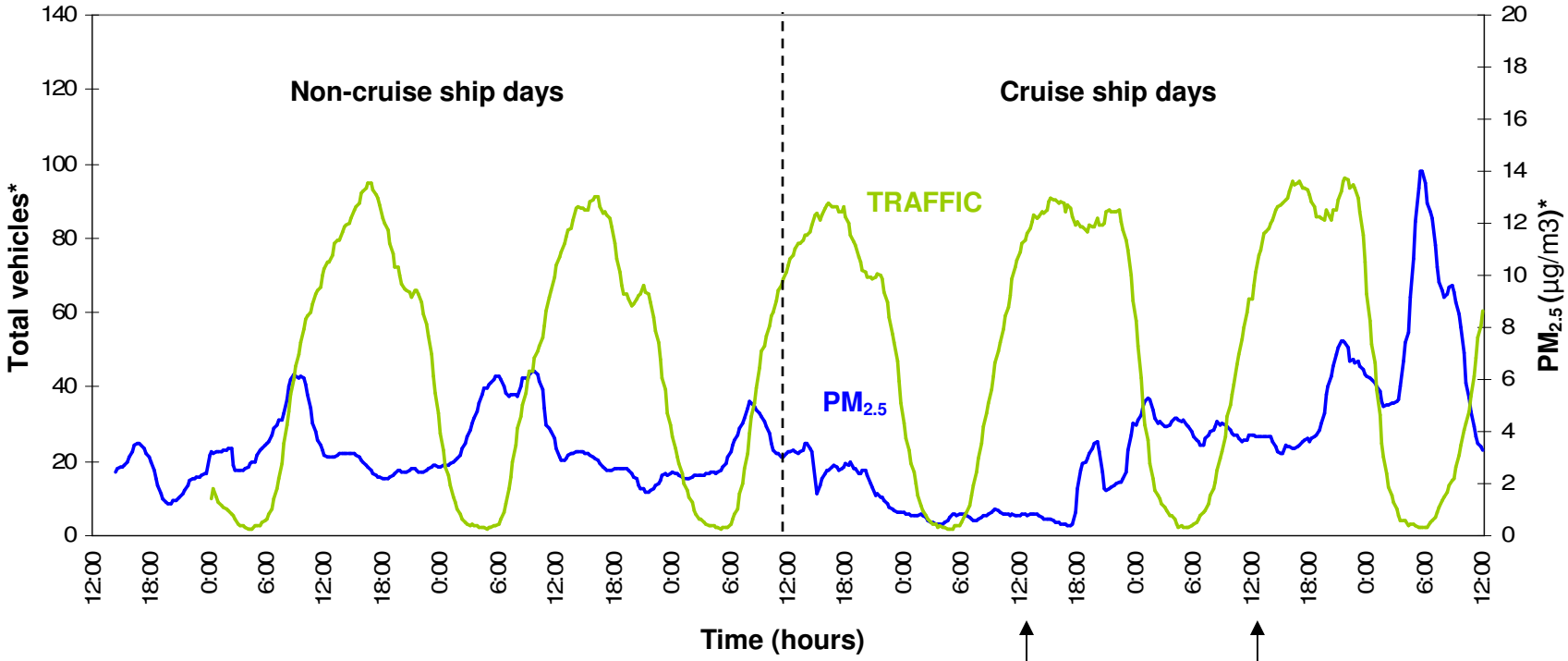
(d) $PM_{2.5}$ and traffic (nephelometer and traffic counters): Site E-1 July 30th to August 5th



*Smoothed 15 minute averages, approximating 1-hour average

See Figure 30 for details

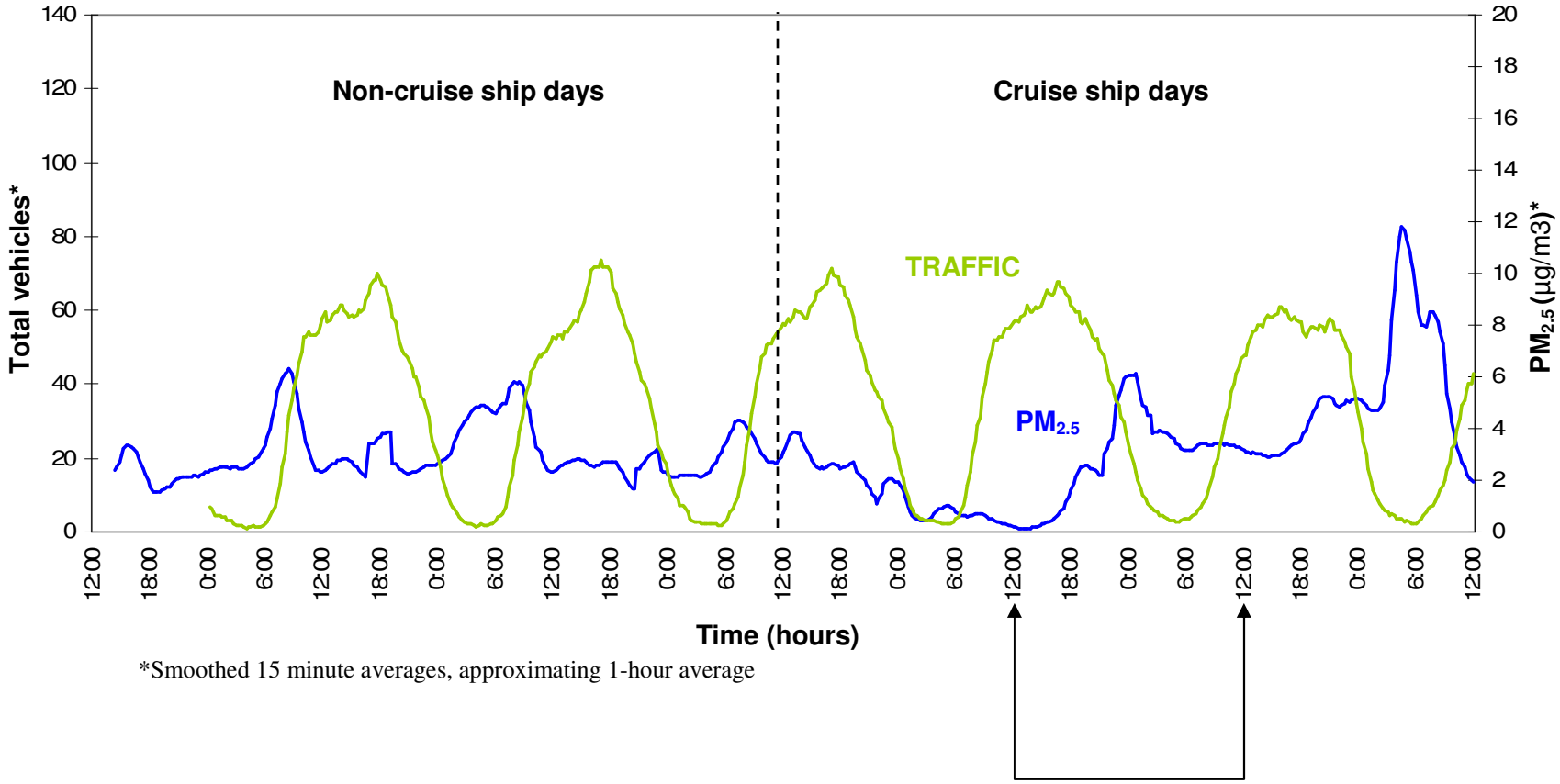
(e) $PM_{2.5}$ and traffic (nephelometer and traffic counters): Site E-2 July 30th to August 5th



*Smoothed 15 minute averages, approximating 1-hour average

See Figure 30 for details

(f) $PM_{2.5}$ and traffic (nephelometer and traffic counters): Site E-3 July 30th to August 5th



*Smoothed 15 minute averages, approximating 1-hour average

See Figure 30 for details

Figure 29. $PM_{2.5}$ event associated with cruise ship departures on June 30th to July 1st, 2007 at Sites D-1, D-2 and D-3

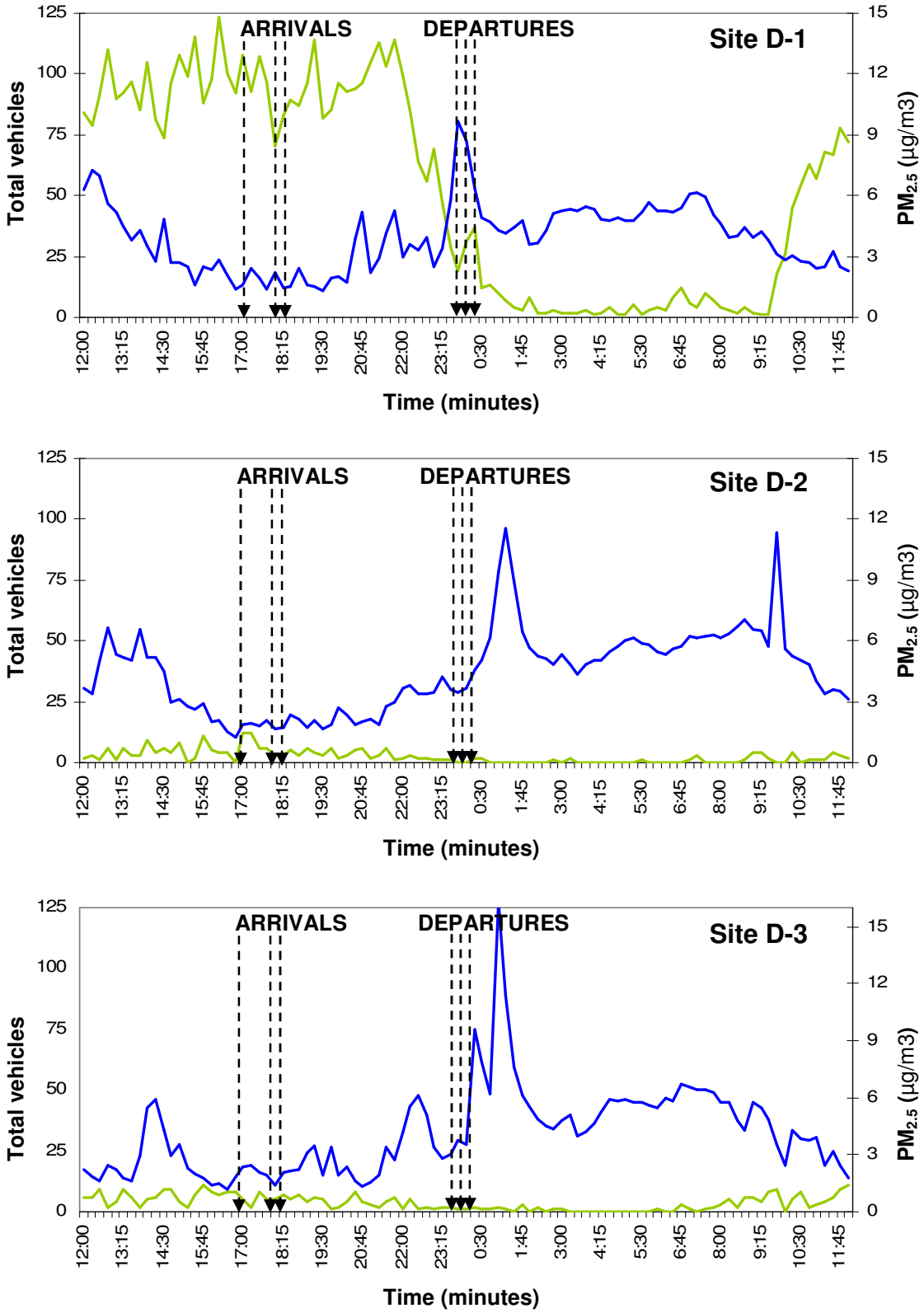


Figure 30. $PM_{2.5}$ event associated with cruise ship activity on August 3rd and 4th, 2007 at Sites E-1, E-2 and E-3

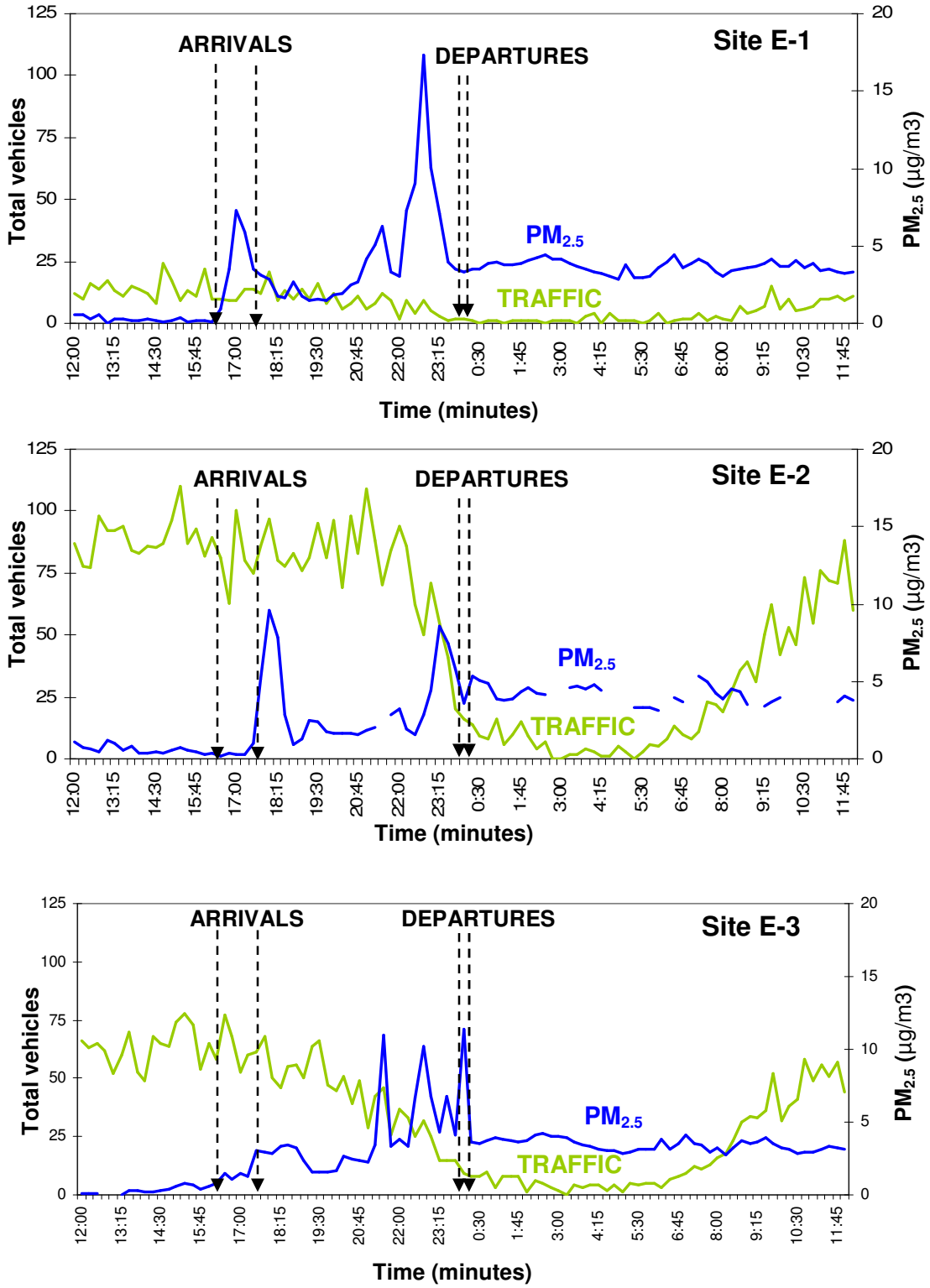
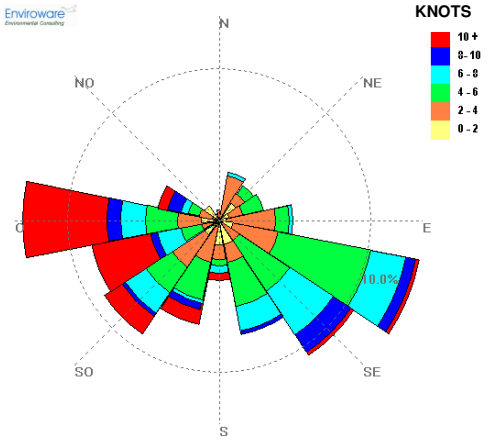


Figure 31. Windroses and precipitation for $PM_{2.5}$ samples

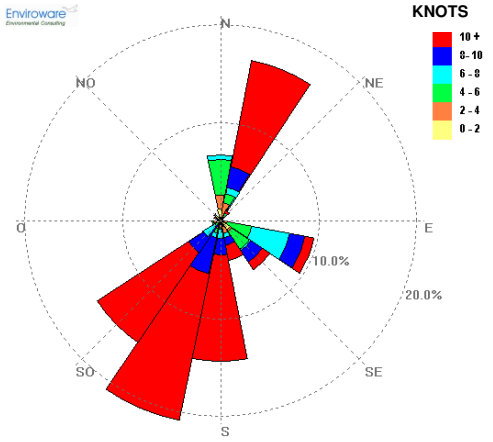
(a) Windroses (Ogden Point Station)

Sites D-1 and D-2

Days with cruise ships

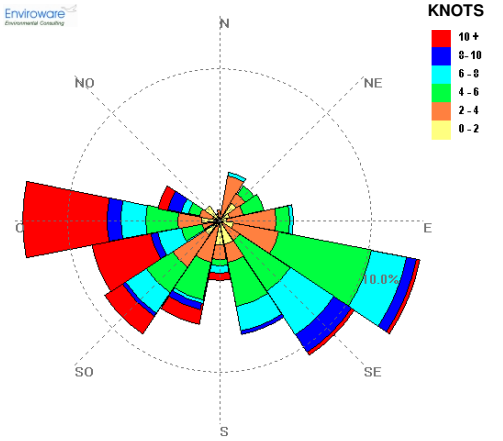


Days without cruise ships

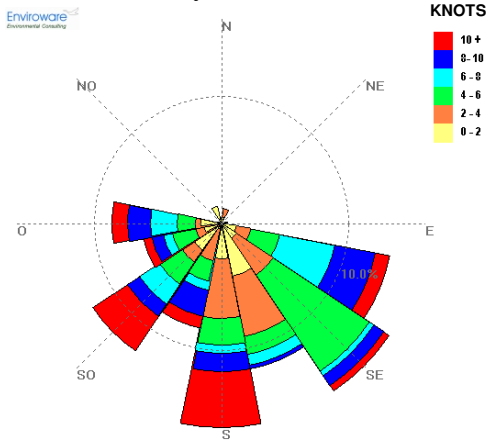


Site D-3

Days with cruise ships

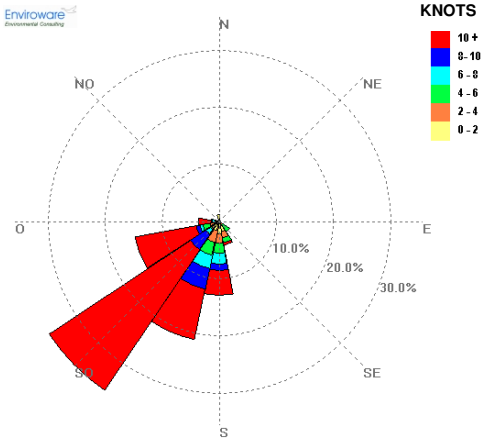


Days without cruise ships

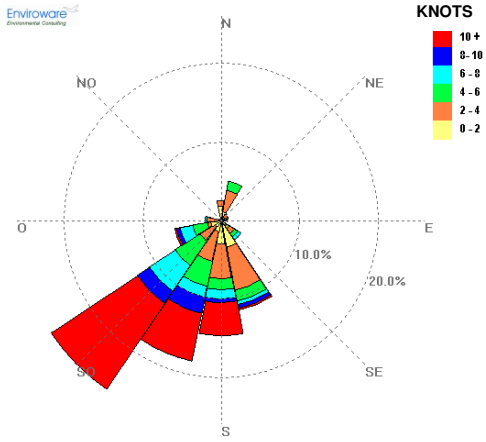


Sites E-1, E-2 and E-3

Days with cruise ships



Days without cruise ships



(b) Precipitation (James Bay Community School site)

Sites D-1, D-2 and D-3:

Days with cruise ships	Time	Precipitation (mm)	Notes
		none recorded	

Days without cruise ships	Time	Precipitation (mm)	Notes
June 28th	2pm – 7pm	4.32	Non-cruise ship day
June 29th	2pm – 3:30pm	1.27	Non-cruise ship day

Sites E-1, E-2 and E-3

Days with cruise ships	Time	Precipitation (mm)	Notes
		none recorded	

Days without cruise ships	Time	Precipitation (mm)	Notes
		none recorded	

What are the limitations of the monitoring equipment and sampling design?

The nephelometers and traffic counters measured short term levels (5 minute averages and 15 minute totals respectively), so detailed information is available to interpret trends.

How do we interpret the monitoring results?

24-hour average $PM_{2.5}$ levels in the James Bay area ranged from 1.3 to 6.5 µg/m3.

The three highest 24-hour average levels measured in the June/July sampling period were 4.5, 4.1, and 3.9, at sites D-2, D-3 and D-1 respectively on June 30th – 31st. These were

days with cruise ships present. At Topaz station, the 24-hour average $PM_{2.5}$ level for this period was 4.4 µg/m3, and at Royal Roads University station, the level was 4.5 µg/m3.

The three highest 24-hour average levels measured in the July/August sampling period were 6.5, 5.4, and 5.3 µg/m3, measured at sites E-2, E-1 and E-3 respectively, on August $4^{th} – 5^{th}$. These were days with cruise ships present. Data for Royal Roads University station were not available for this sampling period at the time of writing.

Traffic volumes on roads adjacent to the sampling sites did not appear to affect the short-term $PM_{2.5}$ levels at all locations. Figure 28 provides graphs of the $PM_{2.5}$ levels (smoothed to approximate a moving 1-hour average) and traffic counts, and shows that regardless of different traffic volumes among sampling sites, the pattern and levels of $PM_{2.5}$ remained similar. This suggests that traffic emissions very near the monitors had less influence than area wide sources in general. For example, $PM_{2.5}$ from traffic on a busy road may influence $PM_{2.5}$ levels on nearby, less busy roads.

Short-term $PM_{2.5}$ levels (moving 1-hour average) ranged from near 0 to 14 µg/m3. The graphs in Figure 28 suggest higher levels and more irregular patterns are associated with the presence of cruise ships.

Very short-term $PM_{2.5}$ levels (5 minute averages) clearly showed events associated with cruise ship activity. Figures 29 and 30 provide detailed views of two such events. In the first instance, a peak in $PM_{2.5}$ levels at all three sampling sites is associated with the departure of three cruise ships from the Ogden Point terminal, and levels remained elevated for some time after departure. The maximum 5 minute average level reached was 15 µg/m3. In the second example, peaks in 5 minute average levels are observed at all three sampling sites both on cruise ship arrivals and on departures. The arrival peaks are lower, reaching approximately 10 µg/m3 at one site, while the departure peaks are higher, reaching approximately 17 µg/m3 at one site.

How do these levels compare to those measured at other times or locations?

Levels of $PM_{2.5}$ on winter evenings were measured by UVIC researchers in an unrelated study of woodsmoke impacts on air quality in the CRD.[28] These data were collected using the same nephelometers employed for the current study, but were set to record average light scatter every 15 seconds. In general, 15 second average levels ranged from as high as 15 to 25 $\mu g/m^3$ (Figure 32) to less than 5 $\mu g/m^3$ (Figure 33) in the James Bay neighbourhood, depending on wind conditions and temperature.

[28] Lightowlers C, 2007. Spatial Modelling of Woodsmoke Exposure and Health Risk Associated with Residential Wood-burning. MSc thesis, Department of Geography, University of Victoria, Victoria, BC.

Figure 32. Mobile nephelometer measurements of $PM_{2.5}$ on the evening of January 18th, 2006

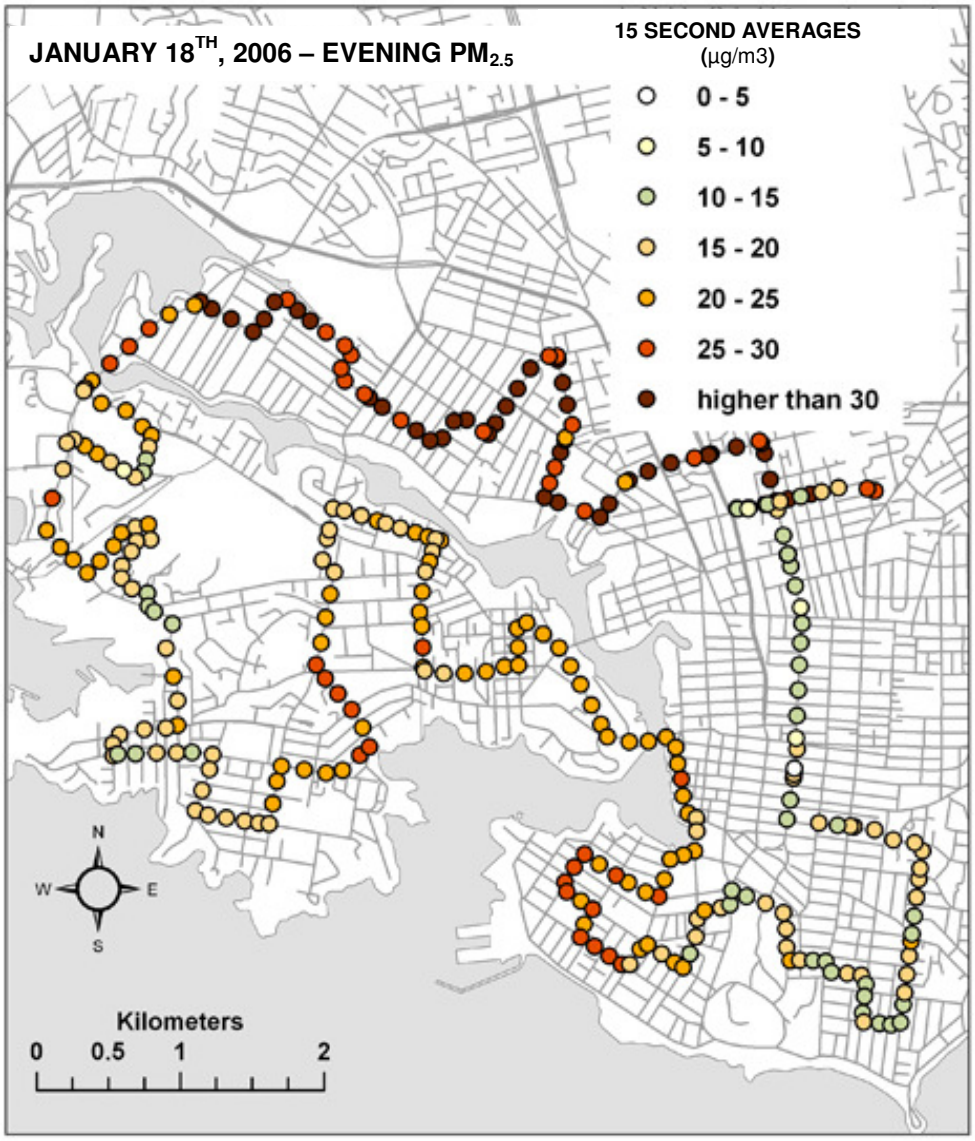
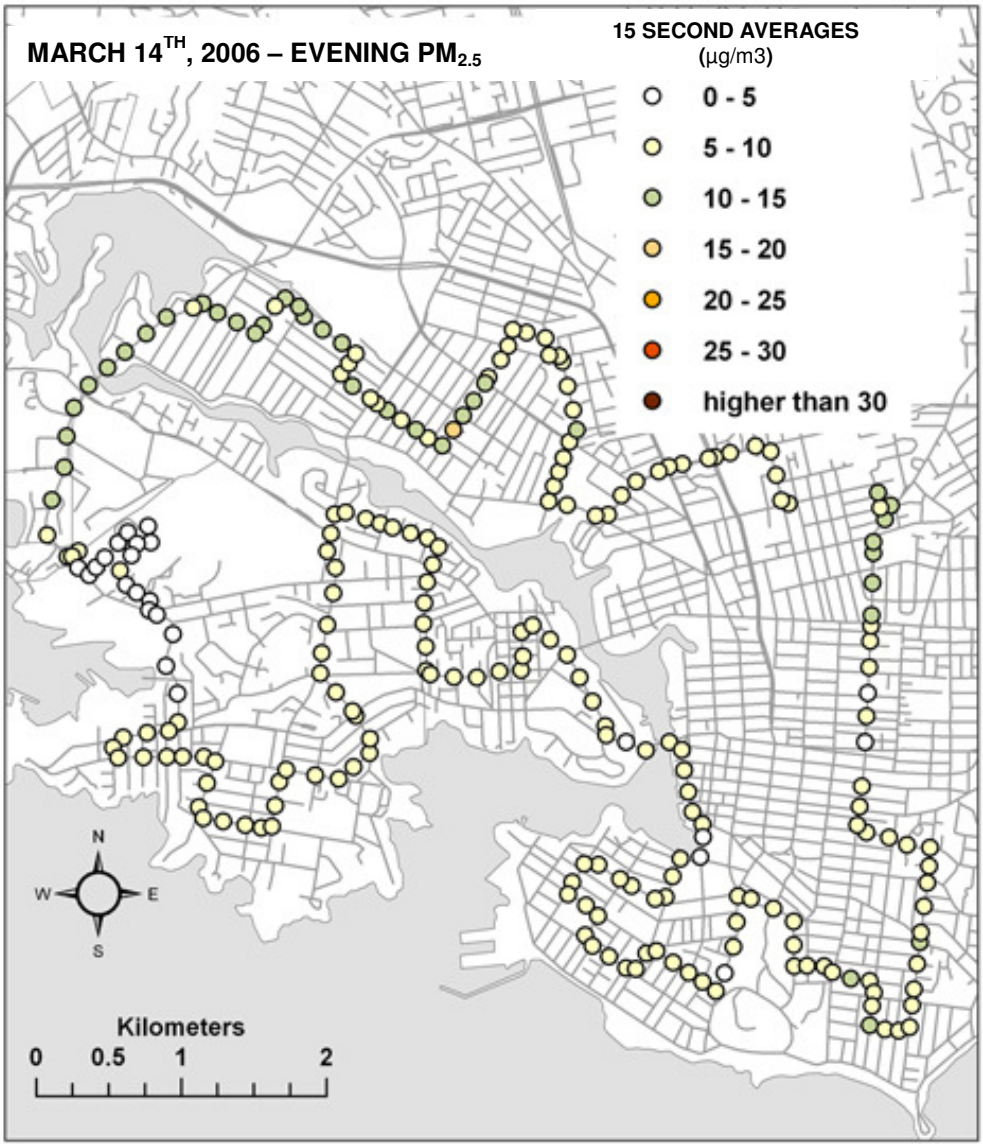


Figure 33. Mobile nephelometer measurements of $PM_{2.5}$ on the evening of March 14th, 2006



An analysis of the daily pattern of $PM_{2.5}$ levels was conducted using 2006 data for Topaz and Royal Roads monitoring stations. Data were sorted into three groups – days with cruise ships present, days without cruise ships present but during the cruise season (May – October) and off season days (January – April and November – December). The average level for 1am, 2am, 3am, and so on for each group was then calculated and graphed to show the average daily pattern for each group, as shown in Figure 34 and Figure 35.

In general, the averaged hourly levels of $PM_{2.5}$ at Topaz station range from 3 to 9 µg/m3, and from about 3 to 6 µg/m3 at the Royal Roads University station. $PM_{2.5}$ levels peak in the morning due to increased vehicle traffic and then peak again at about 10pm. These later peaks are associated with increased $PM_{2.5}$ from residential heating, particularly wood-burning fireplaces. The morning peak at Topaz station is highest on non-cruise days, which tend to be weekdays and therefore have more morning traffic. The evening peak is highest on off-season days, which occur between November and April when most residential heating is required. The daily pattern at Royal Roads University station is similar, but peak levels are much lower.

There is no evidence that $PM_{2.5}$ associated specifically with cruise ship emissions is generally reaching either the Topaz or Royal Roads University station.

These levels cannot be compared directly to the 2007 field data, as the averaging periods are different.

Figure 34. Average diurnal pattern of $PM_{2.5}$ at Topaz Station, 2006 on days with cruise ships, days without, and off season

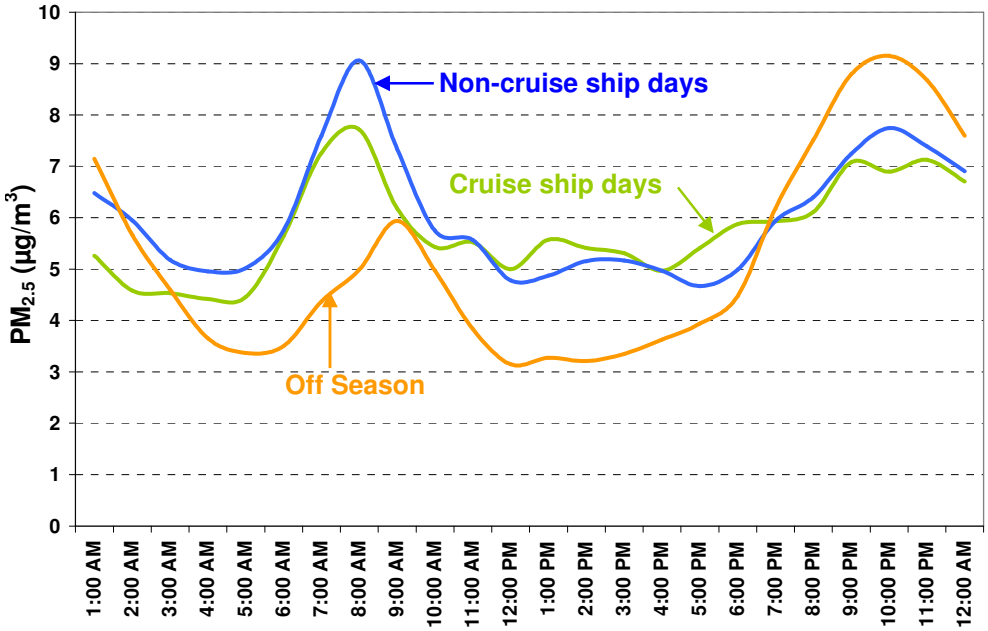
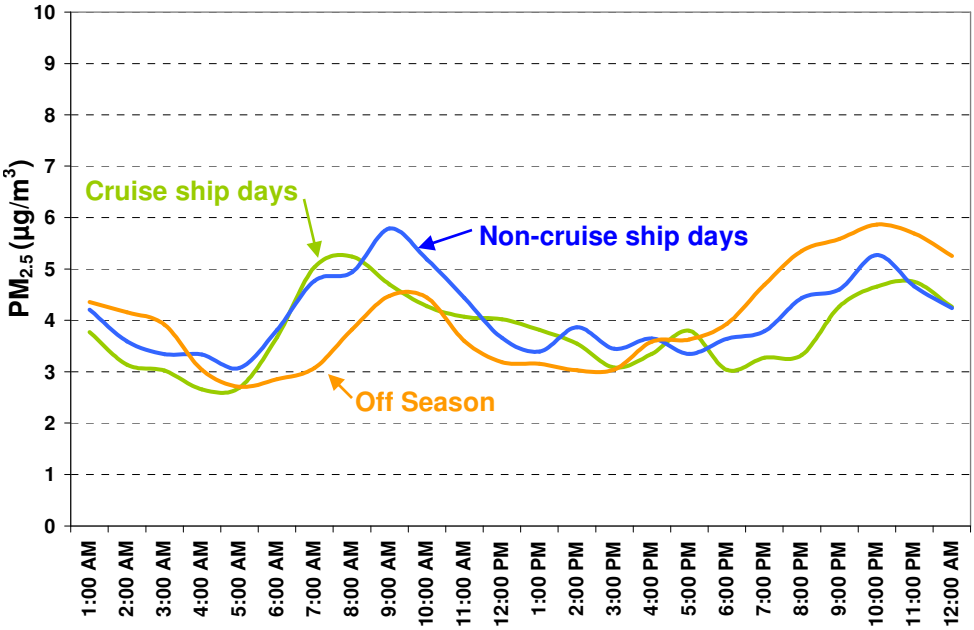


Figure 35. Average diurnal pattern of $PM_{2.5}$ at Royal Roads University Station, 2006 on days with cruise ships, days without, and off season



How do these levels compare to air quality standards or guidelines?

The Canada Wide Standard for $PM_{2.5}$ is a 24-hour average of 30 µg/m^3. To ascertain whether or not an area is above or below the standard, the 98th percentile of all the 24-hour averages in a year is taken for each of three consecutive years and averaged. If the value is 30 µg/m^3 or higher, the area is not meeting the standard. The 98th percentile is the 7th highest level measured in any given year.

The highest 24-hour average level of $PM_{2.5}$ measured in the James Bay neighbourhood was 6.5 µg/m^3.

Conclusions about fine particulates

Levels of $PM_{2.5}$ are low, with 24-hour averages ranging from 1.3 to 6.5 µg/m3. These levels are well below the current 24-hour standard.

There is no indication that 24-hour average $PM_{2.5}$ levels are consistently higher on days with cruise ships present in the study area. While the highest 24-hour average $PM_{2.5}$ levels in the study area were measured on days when cruise ships were in port, $PM_{2.5}$ levels at Topaz and Royal Roads University stations, which are not expected to be affected by cruise ship and related traffic emissions, are similar to or higher than levels measured in the study area, regardless of the presence of absence of cruise ships in port.

This suggests regional trends in $PM_{2.5}$ levels are more important than immediate sources, at least for 24-hour average levels.

The influence of cruise ship-related activity can be seen in the five-minute average $PM_{2.5}$ levels, with short term peaks in the range of 10 to 17 $\mu g/m^3$ coinciding with cruise ship arrivals and departures on some days.

Traffic contributes significantly to $PM_{2.5}$ in the area, and is often responsible for short term peaks during morning commute times. $PM_{2.5}$ does not diminish quickly with distance from roads, but contributes to area-wide levels in the James Bay neighbourhood.

Short tem levels (15 second averages) of $PM_{2.5}$ associated with winter residential wood burning range from less than 5 $\mu g/m^3$ to 25 $\mu g/m^3$.

FINE PARTICULATE COMPOSITION

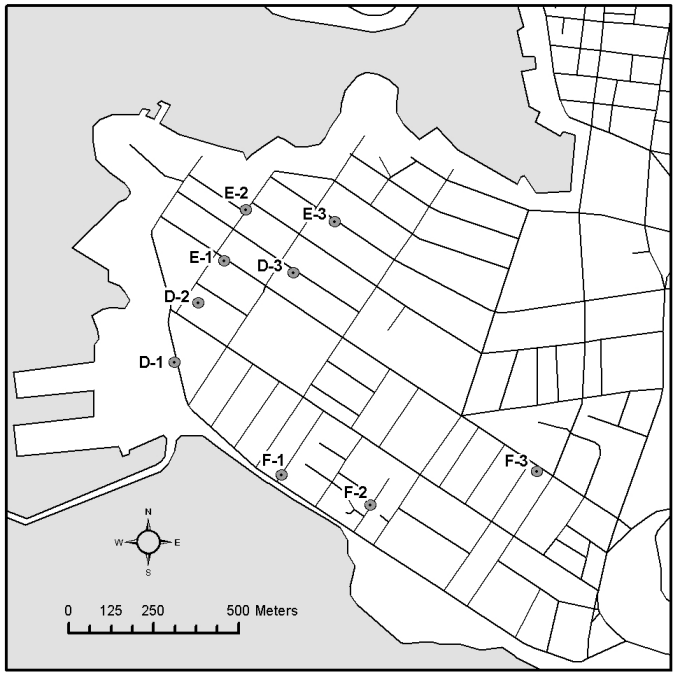
What is the composition of fine particulate matter?

Particulate matter is the product of a number of sources and therefore includes a variety of materials. $PM_{2.5}$ can include organic and inorganic carbon compounds, sulphates, nitrates, ammonium and various trace metals.[29] Analysis of $PM_{2.5}$ composition can indicate which sources are contributing to measured levels. For example, elemental carbon is associated with diesel exhaust[30], while vanadium and nickel can be association with the combustion of heavy residual fuel oil typically used in large ocean-going vessels.[31]

What are the results of the field monitoring?

Figures 36 through 41 provide the monitoring sites and results, and supporting information on wind speed and direction, precipitation, and the presence of cruise ships during sampling periods.

Figure 36. $PM_{2.5}$ composition (metals and absorbance) monitoring sites:



[29] Suzuki N. (2003). Particulate matter in BC: a report on PM10 and PM2.5 mass concentrations up to 2000. BC Ministry of Water, Land and Air Protection and the Pacific and Yukon region of Environment Canada. Victoria, BC

[30] Henderson S, Brauer M, 2005. Measurement and modeling of traffic-related air pollution on the British Columbia Lower Mainland for use in health risk assessment and epidemiological analysis. School of Occupational and Environmental Hygiene, University of British Columbia BC.

[31] Hopke PK, Hwang I, Kim E, and Lee JH 2006. Analyses of PM-related Measurements for the Impacts of Ships. Final report to the Air Resources Board Contract 04-326.

Figure 37. $PM_{2.5}$ composition sampling dates

Sampling dates	Days with cruise ships	Days without cruise ships
D-1	July 1st – July 4th	June 28th – July 1st
D-2	June 25th – 28th	June 28th – July 1st
D-3	June 25th – 28th	June 28th – July 1st
E-1	July 30th – Aug 2nd	Aug 2nd – Aug 5th
E-2	July 30th – Aug 2nd	Aug 2nd – Aug 5th
E-3	July 30th – Aug 2nd	Aug 2nd – Aug 5th
F-1	September 18th – Sept 20th	Sept 21st – Sept 23rd
F-2	September 18th – Sept 20th	Sept 21st – Sept 23rd
F-3	September 18th – Sept 20th	Sept 21st – Sept 23rd

Figure 38. Sampling results - $PM_{2.5}$ composition (partisol filters)

	Days with cruise ships				Days without cruise ships			
Site	V µg/m³	Ni µg/m³	Abs. coefficient	Mass µg/m³	V µg/m³	Ni µg/m³	Abs. coefficient	Mass µg/m³
D-1	0.0098	0.0046	4.00	4.90	0.0039	0.0018	4.01	4.07
D-2	0.0095	0.0043	4.05	5.05	0.0042	0.0018	4.21	4.21
D-3	0.0106	0.0046	4.12	5.51	0.0051	0.0026	4.18	4.80

	Days with cruise ships				Days without cruise ships			
Site	V µg/m³	Ni µg/m³	Abs. coefficient	Mass µg/m³	V µg/m³	Ni µg/m³	Abs. coefficient	Mass µg/m³
E-1	0.0243	0.0093	4.11	5	0.0057	0.0023	4.02	5
E-2	0.0236	0.0093	4.14	5	0.0058	0.0023	4.02	5
E-3	0.0367	0.0163	4.09	7	0.0062	0.0023	4.05	6

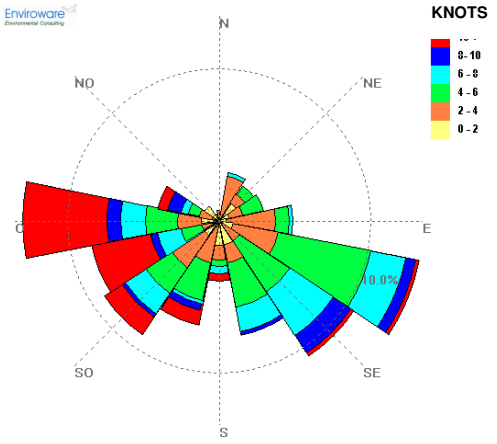
	Days with cruise ships				Days without cruise ships			
Site	V µg/m³	Ni µg/m³	Abs. coefficient	Mass µg/m³	V µg/m³	Ni µg/m³	Abs. coefficient	Mass µg/m³
F-1	0.0052	0.0024	5.92	5.70	0.0035	0.0025	6.11	6.11
F-2	0.0045	0.0024	5.90	5.63	0.0033	0.0017	6.08	4.78
F-3	0.0053	0.0020	5.95	5.08	0.0035	0.0017	6.16	4.78

Figure 39. Windroses for $PM_{2.5}$ composition samples

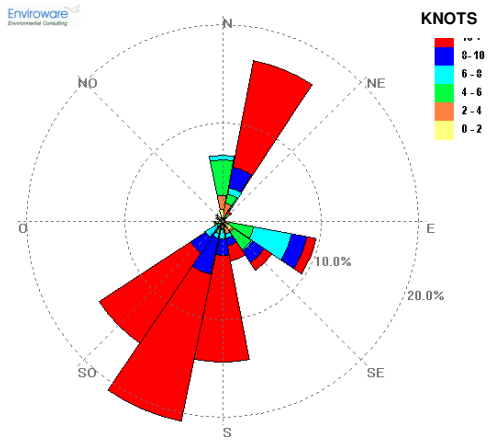
(a) Windroses (Ogden Point Station) for Sites D-1, D-2 and D-3

Sites D-1 and D-2

Days with cruise ships

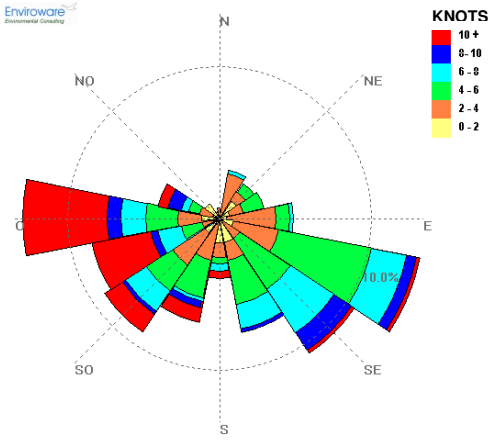


Days without cruise ships

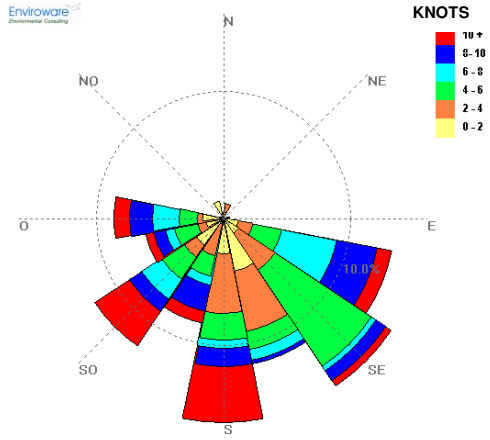


Site D-3

Days with cruise ships



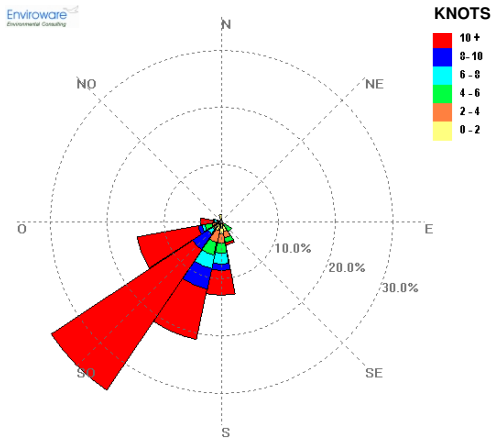
Days without cruise ships



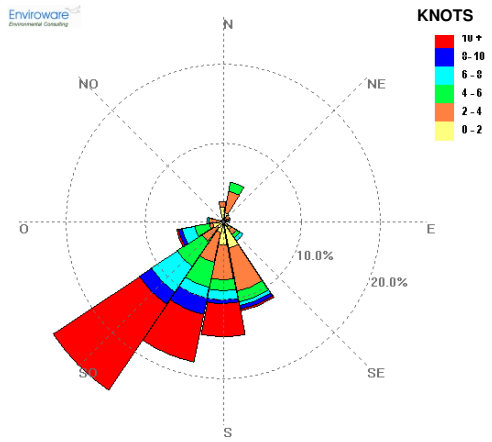
(b) Windroses (Ogden Point Station) for Sites E-1, E-2 and E-3

Sites E-1, E-2 and E-3

Days with cruise ships



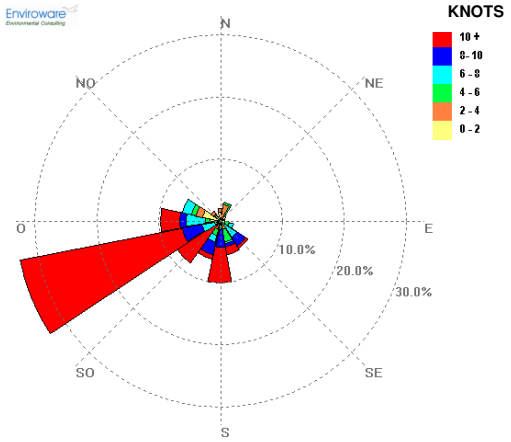
Days without cruise ships



(c) Windroses (Ogden Point Station) for Sites F-1, F-2 and F-3

Sites F-1, F-2 and F-3

Days with cruise ships



Days without cruise ships

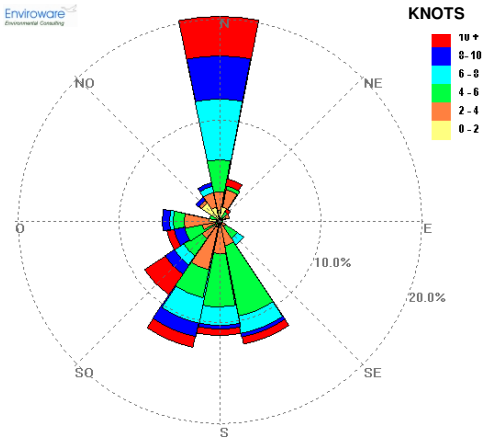


Figure 40. Precipitation for $PM_{2.5}$ composition samples

(a) Sites D-1, D-2 and D-3

Days with cruise ships	Time	Precipitation (mm)	Notes
		none recorded	

Days without cruise ships	Time	Precipitation (mm)	Notes
June 28th	2pm – 7pm	4.32	Non-cruise ship day
June 29th	2pm – 3:30pm	1.27	Non-cruise ship day

(b) Sites E-1, E-2 and E-3

Days with cruise ships	Time	Precipitation (mm)	Notes
		none recorded	

Days without cruise ships	Time	Precipitation (mm)	Notes
		none recorded	

(c) Sites F-1, F-2 and F-3

Days with cruise ships	Time	Precipitation (mm)	Notes
September 20th	8am to 9am	0.51	1 cruise ship 6pm to midnight
September 21st	3am to 5pm	1.02	2 cruise ships 5/6pm to midnight
September 22nd	2pm to 3pm	0.51	2 cruise ships 7/8am to 4/5pm 3 cruise ships 5/6pm to midnight

Days without cruise ships	Time	Precipitation (mm)	Notes
		none recorded	

Figure 41. Cruise ship presence during $PM_{2.5}$ composition samples

(a) Sites D-1, D-2 and D-3

Days with cruise ships - total sample hours: 36

	No ships	1 ship	2 ships	3 ships
Hours	16	9	5	6
Percent of total sample hours	44	25	14	17

Days without cruise ships - total sample hours: 36

	No ships	1 ship	2 ships	3 ships
Hours	30	6	--	--
Percent of total sample hours	83	17	--	--

(b) Sites E-1, E-2 and E-3

Days with cruise ships - total sample hours: 36

	No ships	1 ship	2 ships	3 ships
Hours	17	8	5	6
Percent of total sample hours	47	22	14	17

Days without cruise ships - total sample hours: 36

	No ships	1 ship	2 ships	3 ships
Hours	36	--	--	--
Percent of total sample hours	100	--	--	--

(c) Sites F-1, F-2 and F-3

Days with cruise ships - total sample hours: 36

	No ships	1 ship	2 ships	3 ships
Hours	13	4	13	6
Percent of total sample hours	36	11	36	17

Days without cruise ships - total sample hours: 36

	No ships	1 ship	2 ships	3 ships
Hours	36	--	--	--
Percent of total sample hours	100	--	--	--

What are the limitations of the monitoring equipment and sampling design?

The filters used for metals analysis and absorbance were in the field for three full days, which would include a substantial amount of time when no cruise ships were present. This would tend to diminish the chances of seeing differences between filters used on days with cruise ships present and those used on days with no cruise ships present.

How do we interpret the monitoring results?

Vanadium (V) and nickel (Ni) were detected in all the filter samples. This indicates that emissions from large ocean going vessels contributed to the $PM_{2.5}$ levels measured in the study. At all sites, V was always higher on days with cruise ships in port. Ni was higher on days with cruise ships in port in comparison to days without, with the exception of Site F-1 (Figure 36), where Ni levels were very similar but slightly higher during the period without cruise ships in port. The difference was most obvious in the July/August sampling period. During this period, wind speed and direction was similar on both days with and without cruise ships, and the sampling sites were immediately downwind of the Ogden Point terminal, providing good conditions for detecting the influence of cruise ship emissions. Conditions in the other two sampling periods were not as favourable for capturing cruise ship-related emissions, with wind speeds being lighter and wind direction not coming predominantly from the Ogden Point terminal with respect to the sampling sites.

Absorbance levels of the $PM_{2.5}$ suggested diesel emissions were slightly higher on days with no cruise ships (weekdays) in two sampling periods. This suggests that weekday traffic, which might include more frequent buses, may be a more significant source of diesel emissions in the study area. In one study period, absorbance was higher on days with cruise ships (generally weekends) than on days without, when all sampled sites were downwind of the Ogden Point Terminal, suggesting that diesel emissions from the terminal area influenced the results. This suggests that sources other than cruise ships and their related traffic can have an equal or potentially greater influence on $PM_{2.5}$ composition depending on meteorological conditions.

How do these levels compare to those measured at other times or locations?

Analyses for the presence of metals in $PM_{2.5}$ have been conducted by the BC Ministry of Environment using filters at the Topaz Station, and by researchers under contract to the California Air Resources Board for a study of $PM_{2.5}$ along the Pacific coast[32].

[32] Hopke PK, Hwang I, Kim E, and Lee JH 2006. Analyses of PM-related Measurements for the Impacts of Ships. Final report to the Air Resources Board Contract 04-326.

At Topaz station, PM filters are deployed for 24-hours on one day out of every seven, and these filters were subsequently analysed for metals present in the $PM_{2.5}$ fraction. In total, 47 filter samples were collected in 2006. Of these, 11 (23 percent) were taken on days when cruise ships were in port, 16 (34 percent) were taken on days without cruise ships between May and October, and the remaining 20 (43 percent) were taken on off-season days in the winter and early spring. Vanadium and nickel levels measured at Topaz Station are provided in Appendix D. Levels of V and Ni measured for this study are compared with those measured at Topaz Station in 2006 in Table 3.

Table 3. Comparison of Vanadium and Nickel levels in James Bay and at Topaz Station

	Level in micrograms per cubic metre (µg/m^3) of air					
	Days with Cruise ships		**Days with no cruise ships**		**Off season**	
	Avg.	Max.	Avg.	Max.	Avg.	Max.
Vanadium						
Sites 1 – 9*	0.014	0.037	0.005	0.006	--	--
Topaz**	0.011	0.021	0.007	0.015	0.002	0.006
Nickel						
Sites 1 – 9*	0.006	0.016	0.002	0.003	--	--
Topaz**	0.008	0.018	0.009	0.011	0.005	0.009

* Averages based on 9 three-day samples in 2007

** Averages based on 11 one-day samples (cruise ships present), 16 one-day samples (no cruise ships present), or 20 one-day samples (off-season) in 2006

In the study of $PM_{2.5}$ composition at sites along the Pacific Coast[33], V and Ni associated with residual fuel oil combustion was found at four sites in the vicinity of the study area. Figure 42 shows the location of the Olympic National Park site the locations of three sites in the Seattle area. At the Olympic National Park site, average V was 0.001 µg/m^3; average Ni was 0.0004, based on 293 filter samples taken between August 2001 and May 2004. These levels can reasonably be considered to be representative of a clean, rural area. Still, it was noted that the signal for residual fuel oil combustion showed " a strong summer-high seasonal variation and weekend-high variation…suggesting the sources of the oil combustion are likely residual oil burning ships and ferries that show increased activities on the weekend in the summer."[34] In Seattle, average levels of V ranging from 0.004 to 0.007 µg/m^3, and average levels of Ni ranging from 0.002 to 0.004 µg/m^3 were reported at three sites. No seasonal variation was observed at these sites, and the likely sources of the emissions were identified as cargo ships, tugs, commercial harbour craft,

[33] Hopke PK, Hwang I, Kim E, and Lee JH 2006. Analyses of PM-related Measurements for the Impacts of Ships. Final report to the Air Resources Board Contract 04-326.
[34] Ibid., pg 64.

ferries, cargo-handling machines and trains associated with the Port of Seattle[35]. These three sites are located between 2 and 6 km away from the waterfront. Table 4 provides a comparison of these levels with the results from the field monitoring and levels measured at Topaz station in 2006.

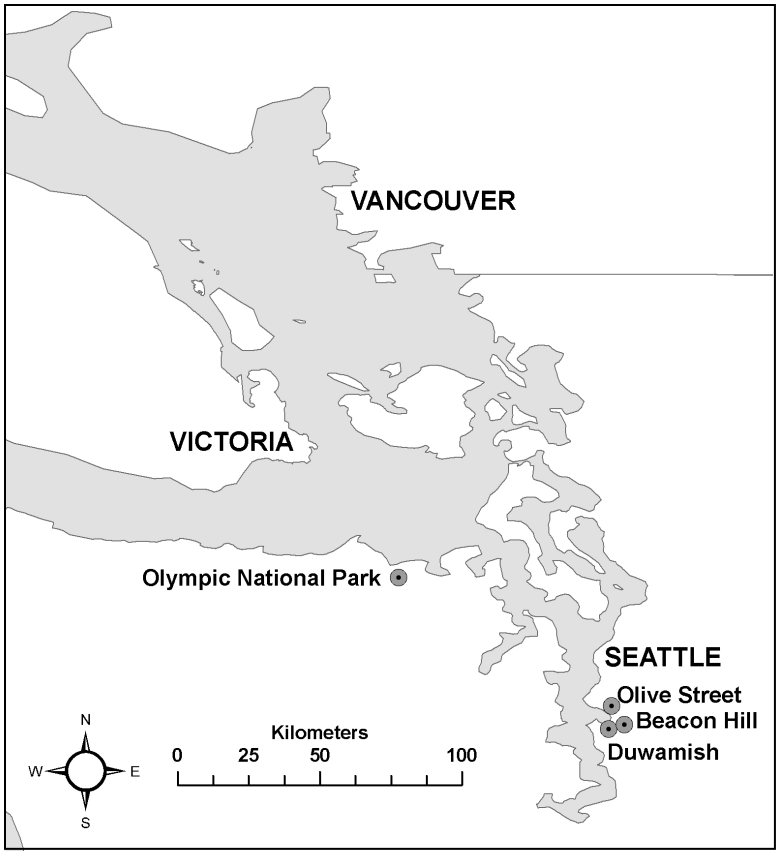
Table 4. Comparison of vanadium and nickel levels in the study area and at sites located in Washington State

Location	Vanadium (µg/m^3)		Nickel (µg/m^3)	
	average	maximum	average	maximum
All sites in James Bay (18 3-day samples, 2007)	0.009	0.037	0.004	0.016
Topaz (47 one-day samples, 2006)	0.006	0.021	0.006	0.018
Olympic National Park (293 one-day samples, 2001-2004)	0.001	0.006	0.0004	0.002
Olive St, Seattle WA (128 one-day samples, 2000-2005)	0.005	0.027	0.002	0.009
Beacon Hill, Seattle WA (546 one-day samples, 2000-2005)	0.004	0.047	0.002	0.032
Duwamish, Seattle WA (154 one-day samples, 2000-2005)	0.007	0.039	0.004	0.036

In summary, levels of V and Ni measured in James Bay for this study in 2007 were consistent with levels measured at the Topaz Station in 2006 and with more distant sites in the Georgia Basin – Puget Sound area measured in 2000 to 2005. Overall, these results indicate that cruise ship emissions do contribute to $PM_{2.5}$ in the study area above background levels; however, even when cruise ships are present, $PM_{2.5}$ levels are low in the study area in relation to other locations in the Victoria area (see previous section). Complete results for all metals are provided in Appendix D.

[35] Hopke PK, Hwang I, Kim E, and Lee JH 2006. Analyses of PM-related Measurements for the Impacts of Ships. Final report to the Air Resources Board Contract 04-326.

Figure 42. Locations of monitoring sites included in the Pacific coast study[36]



How do these levels compare to air quality standards or guidelines?

There are no air quality standards or guidelines for vanadium or nickel, or for absorbance.

Conclusions about fine particulate composition.

Absorbance levels of the $PM_{2.5}$ suggest diesel emissions were slightly higher on days without cruise ships than on days with in two sampling periods. In one sampling period, absorbance was higher on days with cruise ships than on days without. This suggests that sources other than cruise ships and their related traffic have an equal or potentially greater influence on $PM_{2.5}$ composition depending on meteorological conditions.

The influence of cruise ship emissions can be detected in the levels of vanadium and nickel present in the $PM_{2.5}$, indicating that cruise ship related emissions contribute to $PM_{2.5}$ in the area. Levels of vanadium and nickel measured in the James Bay area were consistent with levels measured at Topaz station and in the Pacific northwest.

[36] Hopke PK, Hwang I, Kim E, and Lee JH 2006. Analyses of PM-related Measurements for the Impacts of Ships. Final report to the Air Resources Board Contract 04-326.

VOLATILE ORGANIC COMPOUNDS

What are volatile organic compounds?

Volatile organic compounds are present in outdoor air mainly as gases, and come from a variety of sources. In this study, benzene, ethylbenzene/xylene, toluene (commonly referred to together as BTEX) and naphthalene were measured. In outdoor air, the combustion and evaporation of fuels, paints or solvents are the main sources of BTEX and naphthalene. Naphthalene is also released when wood is burned.[37]

What are the sources of volatile organic compounds in the James Bay neighbourhood?

There are a number of BTEX and naphthalene emissions sources in the study area, including cruise ships, other large marine vessels, float planes and helicopters. The largest sources of BTEX and naphthalene in the study area include motor vehicles, turboprop floatplanes and helicopters.[38] The Imperial Oil Terminal, located in Esquimalt, immediately west of the James Bay neighbourhood across the harbour, is reported to release BTEX as well as n-Hexane, trimethylbenzne and other VOCs. [39]

What are the results of the field monitoring?

Monitoring was conducted by researchers from the AERL, Chemistry Department, Malaspina University College with support from CANTEST, for two periods during 2007. An in-house constructed MIMS-MS/MS system was used to monitor BTEX and naphthalene continuously while in operation. Membrane introduction mass spectrometry (MIMS) is a powerful technique, in which air is drawn through a semi-permeable membrane to a mass spectrometer, where compounds in the air can be measured using advanced techniques such as tandem mass spectrometry (MS/MS). MIMS has been shown to have detection limits in the parts-per-trillion (pptrv) for volatile organic compounds (VOCs) in air[40].

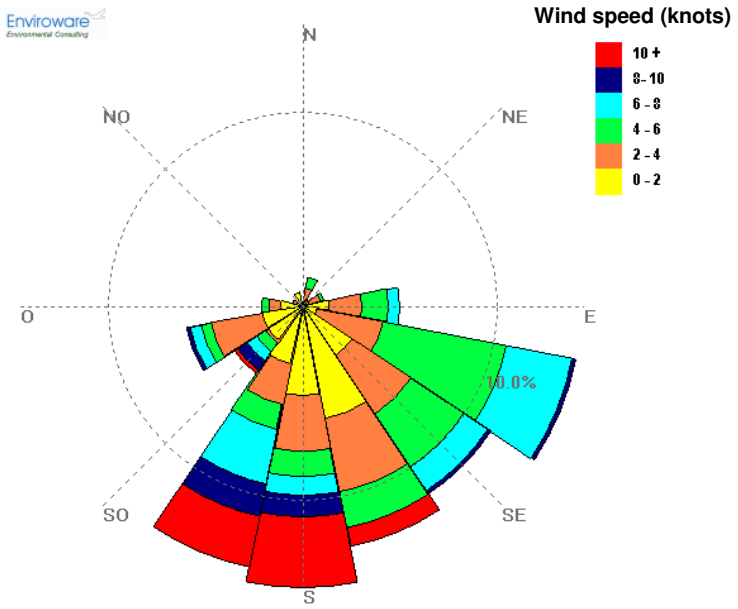
The original objective of this monitoring was to identify unique emissions signatures for different sources, specifically float planes, helicopters, bus traffic, and cruise ships, then to conduct mobile monitoring throughout the study area to identify signature emissions. There were, however, few opportunities to conduct monitoring for BTEX and naphthalene due to the limited availability of the CANTEST van and the logistics

[37] Agency for Toxic Substances and Disease Registry: http://www.atsdr.cdc.gov/toxprofiles/tp67.html
[38] Tradewinds Scientific Ltd. (2000). Victoria Harbour Air Quality Impact Study, March 29, 2000. Prepared for Transport Canada Programs Branch, Vancouver, B.C.
[39] National Pollutant Release Inventory : http://www.ec.gc.ca/pdb/npri/npri_online_data_e.cfm
[40] M. E. Cisper, C. G. Gill, L. E. Townsend and P. H. Hemberger, *Anal.Chem.*, 1995, **67**, 1413-1417.

involved in mounting the MIMS-MS/MS system in the van. For these reasons, sampling was conducted between July 17th – 20th and August 2nd – 5th when weather conditions were less than favourable in both periods. During July 17th – 20th, winds were generally light, but predominantly from the south and southeast, which would tend to transport emissions from marine vessels, floatplanes and helicopters away from land over the inner and outer harbour (Figure 43). Precipitation was high, particularly on July 17th and 18th. During August 2nd – 5th, winds were consistently high and predominantly from the southwest (Figure 44), which would tend to transport emissions from marine vessels, floatplanes and helicopters over the western part of the James Bay neighbourhood, but could also disperse emissions rapidly.

Figure 43. Meteorological conditions during MIMS-MS/MS sampling: July 17th – 20th, 2007

(a) Wind rose (Ogden Point Station)

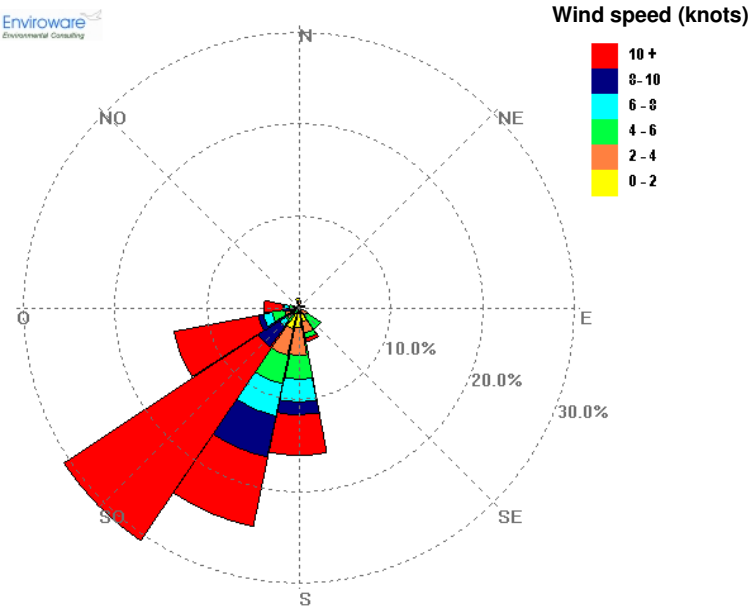


(b) Precipitation (James Bay Community School site)

Date	Time	Precipitation (mm)
July 17th	7:30am – 3:30pm	6.86
July 18th	10:30am – 4:15pm	5.33
July 19th	4:00am – 5:30pm	1.78
July 20th	10am – 4:30pm	1.78

Figure 44. Meteorological conditions during MIMS-MS/MS sampling: August 2nd – 5th, 2007

(a) Wind rose (Ogden Point Station)



No precipitation was recorded in this sampling period.

Although the weather was not optimal and the original objectives of this monitoring could not be met, the MIMS-MS/MS system did capture some measurements of interest, including:

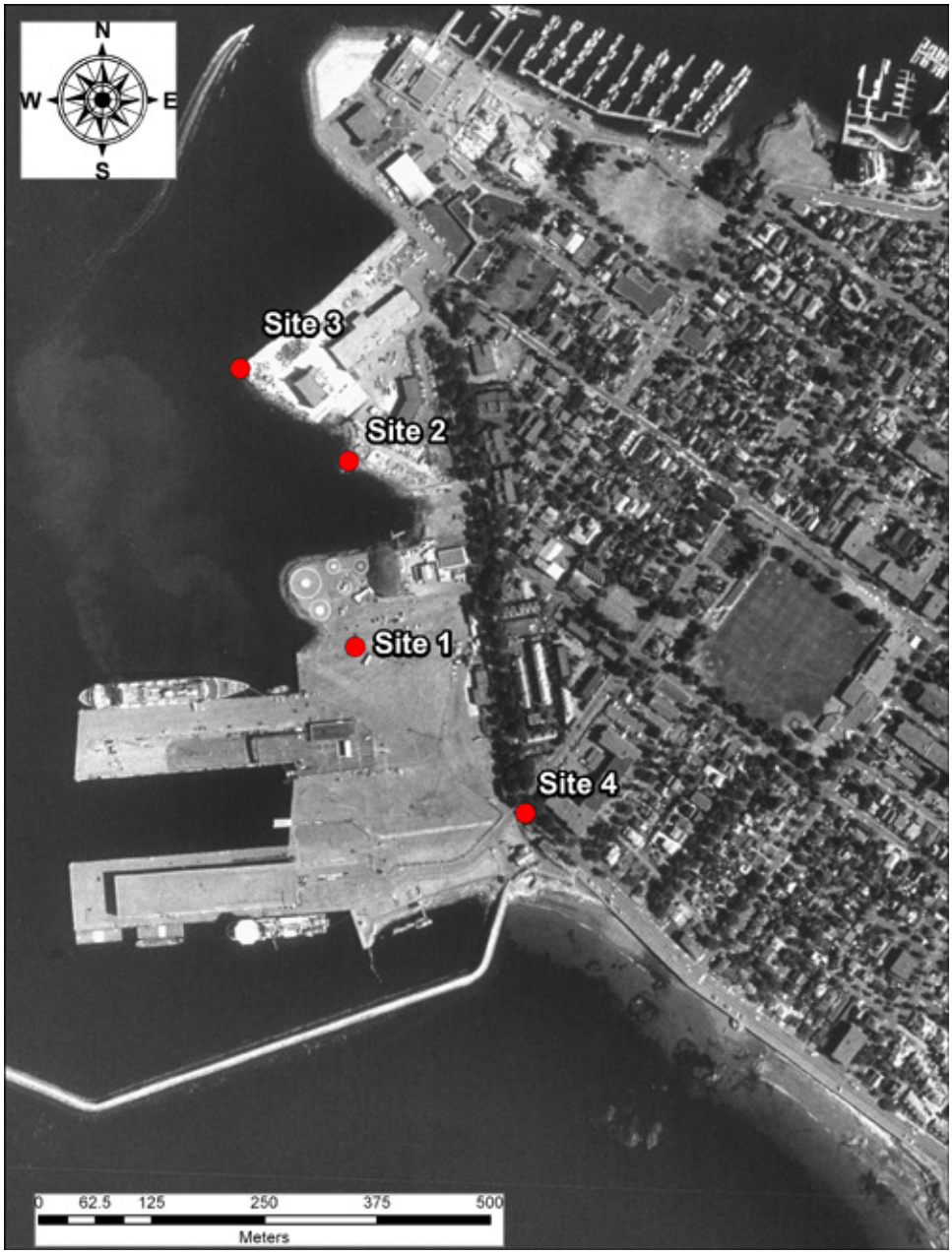
- Data collected between 2am and 6am on July 19th during high winds, to establish BTEX and naphthalene levels when no significant activities were occurring (Site 1 on Figure 45, results in Figure 46).

- Data collected between 2:50pm and 4:10pm on July 19th, showing increased levels associated with a helijet departing from near Ogden Point (Site 2 on Figure 45, results in Figure 47).

- Data collected between 11pm and 12:30am on July 19th/20th , showing increased levels associated with a cruise ship departing from Ogden Point (Site 3 on Figure 45, results in Figure 48)

- Data collected between 5:30pm and 7:30pm on July 20th, showing increased levels associated with cruise ship-related traffic at the exit from Ogden Point Terminal (Site 4 on Figure 45, results in Figure 49).

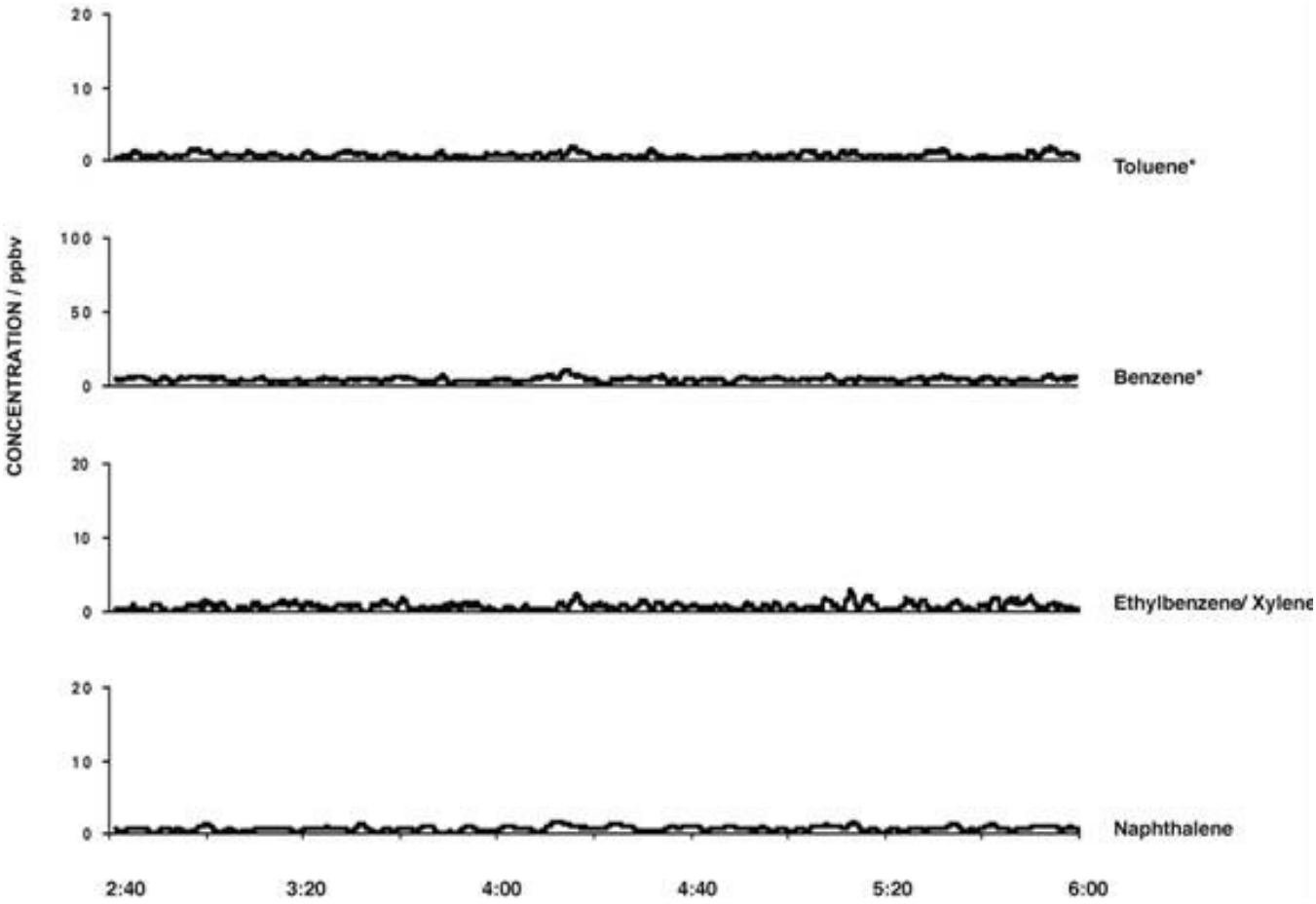
Figure 45. MIMS-MS/MS sampling sites



Aerial photography from 1999

Figure 46. Background levels at Site 1

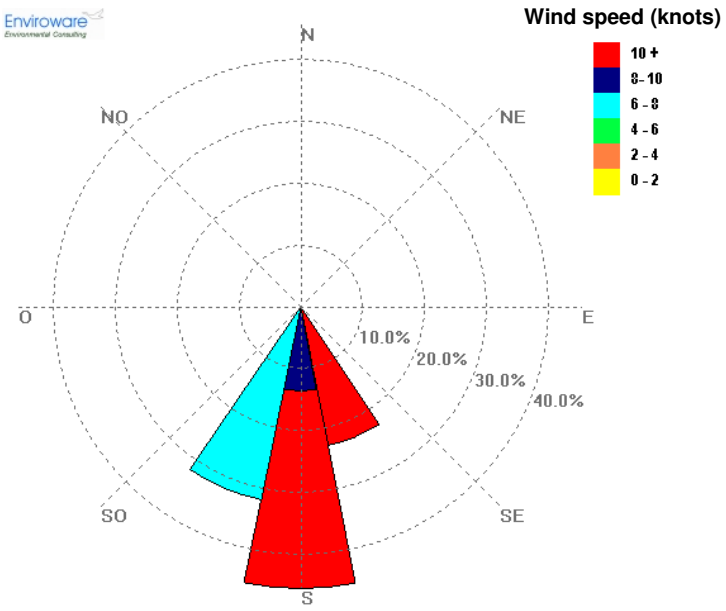
(a) Site 1: Graph of BTEX and Naphthalene levels



(b) Site 1: BTEX and naphthalene levels (approximately 1 minute averages)

Compound	**Average** (ppbv)	**Std Dev** (ppbv)	**Min** (ppbv)	**Max** (ppbv)
Toluene	0.5	0.8	0	1.7
Benzene	3.7	3.2	0.5	10.6
Etbz/Xyl	1.2	1.3	0.2	3.7
Naphthalene	0.5	0.4	0	1.5

(c) Site 1: Windrose



(d) Site 1: Wind speed and direction

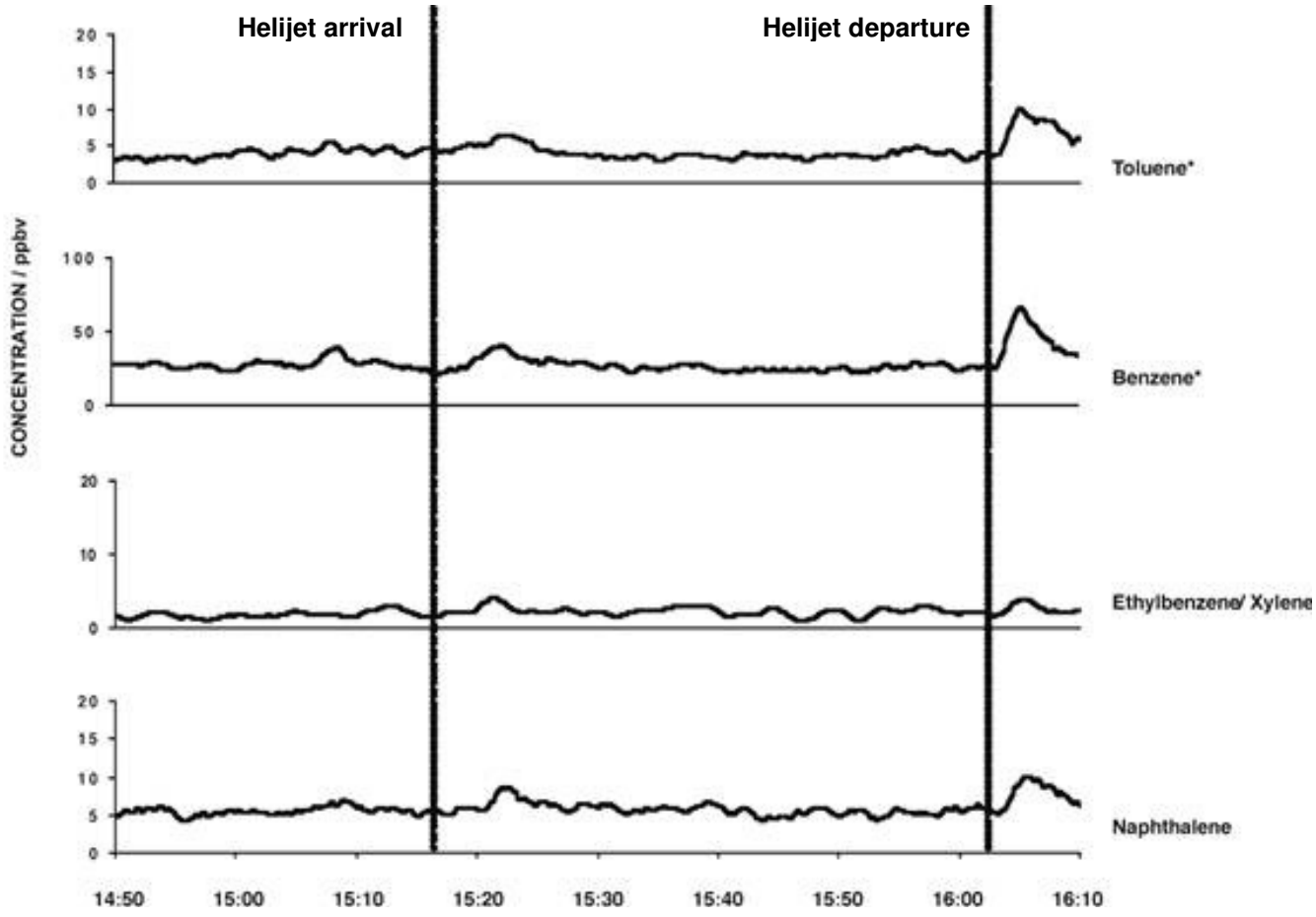
July 19th - time	Wind speed (knots)	Wind direction (degrees, from →)
2:40:00	6.4	201
2:50:00	7	197
3:00:00	7.6	197
3:10:00	7.6	203
3:20:00	7.4	202
3:30:00	7.7	197
3:40:00	9.2	183
3:50:00	9.1	176
4:00:00	9.2	183
4:10:00	10.2	179
4:20:00	11.2	171
4:30:00	10.1	165
4:40:00	11.5	162
4:50:00	12.8	162
5:00:00	10.9	161
5:10:00	12.4	163
5:20:00	13.2	172
5:30:00	13	186
5:40:00	13.1	183
5:50:00	12.9	173
6:00:00	13.2	170

(e) Site 1: Precipitation

3:55am to 4:26am: 0.76 mm of rain

Figure 47. Helijet departure at Site 2

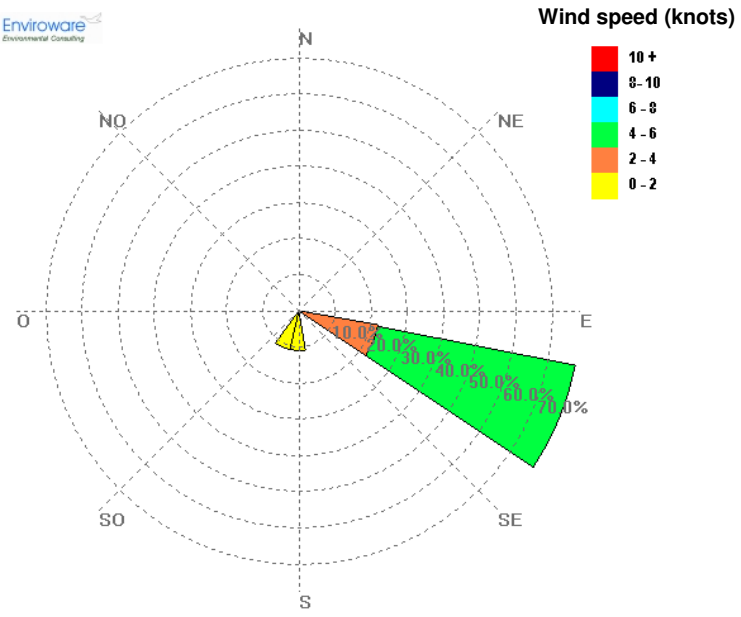
(a) Site 2: Graph of BTEX and naphthalene levels



(b) Site 2: BTEX and naphthalene levels (approximately 1 minute averages)

Compound	**Average** (ppbv)	**Std Dev** (ppbv)	**Min** (ppbv)	**Max** (ppbv)
Toluene	4.1	1.7	2.6	9.8
Benzene	23.5	8.6	15.5	60.8
Etbz/Xyl	2.2	0.8	0.9	4.4
Naphthalene	5.7	1.5	4.1	9.9

(c) Site 2: Windrose



(d) Site 2: Wind speed and direction

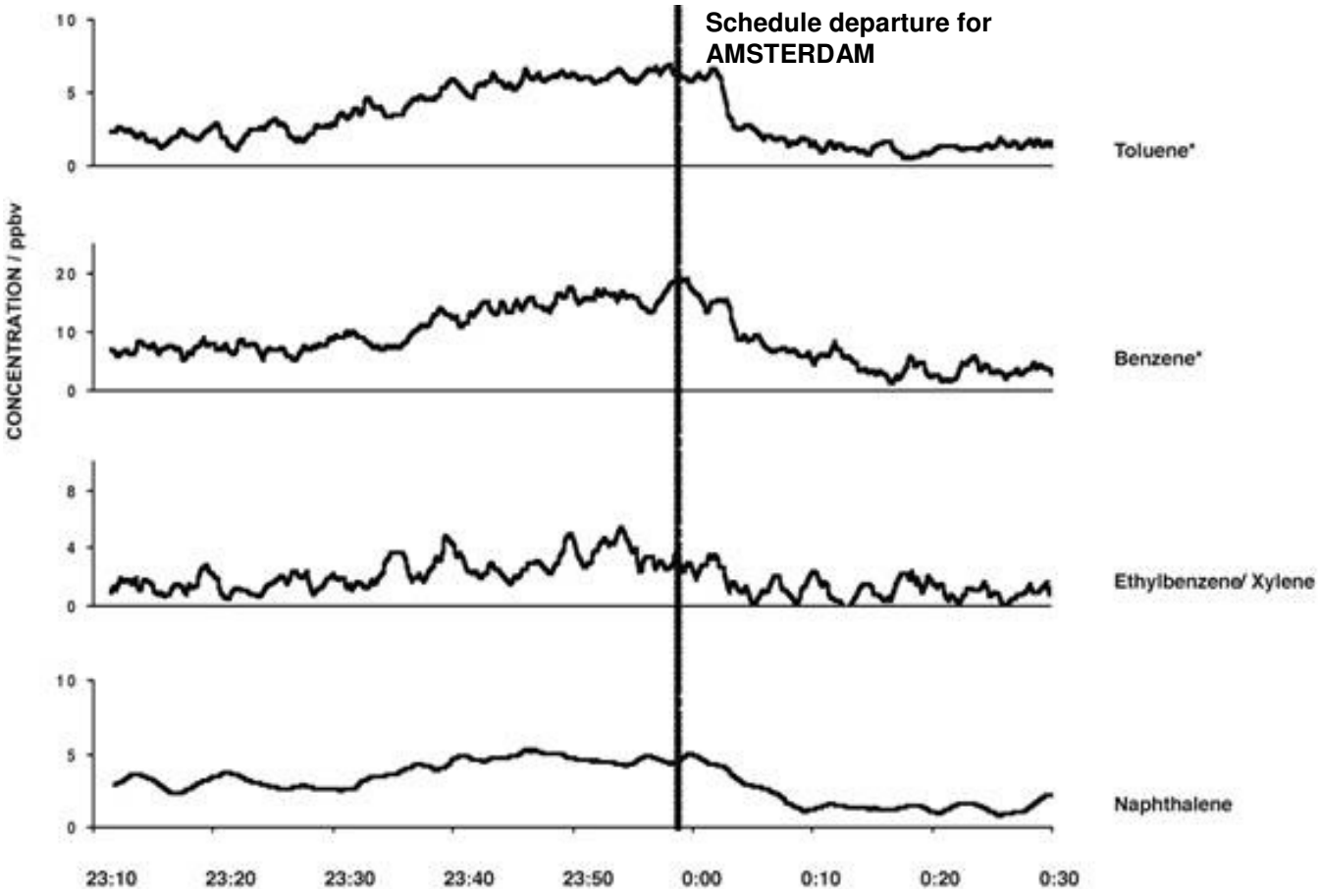
July 19th - time	Wind speed (knots)	Wind direction (degrees from →)
14:50:00	5.1	103
15:00:00	5.6	113
15:10:00	4.7	115
15:20:00	3.7	119
15:30:00	5	120
15:40:00	4.9	117
15:50:00	2.5	110
16:00:00	1.6	175
16:10:00	0.4	192

(e) Site 2: Precipitation

2:50pm to 4:10pm: 0.25 mm

Figure 48. Cruise ship departure at Site 3

(a) Site 3: Graph of BTEX and Naphthalene levels



(b) Site 3: BTEX and naphthalene levels (approximately 1 minute averages)

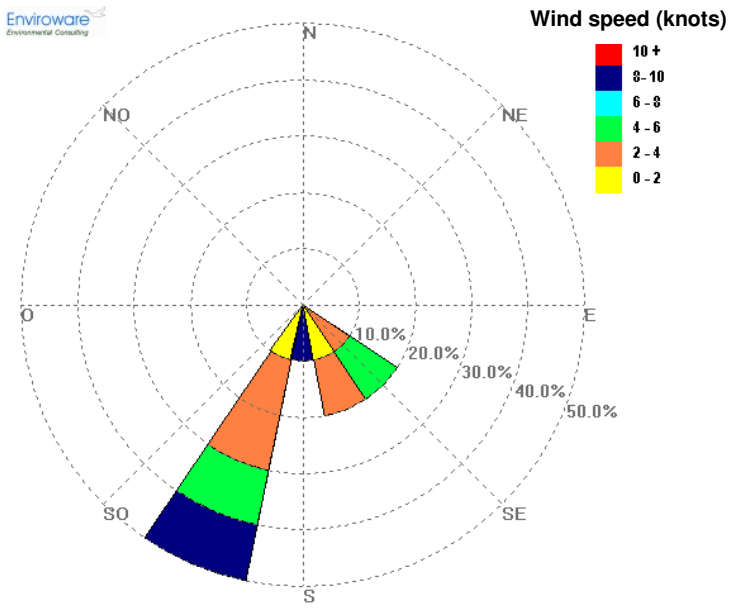
Background

Compound	**Average** (ppbv)	**Std Dev** (ppbv)	**Min** (ppbv)	**Max** (ppbv)
Toluene	2.2	1.0	1.0	3.6
Benzene	7.1	3.2	5.0	9.1
Etbz/Xyl	1.5	1.8	0.4	3.0
Naphthalene	2.9	0.5	2.2	3.7

Departure (23:42 – 0:01 hrs)

Compound	**Average** (ppbv)	**Std Dev** (ppbv)	**Min** (ppbv)	**Max** (ppbv)
Toluene	6.1	1.2	5.2	6.8
Benzene	15.5	3.9	12.7	19.0
Etbz/Xyl	3.4	2.3	1.6	5.9
Naphthalene	4.6	0.4	4.1	5.2

(c) Site 3: Windrose



(d) Site 3: Wind speed and direction

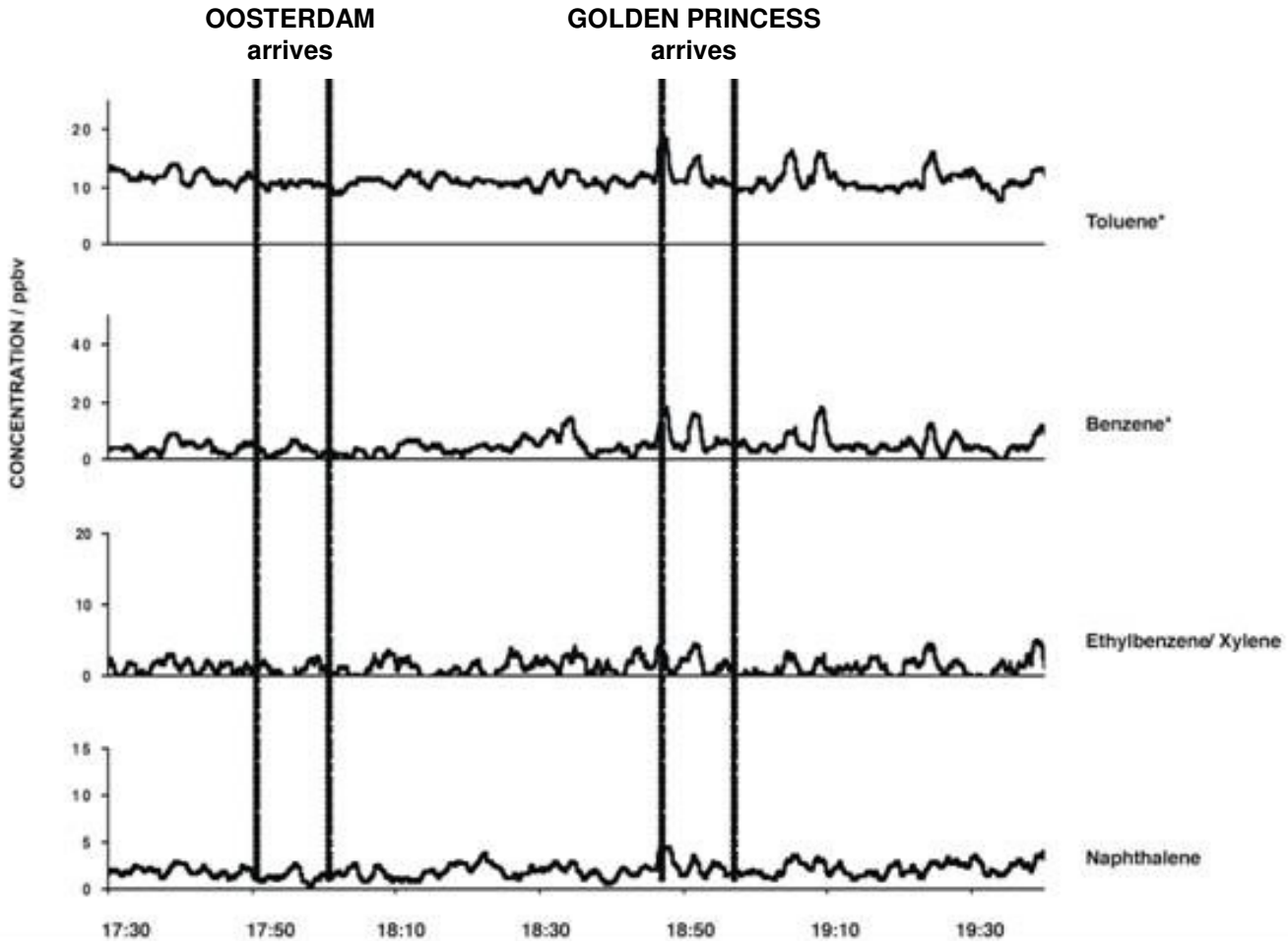
July 19th - time	Wind sped (knots)	Wind direction (degrees from →)
23:10:00	4.6	142
23:20:00	9.6	176
23:30:00	9.7	194
23:40:00	5.7	200
23:50:00	3.2	195
0:00:00	2	167
0:10:00	2	211
0:20:00	3	154
0:30:00	3.9	136

(e) Site 3: Precipitation

11:10pm to 1:30am: no precipitation recorded

Figure 49. Traffic associated with Cruise ship arrivals at Site 4

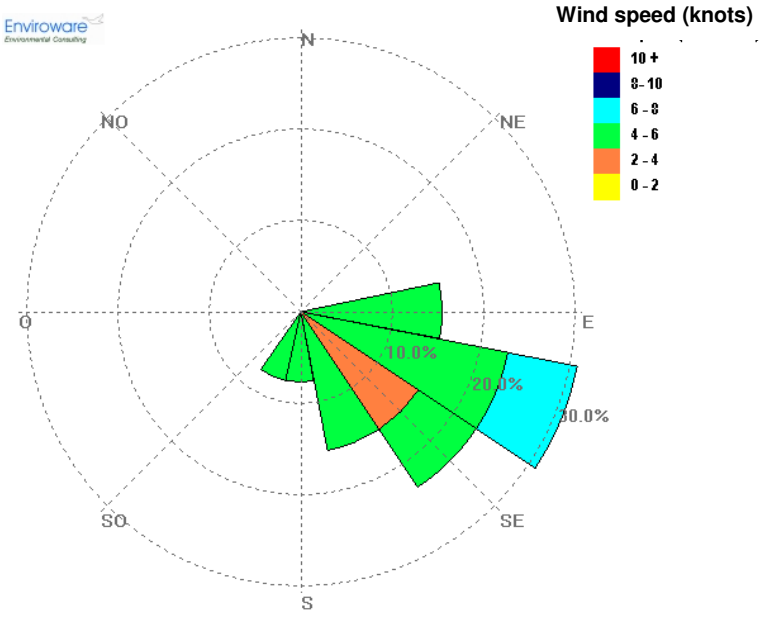
(a) Site 4: Graph of BTEX and Naphthalene levels



(b) Site 4: BTEX and naphthalene levels (approximately 1 minute averages)

Compound	Average	Std Dev	Min	Max
Toluene	11.0	3.0	7.4	18.4
Benzene	4.4	6.1	0	17.5
Etbz/Xyl	1.2	3.3	0	5.4
Naphthalene	1.9	1.5	0.2	4.4

(c) Site 4: Windrose



(d) Site 4: Wind speed and direction

July 20th - time	Wind Speed (knots)	Wind Direction (degrees from →)
17:30:00	2.3	144
17:40:00	4.7	149
17:50:00	5.5	197
18:00:00	4.2	176
18:10:00	5.7	149
18:20:00	5	135
18:30:00	3.4	125
18:40:00	5.2	109
18:50:00	5.5	102
19:00:00	4.2	83
19:10:00	4.6	95
19:20:00	5.9	108
19:30:00	6.2	114

(e) Site 4: Precipitation

5:30pm to 7:30pm: no precipitation recorded

What are the limitations of the monitoring equipment and sampling design?

For BTEX and naphthalene, the MIMs-MS/MS has the following detection limits:

Compound	Toluene	Benzene	Etbz/Xyl	Naphthalene
Detection limit*	2.6 ppbv	9.0 ppbv	5.7 ppbv	3.0 ppbv

* calculated based upon S/N = 3

Concentrations below these levels cannot be detected accurately. It is important to note that the averages presented in Figures 46 through 49 are calculated over specific time periods, and may be lower than the detection limit shown above. This is the result of including numerous non-detect measures (essentially measures of zero) in the calculation of the averages.

Benzene concentrations, and to a lesser extent, toluene concentrations may be higher than actual. During measurement, when ethylbenzene or xylene are present, they are ionized and may create ion fragments that are recognized by the mass spectrometer as benzene and/or toluene, when in fact they are not.

As discussed previously, weather conditions were generally unfavourable. Still, during short periods of favourable conditions, emissions from several sources (cruise ships, helicopters, and traffic) were identified.

How do we interpret the monitoring results?

At the Ogden Point terminal, when winds were high and no major source activity was occurring, average background levels were 3.7 ppb (benzene), 0.5 ppb (toluene), 1.2 ppb (ethylbenzen/xylene) and 0.5 ppb (naphthalene). Maximums were 10.6 ppb, 1.7 ppb, 3.7 ppb and 1.5 ppb respectively.

At a site approximately 150 metres downwind, when winds were low, average levels of BTEX and naphthalene from a departing helijet were 23.5 ppb (benzene), 4.1 ppb (toluene), 2.2 ppb (ethylbenzen/xylene) and 5.7 ppb (naphthalene). Maximums were 60.8 ppb, 9.8 ppb, 4.4 ppb and 9.9 ppb respectively. These levels would be expected to decrease with distance from the source. Notably, benzene levels were consistently high for the duration of this period. Researchers present during sampling observed construction activities nearby on the Coast Guard site that may have contributed to these levels.

At a site approximately 400 metres downwind, when winds were light to moderate, average levels of BTEX and naphthalene from a departing cruise ships were 15.5 ppb (benzene), 6.1 ppb (toluene), 3.4 ppb (ethylbenzen/xylene) and 4.6 ppb (naphthalene). Maximums were 19.0 ppb, 6.8 ppb, 5.9 ppb and 5.2 ppb respectively. Within 30 minutes of departure, average levels decreased to 7.1 ppb, 2.2 ppb, 1.5 ppb and 2.9 ppb respectively.

At a site within 10 metres of the intersection of Dallas Road and the Ogden Point Terminal exit, average levels of BTEX and naphthalene associated with traffic including tour buses 4.4 ppb (benzene), 11.0 ppb (toluene), 1.2 ppb (ethylbenzene/xylene) and 1.9 ppb (naphthalene). Maximums were 17.5 ppb, 18.4 ppb, 5.4 ppb and 4.4 ppb respectively. These levels would be expected to decrease with distance from the source.

A limited number of measurements were obtained, therefore it is not possible to make any general conclusions about the typical levels of BTEX and naphthalene in the James Bay neighbourhood under a variety of weather conditions.

How do these levels compare to those at other locations or times?

Because the MIMS-MS/MS could be operated from the mobile laboratory during movement of the vehicle, multiple air quality transects were obtained over the course of this study. To compare relative emissions from surface transportation and vehicle fueling stations, an airshed transect was obtained by traveling through downtown Victoria, including a stop to re-fuel the mobile laboratory generator system with diesel (Figure 50).

In a second series of transects, onboard GPS data confirmed the location of the MIMS-MS/MS for several transects through the Shoal Point/Downtown areas (Figures 51 and 52). By comparison with activities monitored at static locations in the Shoal Point area, the contaminant levels recorded during sampling in downtown traffic and during vehicle fueling were substantially greater (2 to 5 times higher levels), as would be expected, based upon localized concentrations from numerous, close proximity, point source emitters (e.g. vehicles and city buses).

Figure 50. Relative emissions for traffic and diesel fuel fill obtained as part of a cross-downtown airshed transect obtained during rush hour (Douglas Street, Victoria, BC).

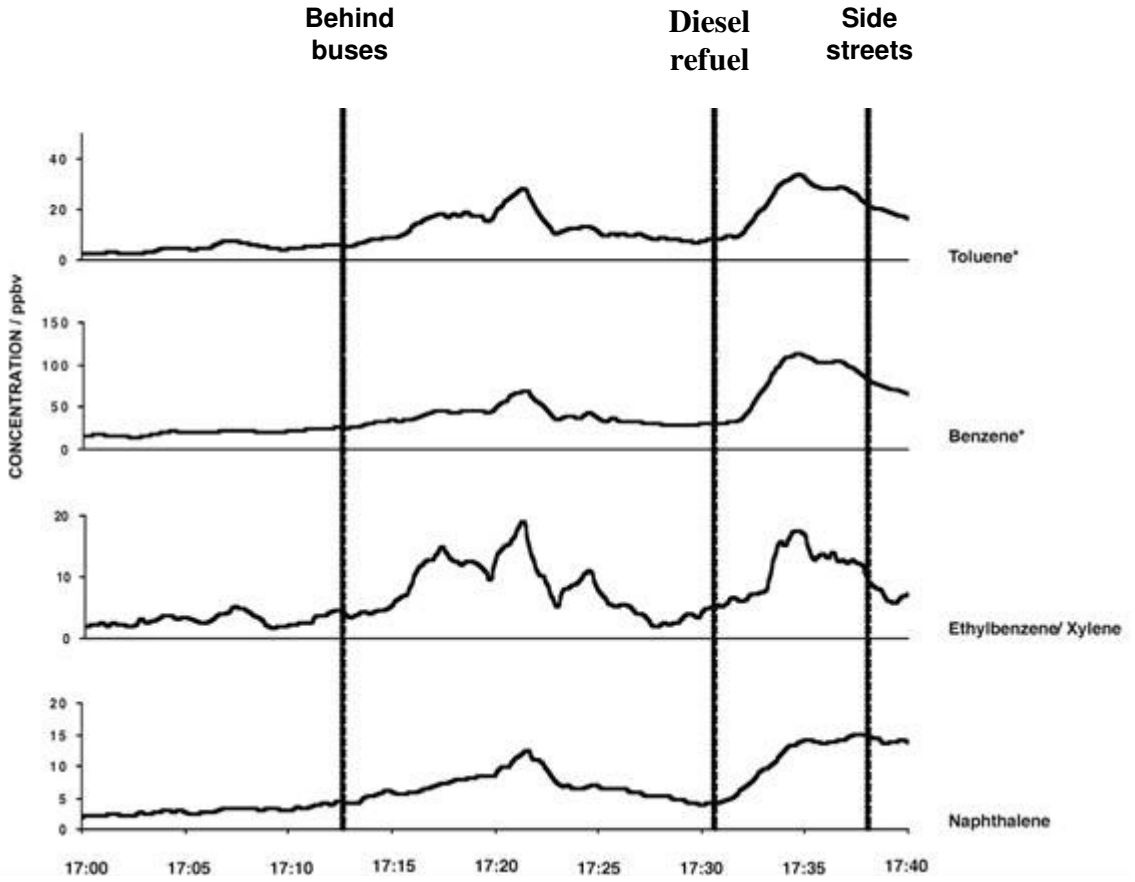
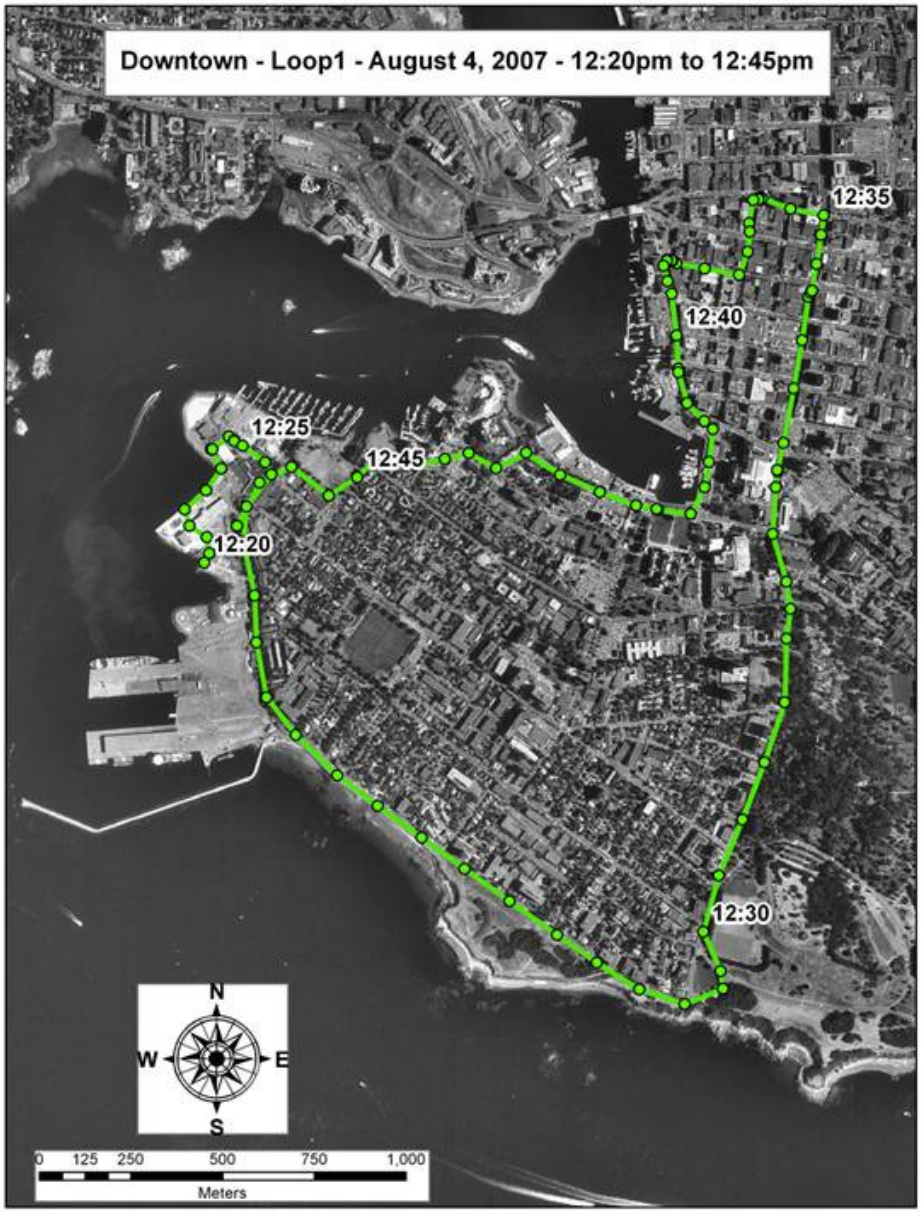
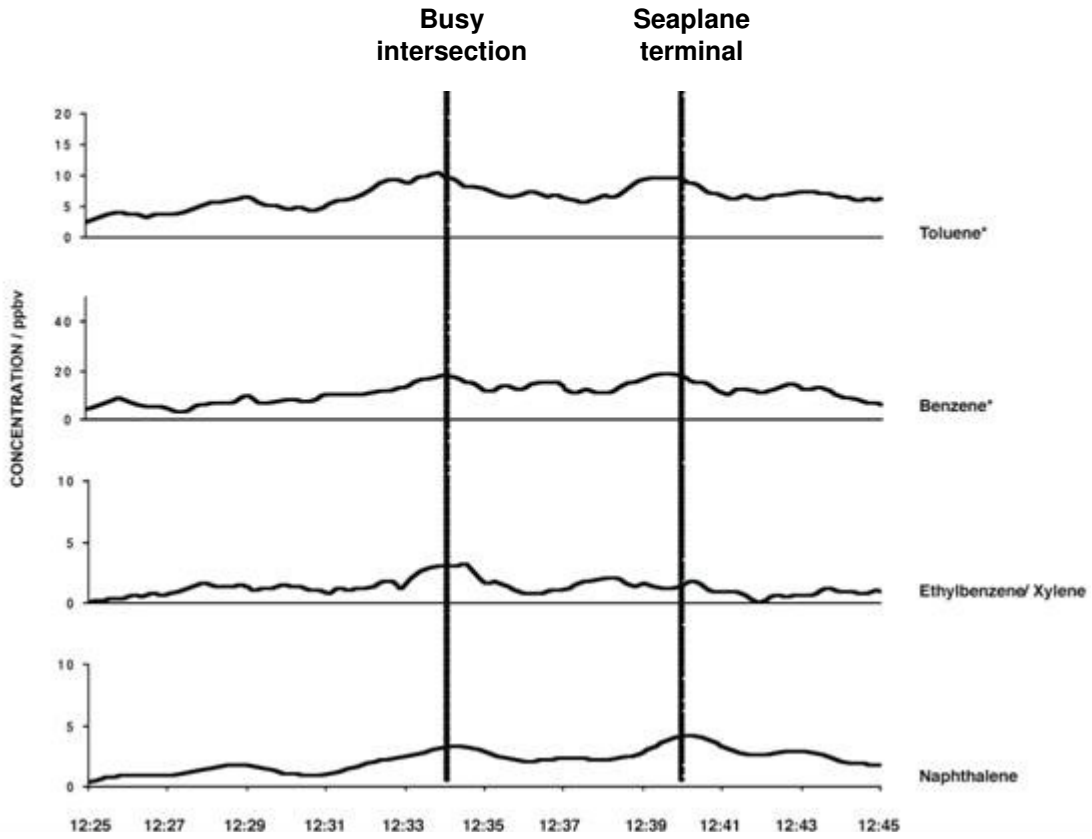


Figure 51. MIMS-MS/MS airshed transect data (Loop1) through downtown Victoria with GPS tracking data.

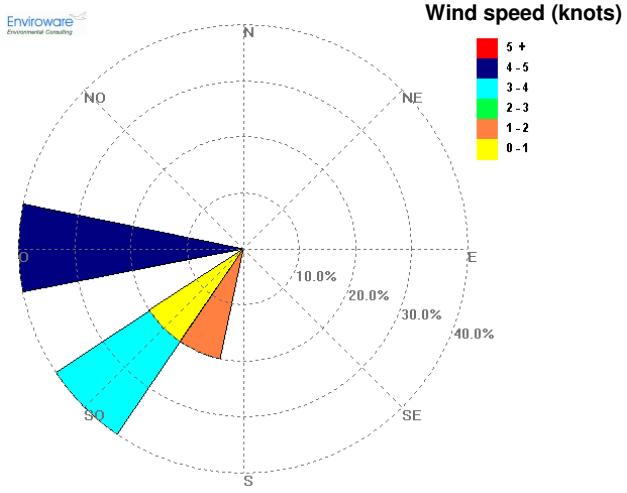
(a) Loop 1 transect



(b) MIMS-MS/MS data obtained for Loop1 Transect



(c) Windrose

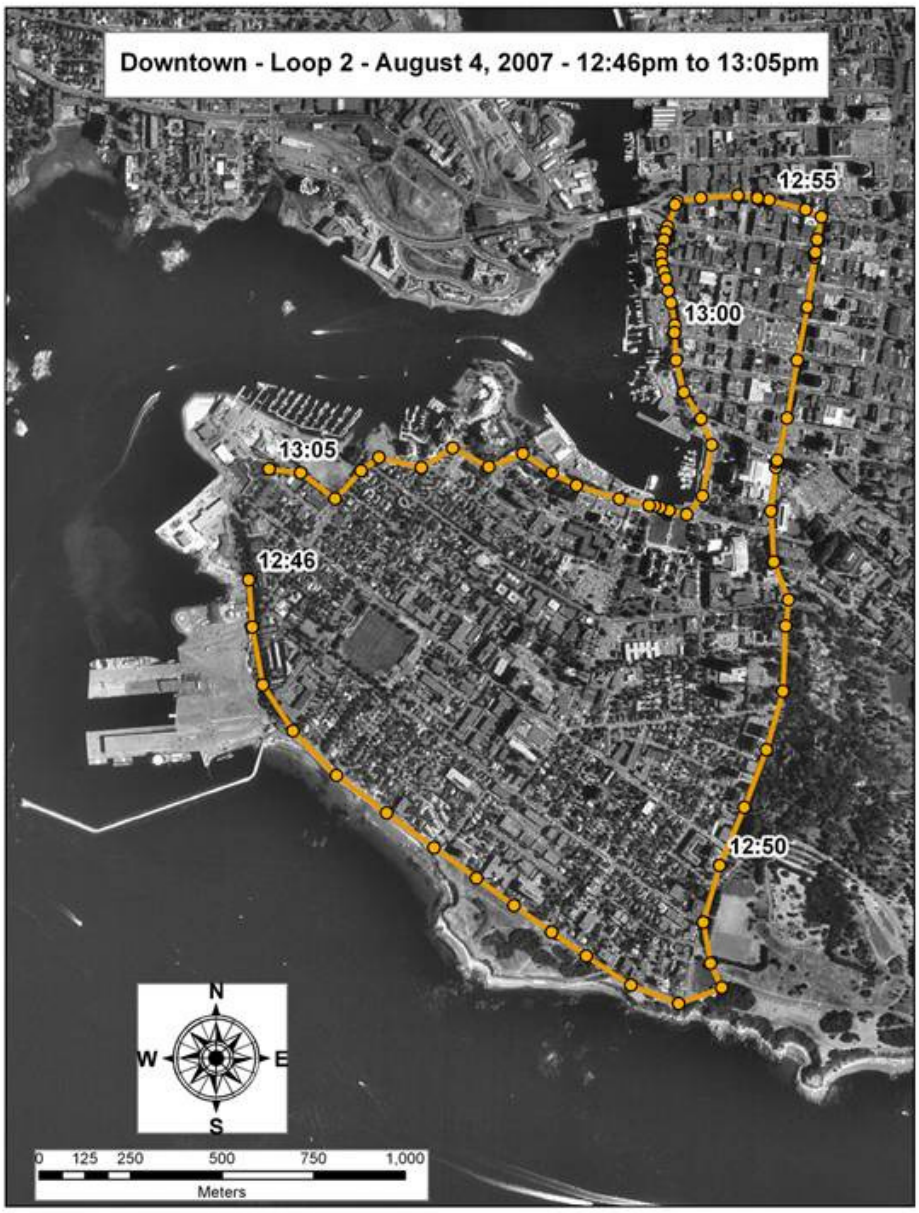


(d) Wind speed and direction

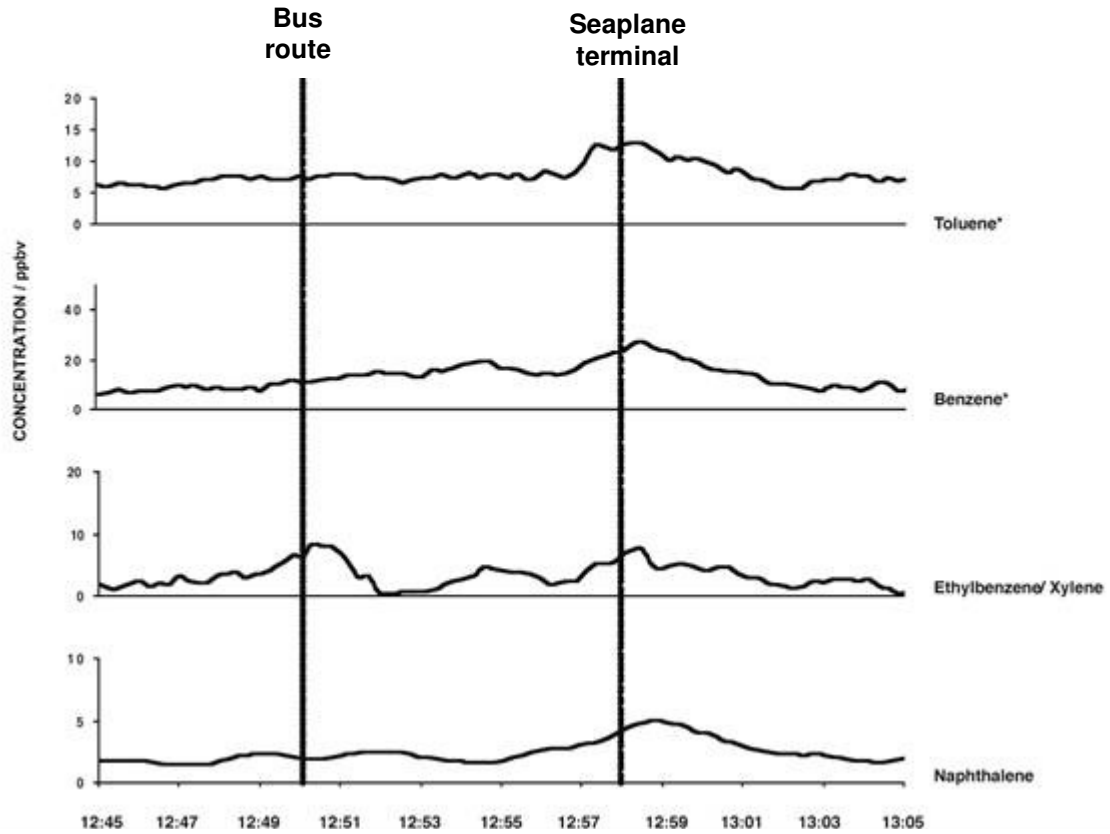
August 4th - time	Wind Speed (knots)	Wind Direction (degrees from →)
12:20:00	4.1	264
12:30:00	3.2	236
12:40:00	1.6	203
12:50:00	0.1	215

Figure 52. MIMS-MS/MS airshed transect data (Loop2) through downtown Victoria with GPS tracking data

(a) Loop 2 transect



(b) MIMS-MS/MS data obtained for Loop 2 Transect



(c) Wind data

Not Available

Additional measurements of VOCs were conducted in 2000 in an unrelated study investigating air quality associated with activities at the Victoria Harbour Airport.[41] Air samples were pumped into sterile canisters and sent for lab analysis. Table 5 summarized the results of the measurements taken at the Helipad (near Site 1 in Figure 40). Given the relatively long average times (one to 48 hours) compared to the MIMS-MS data (approximately 1 minute averages), it is difficult to compare these results; however, both the levels measured in 2000 and the levels measured for this study appear to be in the same general range.

[41] Tradewinds Scientific Ltd. (2001). Volatile Organic Compound Monitoring Program at Victoria Harbour Airport. Prepared for Transport Canada Programs Branch, Vancouver, B.C.

Table 5. Measures of BTEX and naphthalene from September, 2000[42]

Date and duration	Hourly average over sampling duration, parts per billion				
	Benzene	**Toluene**	**Ethylbenzene**	**Xylene***	**Naphthalene**
Sept 1st 8 hours	1.4	--	--	--	17
Sept 6th 1-hour (6 helicopters)	1.3	--	--	--	--
Sept 7th 1-hour (6 helicopters)	--	--	--	--	--
Sept 8th 48 hours	7.6	12	--	3.6 / 6.3	--
Sept 10th 24-hours	0.9	1.3	--	--	not analyzed

*includes m&p-Xylene and o-Xylene

How do these levels compare to air quality standards or guidelines?

The measurements collected for this study represent 1 minute averages. There are no existing comparable air quality standards.

Conclusions about BTEX and naphthalene

Measurements conducted for this study are limited, and it is not possible to establish whether the levels observed are typical.

Although conditions were generally unfavourable, distinct emissions events were measured with the MIMS-MS/MS.

The concentrations of benzene, toluene, ethylbenzene/xylenes, and naphthalene were low relative to concentrations measured in traffic in downtown Victoria and while at a gas station.

The levels of benzene and toluene reported are likely too high, due to a methodological bias in the sampling equipment, and should be considered as a maximum level.

There are no directly comparable air quality standards and guidelines for these VOCs.

[42] Tradewinds Scientific Ltd. (2001). Volatile Organic Compound Monitoring Program at Victoria Harbour Airport. Prepared for Transport Canada Programs Branch, Vancouver, B.C.

Measurements conducted for this study are limited, and it is not possible to establish whether the levels measured are typical.

NEXT STEPS

This report provides results of the first phase of a two phase project. The following recommendations are based on the project results at the completion of this first phase, and on consultation with the project advisors:

1. The field monitoring was limited to measuring relatively long-term average pollutant levels for NO, NO_2 and SO_2. Analysis of data from Topaz station suggests there may be short-term peaks in NO_2 and SO_2 related to cruise ship activity. The Phase 2 pollutant dispersion modelling should include these pollutants and provide estimates of 1-hour, 24-hour, and seasonal average levels.

2. The field monitoring was limited to measuring pollutant levels near ground level. It is possible that under certain meteorological conditions, pollutants may be kept aloft and therefore be present in higher concentration at elevations well above ground level. This is of particular concern to residents of multi-story apartment buildings in the study area. The Phase 2 pollutant dispersion modelling should include estimates of 1-hour, 24-hour, and seasonal average pollutant levels at varying elevations above ground level, with a focus on residential apartment buildings in the study area.

3. Typical levels of VOCs (BTEX and naphthalene) were not established by the field monitoring, and will not be estimated in the pollutant dispersion model due to the difficulties of accurately modelling the complex behaviour of these pollutants in the atmosphere. An existing study of VOCs in the Victoria Inner Harbour was conducted in 2001[43], but monitored levels at only four sites, only one of which was in the current study area. Since then, floatplane activity has increased substantially, and the levels measured in 2001 may not be representative of current conditions. Data on VOCs remains a significant gap at this time and should be the subject of additional study.

4. Together, the two phases of this study will provide a reasonable characterization of the typical short- and long-term levels of NO, NO_2, SO_2 and $PM_{2.5}$ in the study area. This report and the one planned for Phase 2, however, do not constitute a health risk assessment. It is recommended that these reports be provided to an appropriate expert for the purpose of conducting a comprehensive health risk assessment, including a review of all relevant provincial, national and international health-based air quality standards.

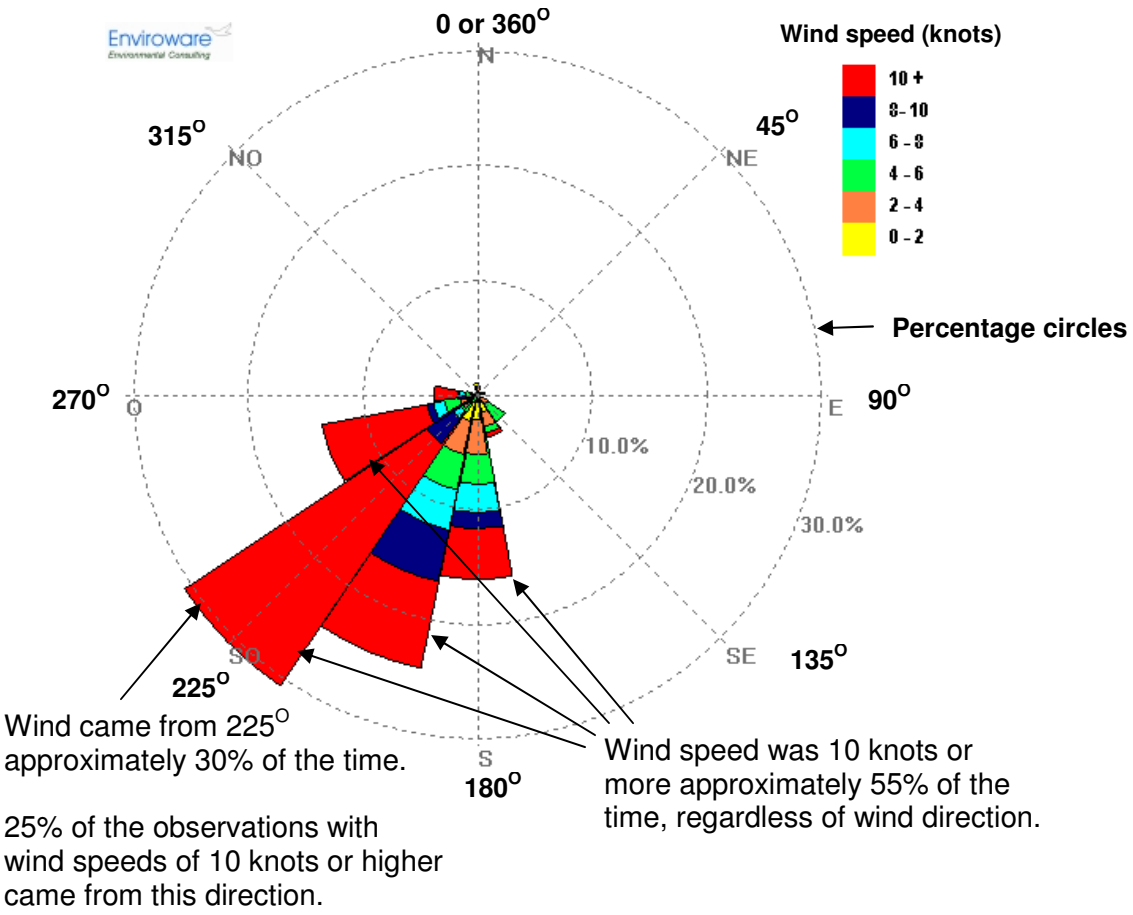
[43] Tradewind Scientific Ltd (2001). Volatile Organic Compound Monitoring Program at Victoria Harbour Airport. Prepared for Transport Canada Programs Branch, Vancouver, B.C.

APPENDIX A. WINDROSE EXAMPLE AND WIND SPEED CONVERSION TABLE

A windrose is a graphical representation of the wind speed and wind direction frequencies. For any given length of time, observations of wind speed and direction are sorted according to direction first. Then, within each direction group, wind speed is sorted into categories from low to high and the frequency (expressed as a percentage of the total number of observations in the same category) is calculated.

Each direction group is plotted around a compass circle, like petals around a flower's centre. The overall length of each direction group indicates how often winds come from that direction. Within each direction group, lower wind speed categories are nearest the centre and high wind speed categories are at the outer edge. The length of each wind speed segment indicates how often the wind speed was in that category. The compass circle includes concentric rings that indicate percentages, and these can be used to determine the frequencies of wind direction and speed.

Figure A-1. Windrose



In this report, wind speed is reported in knots. Table A-1 provides equivalent speeds in kilometers/hour and meters/second.

Table A-1. Wind speed in knots, kilometers/hour, and metres per second

Knots	Km/hour	M/second	Knots	Km/hour	M/second
1	1.9	0.5	26	48.2	13.4
2	3.7	1.0	27	50.0	13.9
3	5.6	1.5	28	51.9	14.4
4	7.4	2.1	29	53.7	14.9
5	9.3	2.6	30	55.6	15.4
6	11.1	3.1	31	57.4	15.9
7	13.0	3.6	32	59.3	16.5
8	14.8	4.1	33	61.1	17.0
9	16.7	4.6	34	63.0	17.5
10	18.5	5.1	35	64.8	18.0
11	20.4	5.7	36	66.7	18.5
12	22.2	6.2	37	68.5	19.0
13	24.1	6.7	38	70.4	19.5
14	25.9	7.2	39	72.2	20.1
15	27.8	7.7	40	74.1	20.6
16	29.6	8.2	41	75.9	21.1
17	31.5	8.7	42	77.8	21.6
18	33.3	9.3	43	79.6	22.1
19	35.2	9.8	44	81.5	22.6
20	37.0	10.3	45	83.3	23.2
21	38.9	10.8	46	85.2	23.7
22	40.7	11.3	47	87.0	24.2
23	42.6	11.8	48	88.9	24.7
24	44.4	12.3	49	90.7	25.2
25	46.3	12.9	50	92.6	25.7

APPENDIX B. TECHNICAL DETAILS – NITRIC OXIDES, NITROGEN DIOXIDE, AND SULFUR DIOXIDE SAMPLERS

We used Ogawa passive samplers[44] to measure long-term average levels of these pollutants in the study area. These samplers are 'passive', meaning that they simply absorb pollutants from the surrounding air, and therefore require relatively long exposure times, on the order of 14 days. Table B.1 displays the lowest detectable range of NO_2, NO_x and SO_2 for the Ogawa samplers based on 24-hour and 168 hour exposures; our samplers were exposed for 336 hours and so the 168 hour levels are applicable.

Table B.1 Lowest detectable range of Ogawa* Samplers

Pollutant	24 hr ($\mu g/m^3$)	168 hr ($\mu g/m^3$)
NO_2	4.4	0.6
NO_x	4.4	0.6
SO_2	10.0	1.0

*Ogawa and Company (http://www.ogawausa.com/faq.htm)

While the Ogawa passive sampler results from lab analysis were reported in parts per billion, these values have all been converted into average micrograms per cubic meter ($\mu g/m^3$) per hour of sampling for this report, assuming a temperature of 20 degrees Celsius and 1 atmospheric pressure.

In May, samplers were exposed for 14 consecutive days. During June/July, paired samplers were deployed at 10 sites in the James Bay area. On days when cruise ships were in port, one of the paired samplers at each location was exposed, and on days without cruise ships in port, the other sampler was exposed. This procedure was repeated until each of the samplers had been exposed for 14 days in total. Between exposures, each sampler was kept sealed in an airtight Ziploc plastic bag stored inside an opaque airtight screw-top plastic container, in the Spatial Sciences Research lab at room temperature (20^o C). At one site, a third sampler was deployed to provide a duplicate measure. All samplers were processed at the School of Occupational and Environmental Health Lab at the University of British Columbia, using standard procedures. A second set of paired samplers was deployed during August/September. Samplers at two of the ten sites were vandalized, so data for only eight sites in this second round of monitoring were obtained.

Field blanks and duplicate samplers were used in both sampling rounds for quality control purposes. Field blanks were used to determine how transport and handling may

[44] http://www.ogawausa.com/passive.html

have affected sampler concentrations. Table B.2 displays the levels detected on the field blank from each sampling round. Within each sampling round, these field blank values were subtracted from the results at each sample site (i.e. the values displayed in other tables are blank adjusted).

Table B-2 Field blank concentrations (µg/m^3)

Sampling Period	#	NO_2	NO	NO_x	SO_2
May (5 blanks)	1	0.8	0.6	1.3	0.0
	2	0.8	0.4	1.1	1.3
	3	0.6	1.7	2.3	0.8
	4	0.6	0.8	1.3	1.1
	5	0.8	0.6	1.3	1.1
June/July (1 blank)	1	1.5	1.9	3.4	2.1
August/September (1 blank)	1	1.9	4.6	6.5	0.5

Duplicate samplers were deployed to assess the precision of the Ogawa sampling technique. One set of duplicate samplers was deployed for the June/July sampling round, and two for the August/September round. The relative percent difference between each set of duplicates (one set for the June/July period, and two for August/September) are presented in Tables B-3 and B-4.

Table B-3. Relative percent difference between Ogawa Samplers in the May sampling period

	Duplicate Values (µg/m^3) (Relative Percent Difference)*		
Sample Number	NO_2**	NO	SO_2***
1	8.7 and 9.2 (6%)	13.0 and 13.6 (5%)	0.5 and 0.0 (200%)
2	5.4 and 6.4 (17%)	10.0 and 11.4 (13%)	0.8 and 0.0 (200%)
3	2.5 and 4.1 (49%)	8.5 and 10.0 (16%)	0.0 and 0.0 (0 %)
4	4.3 and 4.4 (2%)	6.2 and 7.0 (12%)	0.0 and 1.6 (200%)
5	3.0 and 4.1 (5%)	5.4 and 5.7 (5%)	0.2 and 0.0 (200%)

*Relative Percent Difference: the absolute difference between the two results for a duplicate pair, divided by the average result, and multiplied by 100 to express as a percentage

**NO_2 values were reported ± 15% although one sampler read anomalously higher than the others

*** SO_2 values appear to be below or at the limit of detection, so relative percent difference is less meaningful. SO_2 levels in May are reported as +/- 50%, in keeping with June/July and August/September samples.

Table B-4. Relative percent difference between duplicate Ogawa Samplers for the June/July and August/September sampling periods

	Duplicate Values (µg/m^3) (Relative Percent Difference)*			
Sampling Period	**NO_2**	**NO**	**NO_x**	**SO_2**
June/July (1 duplicate)	6.7 and 6.4 (5%)	6.9 and 7.1 (3%)	13.6 and 13.5 (1%)	2.9 and 2.4 (19%)
August/September (1 duplicate)	13.4 and 14.9 (11%)	15.5 and 14.3 (8%)	29.0 and 29.2 (1%)	0.5 and 0.8 (46%)

*Relative Percent Difference: the absolute difference between the two results for a duplicate pair, divided by the average result, and multiplied by 100 to express as a percentage
NO_2 values were reported ± 10%, NO values were reported ± 10%, SO_2 values were reported ± 50%

The June/July sample set was found to be more precise, with relative percent differences ranging from 1 percent for NO_x to 19 percent for SO_2. The August/September sample set had relative percent differences ranging from 1 percent for NO_x to 46 percent for SO_2. There was a large difference in precision for SO_2 between the two sampling periods, and many of the samples from the second round measured levels at or near the detection limit.

Details of the exact dates and times samplers were exposed are provided in Tables B-5, B-6 and B-7.

Table B-5. NO_2/NO_x/NO and SO_2 sampling times and dates for May

Site	Street	Distance from curb (m)	OPEN – May 22	CLOSE – June 6
A-01	Superior	0.0	11:26	10:10
A-02		14.7	11:20	10:04
A-03		25.1	11:12	10:01
A-04	Montreal/Dallas	18.0	11:49	10:18
A-05		54.3	11:57	10:23
A-06		76.4	12:09	10:28
A-07	Niagara	0.0	12:51	10:54
A-08		24.7	13:00	10:58
A-09		51.9	1:14	11:02
A-10	Lewis/Dallas	9.4	12:36	10:44
A-11		31.0	12:29	10:41
A-12		55.8	12:22	10:37
A-13	Heather/Toronto	30.0	1:32	11:15
A-14		46.9	1:26	11:10
A-15		79.6	1:39	11:19

Table B-6. $NO_2/NO_x/NO$ and SO_2 Sampling times and dates for June/July

ROUND 1	NON-CRUISE			CRUISE		
SITE	Open	Close	Total Minutes	Open	Close	Total Minutes
B-01	6/17/07 1:15 PM	6/21/07 1:18 PM	5763	6/15/07 1:17 PM	6/17/07 1:12 PM	2875
	6/24/07 1:21 PM	6/26/07 1:20 PM	2879	6/22/07 1:03 PM	6/24/07 1:20 PM	2897
	7/1/07 12:55 PM	7/3/07 1:15 PM	2900	6/28/07 1:15 PM	7/1/07 12:54 PM	4299
	7/8/07 1:01 PM	7/10/07 12:03 PM	2822	7/6/07 1:07 PM	7/8/07 1:00 PM	2873
	7/15/07 1:08 PM	7/17/07 1:09 PM	2881	7/13/07 1:39 PM	7/15/07 1:07 PM	2848
	7/22/07 1:11 PM	7/24/07 1:10 PM	2879	7/20/07 1:05 PM	7/22/07 1:10 PM	2885
				7/27/07 1:34 PM	7/28/07 1:55 PM	1460
		total minutes exposed	**20124**		total minutes exposed	**20137**
B-02	6/17/07 1:24 PM	6/21/07 1:26 PM	5762	6/15/07 1:32 PM	6/17/07 1:23 PM	2871
	6/24/07 1:29 PM	6/26/07 1:26 PM	2877	6/22/07 1:08 PM	6/24/07 1:28 PM	2900
	7/1/07 1:01 PM	7/3/07 1:20 PM	2894	6/28/07 1:21 PM	7/1/07 1:01 PM	4300
	7/8/07 1:07 PM	7/10/07 12:08 PM	2821	7/6/07 1:12 PM	7/8/07 1:06 PM	2874
	7/15/07 1:13 PM	7/17/07 1:15 PM	2882	7/13/07 1:43 PM	7/15/07 1:13 PM	2850
	7/22/07 1:18 PM	7/24/07 1:16 PM	2878	7/20/07 1:13 PM	7/22/07 1:17 PM	2884
				7/27/07 1:39 PM	7/28/07 2:02 PM	1463
		total minutes exposed	**20114**		total minutes exposed	**20142**
B-03	6/17/07 1:33 PM	6/21/07 1:31 PM	5758	6/15/07 1:51 PM	6/17/07 1:31 PM	2860
	6/24/07 1:35 PM	6/26/07 1:31 PM	2876	6/22/07 1:13 PM	6/24/07 1:34 PM	2901
	7/1/07 1:07 PM	7/3/07 1:25 PM	2898	6/28/07 1:26 PM	7/1/07 1:06 PM	4300
	7/8/07 1:12 PM	7/10/07 12:12 PM	2820	7/6/07 1:17 PM	7/8/07 1:12 PM	2875
	7/15/07 1:19 PM	7/17/07 1:20 PM	2881	7/13/07 1:47 PM	7/15/07 1:18 PM	2851
	7/22/07 1:26 PM	7/24/07 1:21 PM	2875	7/20/07 1:18 PM	7/22/07 1:24 PM	2886
				7/27/07 1:44 PM	7/28/07 2:08 PM	1464
		total minutes exposed	**20108**		total minutes exposed	**20137**

ROUND 1	NON-CRUISE			CRUISE		
SITE	Open	Close	Total Minutes	Open	Close	Total Minutes
B-04	6/17/07 1:39 PM	6/21/07 1:37 PM	5758	6/15/07 2:01 PM	6/17/07 1:38 PM	2857
	6/24/07 1:40 PM	6/26/07 1:36 PM	2877	6/22/07 1:20 PM	6/24/07 1:39 PM	2899
	7/1/07 1:12 PM	7/3/07 1:30 PM	2898	6/28/07 1:30 PM	7/1/06 1:11 PM	4301
	7/8/07 1:18 PM	7/10/07 12:18 PM	2820	7/6/07 1:22 PM	7/8/07 1:17 PM	2875
	7/15/07 1:23 PM	7/17/07 1:25 PM	2882	7/13/07 1:51 PM	7/15/07 1:22 PM	2851
	7/22/07 1:32 PM	7/24/07 1:27 PM	2875	7/20/07 1:22 PM	7/22/07 1:31 PM	2889
				7/27/07 1:48 PM	7/28/07 2:14 PM	1466
		total minutes exposed	**20110**		total minutes exposed	**20138**
B-05	6/17/07 1:46 PM	6/21/07 1:41 PM	5755	6/15/07 2:10 PM	6/17/07 1:44 PM	2854
	6/24/07 1:45 PM	6/26/07 1:41 PM	2876	6/22/07 1:24 PM	6/24/07 1:45 PM	2901
	7/1/07 1:18 PM	7/3/07 1:34 PM	2896	6/28/07 1:35 PM	7/1/07 1:17 PM	4302
	7/8/07 1:25 PM	7/10/07 12:22 PM	2817	7/6/07 1:26 PM	7/8/07 1:24 PM	2878
	7/15/07 1:28 PM	7/17/07 1:29 PM	2881	7/13/07 1:53 PM	7/15/07 1:27 PM	2854
	7/22/07 1:39 PM	7/24/07 1:32 PM	2873	7/20/07 1:26 PM	7/22/07 1:38 PM	2892
				7/27/07 1:53 PM	7/28/07 2:20 PM	1467
		total minutes exposed	**20098**		total minutes exposed	**20148**
B-06	6/17/07 1:53 PM	6/21/07 1:46 PM	5753	6/15/07 2:19 PM	6/17/07 1:51 PM	2852
	6/24/07 1:51 PM	6/26/07 1:35 PM	2874	6/22/07 1:29 PM	6/24/07 1:51 PM	2902
	7/1/07 1:22 PM	7/3/07 1:37 PM	2895	6/28/07 1:40 PM	7/1/07 1:22 PM	4302
	7/8/07 1:30 PM	7/10/07 12:26 PM	2816	7/6/07 1:30 PM	7/8/07 1:29 PM	2878
	7/15/07 1:33 PM	7/17/07 1:33 PM	2880	7/13/07 1:58 PM	7/15/07 1:31 PM	2853
	7/22/07 1:44 PM	7/24/07 1:38 PM	2874	7/20/07 1:31 PM	7/22/07 1:43 PM	2892
				7/27/07 1:57 PM	7/28/07 2:26 PM	1469
		total minutes exposed	**20092**		total minutes exposed	**20148**

ROUND 1	NON-CRUISE			CRUISE		
SITE	Open	Close	Total Minutes	Open	Close	Total Minutes
B-07	6/17/07 2:02 PM	6/21/07 1:52 PM	5750	6/15/07 2:34 PM	6/17/07 1:59 PM	2845
	6/24/07 1:58 PM	6/26/07 1:50 PM	2872	6/22/07 1:34 PM	6/24/07 1:57 PM	2903
	7/1/07 1:29 PM	7/3/07 1:42 PM	2893	6/28/07 1:46 PM	7/1/07 1:27 PM	4301
	7/9/07 1:36 PM	7/10/07 12:31 PM	2815	7/6/07 1:35 PM	7/9/07 1:35 PM	2880
	7/15/07 1:39 PM	7/17/07 1:39 PM	2880	7/13/07 2:02 PM	7/15/07 1:37 PM	2853
	7/22/07 1:54 PM	7/24/07 1:44 PM	2870	7/20/07 1:37 PM	7/22/07 1:53 PM	2896
				7/27/07 2:02 PM	7/28/07 2:34 PM	1472
		total minutes exposed	**20080**		total minutes exposed	**20150**
B-07 DUPLICATE				6/15/07 2:36 PM	6/17/07 2:01 PM	2844
				6/22/07 1:34 PM	6/24/07 1:57 PM	2903
				6/29/07 1:46 PM	7/1/07 1:27 PM	4301
				7/6/07 1:35 PM	7/8/07 1:35 PM	2880
				7/13/07 2:03 PM	7/15/07 1:38 PM	2855
				7/20/07 1:38 PM	7/22/07 1:53 PM	2895
				7/27/07 2:02 PM	7/28/07 2:36 PM	1474
					total minutes exposed	**20152**
B08	6/17/07 2:10 PM	6/21/07 1:58 PM	5748	6/15/07 2:46 PM	6/17/07 2:09 PM	2843
	6/24/07 2:04 PM	6/26/07 1:55 PM	2871	6/22/07 1:40 PM	6/24/07 2:04 PM	2904
	7/1/07 1:35 PM	7/3/07 1:46 PM	2891	6/28/07 1:52 PM	7/1/07 1:34 PM	4302
	7/8/07 1:42 PM	7/10/07 12:36 PM	2814	7/6/07 1:41 PM	7/8/07 1:42 PM	2879
	7/15/07 1:44 PM	7/17/07 1:44 PM	2880	7/13/07 2:10 PM	7/15/07 1:44 PM	2854
	7/22/07 2:01 PM	7/24/07 1:50 PM	2869	7/20/07 1:43 PM	7/22/07 2:00 PM	2897
				7/27/07 2:07 PM	7/28/07 2:24 PM	1457
		total minutes exposed	**20073**		total minutes exposed	**20136**

ROUND 1	NON-CRUISE			CRUISE		
SITE	Open	Close	Total Minutes	Open	Close	Total Minutes
B-09	6/17/07 2:17 PM	6/21/07 2:02 PM	5745	6/15/07 2:58 PM	6/17/07 2:15 PM	2837
	6/24/07 2:10 PM	6/26/07 2:00 PM	2870	6/22/07 1:46 PM	6/24/07 2:09 PM	2903
	7/1/07 1:40 PM	7/3/07 1:51 PM	2891	6/28/07 1:59 PM	7/1/01 1:39 PM	4300
	7/8/07 1:49 PM	7/10/07 12:40 PM	2811	7/6/07 1:46 PM	7/8/07 1:48 PM	2882
	7/15/07 1:50 PM	7/17/07 1:50 PM	2880	7/13/07 2:16 PM	7/15/07 1:49 PM	2853
	7/22/07 2:07 PM	7/24/07 1:57 PM	2870	7/20/07 1:48 PM	7/22/07 2:05 PM	2897
				7/27/07 2:11 PM	7/28/07 2:49 PM	1478
		total minutes exposed	**20067**		total minutes exposed	**20150**
B-10	6/17/07 2:24 PM	6/21/07 2:09 PM	5745	6/15/07 3:09 PM	6/17/07 2:22 PM	2833
	6/24/07 2:16 PM	6/26/07 2:04 PM	2868	6/22/07 1:49 PM	6/24/07 2:15 PM	2906
	7/1/07 1:45 PM	7/3/07 1:55 PM	2890	6/29/07 2:04 PM	7/1/07 1:44 PM	4300
	7/8/07 1:54 PM	7/10/07 12:45 PM	2811	7/6/07 1:50 PM	7/8/07 1:53 PM	2883
	7/15/07 1:55 PM	7/17/07 1:55 PM	2880	7/13/07 2:20 PM	7/15/07 1:54 PM	2854
	7/22/07 2:12 PM	7/24/07 2:03 PM	2871	7/20/07 1:53 PM	7/2//07 2:12 PM	2899
				7/27/07 2:16 PM	7/28/07 2:56 PM	1480
		total minutes exposed	**20065**		total minutes exposed	**20155**
B-11	6/17/07 2:40 PM	6/21/07 2:21 PM	5741	6/15/07 3:29 PM	6/17/07 2:38 PM	2829
	6/24/07 2:29 PM	6/26/07 2:19 PM	2870	6/22/07 2:10 PM	6/24/07 2:28 PM	2898
	7/1/07 2:00 PM	7/3/07 2:09 PM	2889	6/28/07 2:23 PM	7/1/07 1:59 PM	4296
	7/8/07 2:07 PM	7/10/07 12:57 PM	2810	7/6/07 2:04 PM	7/8/07 2:06 PM	2882
	7/15/07 2:07 PM	7/17/07 2:09 PM	2882	7/13/07 2:32 PM	7/15/07 2:06 PM	2854
	7/22/07 2:25 PM	7/24/07 2:17 PM	2872	7/20/07 2:06 PM	7/22/07 2:24 PM	2898
				7/27/07 2:28 PM	7/28/07 3:11 PM	1483
		total minutes exposed	**20064**		total minutes exposed	**20140**

Table B-7. $NO_2/NO_x/NO$ and SO_2 Sampling times and dates for August/September

ROUND 2	NON-CRUISE			CRUISE		
SITE	**Open**	**Close**	**Total**	**Open**	**Close**	**Total**
C-01	8/19/07 1:17 PM	8/22/07 1:06 PM	4312	8/17/07 12:18 PM	8/19/07 1:16 PM	2938
	8/26/07 1:18 PM	8/29/07 1:27 PM	4329	8/24/07 1:19 PM	8/26/07 1:17 PM	2882
	9/2/07 11:01 AM	9/5/07 12:05 PM	4384	8/31/07 1:15 PM	9/2/07 11:00 AM	2745
	9/9/07 12:54 PM	9/12/07 11:55 PM	4261	9/6/07 11:43 AM	9/9/07 12:53 PM	4390
	9/16/07 1:04 PM	9/16/07 2:27 PM	83	9/14/07 12:38 PM	9/16/07 1:03 PM	2905
	9/18/07 1:42 PM	9/20/07 12:09 PM	2787	9/20/07 12:09 PM	9/23/07 11:52 PM	4303
		total minutes exposed	**20156**		total minutes exposed	**20163**
C-02	8/19/07 1:22 PM	8/22/07 1:14 PM	4312	8/17/07 12:28 PM	8/19/07 1:21 PM	2933
	8/26/07 1:25 PM	8/29/07 1:32 PM	4327	8/24/07 1:24 PM	8/26/07 1:24 PM	2880
	9/2/07 11:07 AM	9/5/07 12:11 PM	4384	8/31/07 1:20 PM	9/2/07 11:07 AM	2747
	9/9/07 1:03 PM	9/12/07 11:59 PM	4256	9/6/07 11:47 AM	9/9/07 1:03 PM	4396
	9/16/07 1:10 PM	9/16/07 2:31 PM	81	9/14/07 12:43 PM	9/16/07 1:09 PM	2906
	9/18/07 1:46 PM	9/20/07 12:14 PM	2788	9/20/07 12:15 PM	9/23/07 12:00 PM	4305
		total minutes exposed	**20148**		total minutes exposed	**20167**
C-03	8/19/07 1:32 PM	8/22/07 1:22 PM	4310	8/17/07 12:50 PM	8/19/07 1:31 PM	2921
	8/26/07 1:35 PM	8/29/07 1:37 PM	4322	8/24/07 1:32 PM	8/26/07 1:34 PM	2882
	9/2/07 11:15 AM	9/5/07 12:16 PM	4381	8/31/07 1:26 PM	9/2/07 11:14 AM	2748
	9/9/07 1:10 PM	9/12/07 12:04 PM	4254	9/6/07 11:53 AM	9/9/07 1:10 PM	4397
	9/16/07 1:18 PM	9/16/07 2:36 PM	78	9/14/07 12:47 PM	9/16/07 1:17 PM	2910
	9/18/07 1:52 PM	9/20/07 12:22 PM	2790	9/20/07 12:22 PM	9/23/07 12:07 PM	4305
		total minutes exposed	**20135**		total minutes exposed	**20163**

ROUND 2	NON-CRUISE			CRUISE		
ID	**Open**	**Close**	**Total**	**Open**	**Close**	**Total**
C-04	8/19/07 1:39 PM	8/22/07 1:26 PM	4307	8/17/07 12:59 PM	8/19/07 1:37 PM	2918
	8/26/07 1:39 PM	8/29/07 1:41 PM	4322	8/24/07 1:36 PM	8/26/07 1:39 PM	2883
	9/2/07 11:20 AM	9/5/07 12:19 PM	4379	8/31/07 1:31 PM	9/2/07 11:19 AM	2748
	9/9/07 1:15 PM	9/12/07 12:08 PM	4253	9/6/07 11:56 AM	9/9/07 1:14 PM	4398
	9/16/07 1:23 PM	9/16/07 2:39 PM	76	9/14/07 12:50 PM	9/16/07 1:22 PM	2912
	9/18/07 1:56 PM	9/20/07 12:27 PM	2791	9/20/07 12:27 PM	9/23/07 12:13 PM	4306
		total minutes exposed	**20128**		total minutes exposed	**20165**
C-05	8/19/07 1:44 PM	8/22/07 1:29 PM	4305	8/17/07 1:09 PM	8/19/07 1:44 PM	2915
	8/26/07 1:44 PM	8/29/07 1:44 PM	4320	8/24/07 1:40 PM	8/26/07 1:43 PM	2883
	9/2/07 11:25 AM	9/5/07 12:22 PM	4377	8/31/07 1:36 PM	9/2/07 11:25 AM	2749
	9/9/07 1:21 PM	9/12/07 12:11 PM	4250	9/6/07 12:00 PM	9/9/07 1:20 PM	4400
	9/16/07 1:29 PM	9/16/07 2:42 PM	73	9/14/07 12:52 PM	9/16/07 1:29 PM	2917
	9/18/07 1:59 PM	9/20/07 12:32 PM	2793	9/20/07 12:32 PM	9/23/07 12:17 PM	4305
		total minutes exposed	**20118**		total minutes exposed	**20169**
C-06	8/19/07 1:50 PM	8/22/07 1:33 PM	4299	8/17/07 1:27 PM	8/19/07 1:49 PM	2902
and	8/26/07 1:50 PM	8/29/07 1:49 PM	4319	8/24/07 1:43 PM	8/26/07 1:49 PM	2886
duplicate	9/2/07 11:32 AM	9/5/07 12:25 PM	4373	8/31/07 1:47 PM	9/2/07 11:31 AM	2744
	9/9/07 1:27 PM	9/12/07 12:15 PM	4248	9/6/07 12:03 PM	9/9/07 1:26 PM	4403
	8/16/07 1:36 PM	9/16/07 2:47 PM	71	9/14/07 12:57 PM	9/16/07 1:35 PM	2918
	9/18/07 2:05 PM	9/20/07 12:38 PM	2793	9/20/07 12:40 PM	9/23/07 12:23 PM	4303
		total minutes exposed	**20103**		total minutes exposed	**20156**

ROUND 2	NON-CRUISE			CRUISE		
ID	**Open**	**Close**	**Total**	**Open**	**Close**	**Total**
C-07	8/19/07 1:56 PM	8/22/07 1:39 PM	4303	8/17/07 1:38 PM	8/19/07 1:55 PM	2897
	8/26/07 1:57 PM	8/29/07 1:52 PM	4315	8/24/07 1:48 PM	8/26/07 1:56 PM	2888
	9/2/07 11:37 AM	9/5/07 12:29 PM	4372	8/31/07 1:41 PM	9/2/07 11:37 AM	2756
	9/9/07 1:33 PM	9/12/07 12:19 PM	4246	9/6/07 12:07 PM	9/9/07 1:32 PM	4405
	9/16/07 1:45 PM	9/16/07 2:52 PM	67	9/14/07 1:01 PM	9/16/07 1:44 PM	2923
	9/18/07 2:09 PM	9/20/07 12:45 PM	2796	9/20/07 12:46 PM	9/23/07 12:28 PM	4302
		total minutes exposed	**20099**		total minutes exposed	**20171**
C-08	8/19/07 2:02 PM	8/22/07 1:44 PM	4302	8/17/07 1:50 PM	8/19/07 2:01 PM	2891
	8/26/07 2:04 PM	8/29/07 1:57 PM	4313	8/24/07 1:53 PM	8/26/07 2:04 PM	2891
	9/2/07 11:45 AM	9/5/07 12:35 PM	4370	8/31/07 1:54 PM	9/2/07 11:45 AM	2751
	9/9/07 1:42 PM	9/12/07 12:25 PM	4243	9/6/07 12:13 PM	9/9/07 1:41 PM	4408
	9/16/07 1:55 PM	9/16/07 2:57 PM	62	9/14/07 1:07 PM	9/16/07 1:54 PM	2927
	9/18/07 2:18 PM	9/20/07 12:53 PM	2795	9/20/07 12:53 PM	9/23/07 1:10 PM	4337
		total minutes exposed	**20085**		total minutes exposed	**20205**
C-09	vandalized			8/17/07 2:20 PM	8/19/07 2:28 PM	2887
				8/24/07 2:06 PM	8/26/07 2:18 PM	2892
				8/31/07 2:08 PM	9/2/08 11:58 AM	2750
				9/6/07 12:31 PM	9/9/07 1:55 PM	4404
				9/14/07 1:19 PM	9/16/07 2:11 PM	2932
				9/20/07 1:12 PM	9/23/07 1:25 PM	4333
					total minutes exposed	**20198**

APPENDIX C. TECHNICAL DETAILS – NEPHELOMETERS AND TRAFFIC COUNTERS

For a six day period in each of June and July, light scattering was measured and logged every 5 minutes using three Radiance Research M903 nephelometers. Sampling dates and durations are provided in Table C-1.

The nephelometers used for field monitoring measure light scatter from particles in the air. There is no method for filtering the air prior to measuring light scatter, so particles of all sizes are present in the air sample. The nephelometer does, however, measure $PM_{2.5}$ well, because of the wavelength of the light source in the instrument. Evaluation tests have shown the light scatter measured by a Radiance Research M903 nephelometer compare well with $PM_{2.5}$ levels measured at the same time by a differential TEOM monitor. The differential TEOM monitor filters air samples and weighs differences in filter weight at short intervals.[45]

Equipment was calibrated according to the manufacturer's instructions prior to use in the field. We also operated all three nephelometers side by side for 24-hours in the Spatial Sciences Research Lab after field use, and found a high correlation between the levels measured by each instrument (R^2 between .986 and .991, where a perfect correlation is 1.0 and no correlation is 0). At each site, the nephelometer operated continuously for six continuous days, including three days with no cruise ships at dock and three days with cruise ships at dock.

The light scattering coefficient was converted to $PM_{2.5}$ ($\mu g/m^3$) using the following equation, as per Allen et al. (2003)[46]:

$$PM_{2.5}\ (\mu g/m^3) = ((100{,}000 \times \text{light scatter value}) - 0.01) / 0.28 \quad (1)$$

This equation is based on measurements in one season only, and so may not be the optimal conversion factor; however, the converted $PM_{2.5}$ levels used in this study agree well with the $PM_{2.5}$ levels measured at Topaz and Royal Roads University stations using TEOM equipment.

Converted $PM_{2.5}$ levels were then aggregated into 15 minute averages for presentation and discussion in this report.

[45] Lee JH, Hopke PK, Holsen TM, Lee DW, Jaques PA, Sioutas C, and Ambs JL. 2005. Performance evaluation of continuous PM2.5 mass concentration monitors. Journal of Aerosol Science 36 (2005) 95-109.

[46] Allen. R., Larson, T., Sheppard, L., Wallace, L. and Liu, S. 2003. Use of Real-Time Light Scattering Data to Estimate the Contribution of Infiltrated and Indoor-Generated Particles to Indoor Air. Environmental Science and Technology, Vol 37, No. 16, pp 3282-3492.

Table C-1. Nephelometer and Traffic Counters sampling dates and durations

Site #	Location	Date/Time In	Date/Time Out	Cruise or Non-Cruise
D-01	Dallas	12:02 June 28	12:26 July 1	Cruise
		12:29 July 1	12:17 July 4	Non-Cruise
D-02	Ladysmith	13:36 June 25	12:48 June 28	Non-Cruise
		12:52 June 28	12:05 July 1	Cruise
D-03	Ontario	13:58 June 25	13:00 June 28	Non-Cruise
		13:06 June 28	12:21 July 1	Cruise
E-01	Simcoe	12:35 July 30	12:35 August 2	Non-Cruise
		12:38 August 2	12:35 August 5	Cruise
E-02	St. Lawrence	12:22 July 30	12:09 August 2	Non-Cruise
		12:15 August 2	12:20 August 5	Cruise
E-03	Superior	12:06 July 30	11:57 August 2	Non-Cruise
		12:01 August 2	12:01 August 5	Cruise

APPENDIX D. TECHNICAL DETAILS – PARTISOLS

Model 2000-H Partisol samplers[47] were used to collect $PM_{2.5}$ on pre-weighed GELMAN Teflo 0.38mm filters, provided by CANTEST. The Partisol samplers use an air pump to pull air in through a cyclonic head which settles out larger particulates, and then through the sample filter. Equipment was calibrated for air flow volume according to manufacturer's instructions at the beginning of the field season by BC Ministry of Environment staff.

At each site, one filter was used for two to three days when no cruise ships were at dock, and a second filter was used for two to three days when cruise ships were at dock. In addition, a single filter was exposed to air in the study area for each monitoring period, to serve as a field blank for quality assurance. Used filters were sent first to the School of Occupational and Environmental Health lab at the University of British Columbia, where reflectance of the $PM_{2.5}$ was measured using a M43D Smokestain Reflectometer, then absorbance was calculated from the results. Absorbance is strongly related to the concentration of elemental carbon in the $PM_{2.5}$, which has been shown to be high in $PM_{2.5}$ resulting from incomplete diesel combustion from heavy duty vehicles.[48] Next, the filters were shipped to the CANTEST lab in Vancouver BC, where they were weighed again to determine total mass. The particulate matter collected on each of the filters was then analyzed for a full range of metals by CANTEST Ltd., using procedures based on WCB Method 1051, acid digestion of filter followed by analysis using inductively coupled plasma-mass spectroscopy (ICP/MS). This method is highly sensitive and can detect metals present in quantities as low as 0.005 to 0.75 micrograms (.000000005 to .00000075 grams). Total metals on each filter were measured, and then divided by the total volume of air pumped through the filter to produce an average level per cubic metre of air. Exact dates and durations for each filter sample are provided in Table D-1. Complete results for all metals are provided in Table D-2,

The $PM_{2.5}$ collected on the filters using the Partisol monitors, as described previously, was analyzed for absorbance by staff at the School of Occupational and Environmental Health lab, located at the University of British Columbia. Light absorbance is recognized as an indicator of $PM_{2.5}$ produced by diesel engines in buses and heavy trucks.

[47] These samplers were provided by the Ministry of Environment at no charge.
[48] Henderson S, Brauer M, 2005. Measurement and modeling of traffic-related air pollution on the British Columbia Lower Mainland for use in health risk assessment and epidemiological analysis. School of Occupational and Environmental Hygiene, University of British Columbia BC.

Table D-1. Dates and durations for filter samples

Site #	Location	Date/Time In	Date/Time Out	Cruise or Non-Cruise
D-1	Dallas	12:02 June 28 12:29 July 1	12:26 July 1 12:17 July 4	Cruise Non-Cruise
D-2	Ladysmith	13:36 June 25 12:52 June 28	12:48 June 28 12:05 July 1	Non-Cruise Cruise
D-3	Ontario	13:58 June 25 13:06 June 28	13:00 June 28 12:21 July 1	Non-Cruise Cruise
E-1	Simcoe	12:35 July 30 12:38 August 2	12:35 August 2 12:35 August 5	Non-Cruise Cruise
E-2	St. Lawrence	12:22 July 30 12:15 August 2	12:09 August 2 12:20 August 5	Non-Cruise Cruise
E-3	Superior	12:06 July 30 12:01 August 2	11:57 August 2 12:01 August 5	Non-Cruise Cruise
F-1	San Jose	13:15 September 18 13:09 September 21	11:51 September 20 12:53 September 23	Non-Cruise Cruise
F-2	Lewis	13:29 September 18 13:14 September 21	11:57 September 20 12:42 September 23	Non-Cruise Cruise
F-3	South Turner	13:07 September 18 13:02 September 21	11:43 September 20 12:31 September 23	Non-Cruise Cruise

Table D-2. Metals Analysis – Detection limits, field and lab blanks for June 28th – July 4th – Total Mass

Metal	Detection Limit (ug)	Blanks		Site D-1		Site D-2		Site D-3	
		Field	Lab	Cruise	No cruise	Cruise	No cruise	Cruise	No cruise
Aluminum	0.025	0.75	0.39	1.57	2.52	1.82	2.26	1.76	2.24
Antimony Sb	0.005	<0.01	<0.01	0.021	0.015	0.018	0.017	0.026	0.016
Arsenic As	0.005	<0.01	<0.01	0.036	0.013	0.033	0.019	0.039	0.021
Barium Ba	0.005	<0.01	<0.01	0.18	0.095	0.15	0.079	0.25	0.17
Beryllium Be	0.005	<0.01	<0.01	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Boron B	0.25	2.7	0.8	0.9	2.1	1.4	3.3	1	3.3
Cadmium Cd	0.001	0.002	<0.002	0.005	0.005	0.005	0.004	0.006	0.002
Calcium Ca	0.25	7.1	7.3	7.9	12.4	5.4	176	8.6	16.3
Chromium Cr	0.005	0.13	0.11	0.13	0.17	0.12	0.16	0.16	0.15
Cobalt Co	0.005	<0.01	<0.01	0.006	< 0.005	0.005	< 0.005	0.006	< 0.005
Copper Cu	0.005	0.01	0.02	0.12	0.082	0.12	0.097	0.16	0.11
Iron Fe	0.25	<0.5	<0.5	1.8	2.3	1.4	2.7	2.9	3.8
Lead Pb	0.005	0.02	0.02	0.11	0.095	0.1	0.1	0.13	0.072
Magnesium Mg	0.25	<0.5	<0.5	2	2.3	2	4.7	2.5	3.3
Manganese Mn	0.005	<0.01	<0.01	0.048	0.073	0.041	0.094	0.065	0.066
Molybdenum Mo	0.0025	<0.01	<0.01	0.014	0.009	0.013	0.01	0.019	0.014
Nickel Ni	0.005	<0.01	<0.01	0.33	0.13	0.31	0.13	0.33	0.19
Phosphorus P	0.75	0.6	0.4	< 0.75	0.8	< 0.75	1.1	0.8	0.9
Potassium K	0.5	0.8	0.7	5.7	2.9	4.4	2.5	4.7	3.6
Selenium Se	0.005	<0.3	<0.3	0.011	0.009	0.012	0.012	0.014	0.014
Silver Ag	0.00125	<0.001	<0.001	< 0.00125	< 0.00125	0.002	< 0.00125	0.002	< 0.00125
Sodium Na	0.25	3.7	2	13.3	15.6	14.9	19.8	17.5	26.7
Strontium Sr	0.005	<0.01	<0.01	0.055	0.029	0.049	0.093	0.062	0.036
Tellurium Te	0.005	<0.3	<0.3	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Thallium Tl	0.0005	<0.3	<0.3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Tin Sn	0.005	0.12	0.09	0.1	0.14	0.099	0.065	0.12	0.14
Titanium Ti	0.005	0.01	<0.01	0.07	0.089	0.056	0.08	0.11	0.12
Vanadium V	0.005	<0.01	<0.01	0.7	0.28	0.68	0.3	0.77	0.37
Zinc Zn	0.025	0.55	0.61	0.63	0.88	0.45	10.6	0.68	1.05
Zirconium Zr	0.05	<0.1	<0.1	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

Table D-3. Metals Analysis – Detection limits, field and lab blanks for July 30th – August 5th – Total Mass

	Detection Limit	Blanks		Site E-1		Site E-2		Site E-3	
Metal	(ug)	Field	Lab	Cruise	No cruise	Cruise	No cruise	Cruise	No cruise
Aluminum	0.025	0.97	0.41	1.36	3.29	1.34	2.88	3.01	2.48
Antimony Sb	0.005	<	<	0.013	0.017	0.005	0.009	0.007	0.011
Arsenic As	0.005	0.016	0.009	<	0.012	<	0.017	<	0.014
Barium Ba	0.005	0.034	<	0.18	0.17	0.13	0.094	0.18	0.096
Beryllium Be	0.005	<	<	<	<	<	<	<	<
Boron B	0.25	1.4	0.3	1.0	5.2	<	1.0	0.8	5.8
Cadmium Cd	0.001	0.001	<	0.001	0.001	0.001	0.001	0.002	0.002
Calcium Ca	0.25	3.1	1.7	3.9	8.3	4.5	5.2	9.7	4.6
Chromium Cr	0.005	0.14	0.13	0.13	0.11	0.12	0.12	0.13	0.19
Cobalt Co	0.005	<	<	0.014	<	0.014	<	0.024	<
Copper Cu	0.005	0.022	0.012	0.070	0.10	0.042	0.057	0.055	0.065
Iron Fe	0.25	0.8	0.6	2.6	3.3	1.9	2.3	2.8	3.1
Lead Pb	0.005	0.017	0.009	0.029	0.072	0.045	0.095	0.063	0.060
Magnesium Mg	0.25	0.3	0.3	2.1	3.3	2.2	3.2	3.4	4.4
Manganese Mn	0.005	0.011	0.007	0.037	0.072	0.035	.060	0.048	0.074
Molybdenum Mo	0.0025	0.004	0.004	0.018	0.015	0.019	0.011	0.022	0.014
Nickel Ni	0.005	0.025	<	0.69	0.17	0.69	0.17	1.21	0.17
Phosphorus P	0.75	1.0	1.0	1.3	1.1	1.4	<	1.0	1.2
Potassium K	0.5	1.0	0.7	1.8	3.3	5.0	2.8	2.5	2.9
Selenium Se	0.005	<	<	0.005	0.003	0.005	0.007	0.007	0.009
Silver Ag	0.00125	0.003	<	<	0.004	<	<	<	<
Sodium Na	0.25	3.0	1.3	15.7	29.3	19.1	23.6	22.0	39.1
Strontium Sr	0.005	0.011	<	0.030	0.046	0.030	0.030	0.067	0.031
Tellurium Te	0.005	<	<	<	<	<	<	<	<
Thallium Tl	0.0005	<	<	<	<	<	<	<	<
Tin Sn	0.005	0.064	0.091	0.054	0.027	0.040	0.021	0.028	0.062
Titanium Ti	0.005	0.035	0.026	0.10	0.13	0.076	0.095	0.12	0.13
Vanadium V	0.005	<	<	0.80	0.42	1.75	0.43	2.72	0.46
Zinc Zn	0.025	0.17	0.13	0.19	0.31	0.21	0.23	0.72	0.22
Zirconium Zr	0.05	<	<	<	<	<	<	<	0.05

Table D-4. Metals Analysis – Detection limits, field and lab blanks for September 18th – 23rd – Total Mass

Metal	Detection Limit (ug)	Blanks		Site F-1		Site F-2		Site F_3	
		Field	Lab	Cruise	No cruise	Cruise	No cruise	Cruise	No cruise
Aluminum	0.025	0.82	0.37	1.08	6.69	0.91	2.06	0.61	1.43
Antimony Sb	0.005	< 0.005	0.012	0.007	0.009	< 0.005	0.008	0.006	0.01
Arsenic As	0.005	< 0.005	0.019	0.019	0.011	0.023	0.007	0.049	0.014
Barium Ba	0.005	0.007	< 0.005	0.041	0.065	0.033	0.051	0.034	0.062
Beryllium Be	0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Boron B	0.25	2.6	0.9	0.8	0.8	1.2	4.1	0.4	1
Cadmium Cd	0.001	0.001	0.001	0.001	0.002	0.002	0.003	0.001	0.002
Calcium Ca	0.25	4.9	4.9	6.7	11.4	12.4	7.7	10.5	8.5
Chromium Cr	0.005	0.095	0.11	0.1	0.13	0.11	0.11	0.14	0.13
Cobalt Co	0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Copper Cu	0.005	0.019	0.042	0.043	0.089	0.044	0.059	0.034	0.09
Iron Fe	0.25	0.4	0.3	0.9	2.7	0.7	1.5	0.8	1.8
Lead Pb	0.005	0.01	0.06	0.056	0.1	0.063	0.068	0.056	0.099
Magnesium Mg	0.25	0.3	0.4	4	2.4	5.4	2.3	4.3	2.3
Manganese Mn	0.005	0.009	0.009	0.018	0.069	0.017	0.043	0.021	0.056
Molybdenum Mo	0.0025	< 0.0025	< 0.0025	0.005	0.012	0.005	0.012	0.005	0.014
Nickel Ni	0.005	0.19	0.005	0.12	0.12	0.12	0.082	0.1	0.081
Phosphorus P	0.75	< 0.75	< 0.75	< 0.75	1	1.8	0.8	0.8	0.9
Potassium K	0.5	< 0.5	0.5	2.4	2.9	3.2	2.9	2.5	2.5
Selenium Se	0.005	< 0.005	< 0.005	0.007	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Silver Ag	0.00125	< 0.00125	< 0.00125	< 0.00125	< 0.00125	0.002	< 0.00125	< 0.00125	< 0.00125
Sodium Na	0.25	5.1	2	31.2	15.6	44.4	21.3	31.9	14.1
Strontium Sr	0.005	< 0.005	< 0.005	0.025	0.022	0.037	0.017	0.028	0.02
Tellurium Te	0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Thallium Tl	0.0005	0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Tin Sn	0.005	0.1	0.061	0.023	0.074	0.29	0.07	0.02	0.069
Titanium Ti	0.005	0.011	0.019	0.021	0.073	0.026	0.05	0.023	0.068
Vanadium V	0.005	< 0.005	< 0.005	0.26	0.17	0.22	0.16	0.26	0.17
Zinc Zn	0.025	0.13	0.14	0.24	0.5	0.15	0.39	0.16	0.38
Zirconium Zr	0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	

Table D-5. Metals Analysis: June 28th to July 4th – Mass by Volume

Metal	Amount (micrograms/cubic metre) (< indicates no detectable levels)					
	Site D-01 Cruise	Site D-1 No Cruise	Site D-2 Cruise	Site D-2 No Cruise	Site D-3 Cruise	Site D-3 No Cruise
Aluminum	0.01833255	0.04444865	0.01804495	0.03895735	0.04056987	0.03340157
Antimony Sb	0.00017524	0.00022967	0.00006733	0.00012174	0.00009435	0.00014815
Arsenic As	<	0.00016212	<	0.00022996	<	0.00018856
Barium Ba	0.00242637	0.00229674	0.00175063	0.00127152	0.00242610	0.00129296
Beryllium Be	<	<	<	<	<	<
Boron B	0.01347981	0.07025318	<	0.01352686	0.01078269	0.07811658
Cadmium Cd	0.00001348	0.00001351	0.00001347	0.00001353	0.00002696	0.00002694
Calcium Ca	0.05257127	0.11213489	0.06059872	0.07033966	0.13074010	0.06195453
Chromium Cr	0.00175238	0.00148612	0.00161597	0.00162322	0.00175219	0.00255899
Cobalt Co	0.00018872	<	0.00018853	<	0.00032348	<
Copper Cu	0.00094359	0.00135102	0.00056559	0.00077103	0.00074131	0.00088891
Iron Fe	0.03504752	0.04458375	0.02558612	0.03111177	0.03773941	0.04175197
Lead Pb	0.00039091	0.00097274	0.00060599	0.00128505	0.00084914	0.00080810
Magnesium Mg	0.02830761	0.04458375	0.02962604	0.04328594	0.04582643	0.05926086
Manganese Mn	0.00049875	0.00097274	0.00047132	0.00081161	0.00064696	0.00099666
Molybdenum Mo	0.00024264	0.00020265	0.00025586	0.00014880	0.00029652	0.00018856
Nickel Ni	0.00930107	0.00229674	0.00929180	0.00229957	0.01630882	0.00228962
Phosphorus P	0.01752376	0.01486125	0.01885293	<	0.01347836	0.01616205
Potassium K	0.02426367	0.04458375	0.06733191	0.03787520	0.03369590	0.03905829
Selenium Se	0.00006740	0.00010808	0.00006733	0.00009469	0.00009435	0.00012122
Silver Ag	<	0.00005404	<	<	<	<
Sodium Na	0.21163308	0.39584966	0.13601045	0.31923384	0.29652393	0.52661351
Strontium Sr	0.00040439	0.00062147	0.00040399	0.00040581	0.00090305	0.00041752
Tellurium Te	<	<	<	<	<	<
Thallium Tl	<	<	<	<	<	<
Tin Sn	0.00072791	0.00036478	0.00053866	0.00028406	0.00037739	0.00083504
Titanium Ti	0.00134798	0.00175633	0.00102344	0.00128505	0.00161740	0.00175089
Vanadium V	0.02426367	0.00567430	0.02356617	0.00581655	0.03666114	0.00619545
Zinc Zn	0.00256116	0.00418817	0.00282794	0.00311118	0.00970442	0.00296304
Zirconium Zr	<	<	<	<	<	0.00006731

Table D-6. Metals Analysis – July 30th – August 5th – Mass by Volume

Metal	Site E-01 Cruise	Site E-1 No Cruise	Site E-2 Cruise	Site E-2 No Cruise	Site E-3 Cruise	Site E-3 No Cruise
	Amount (micrograms/cubic metre) (< indicates no detectable levels)					
Aluminum	0.02199095	0.03540569	0.02550484	0.03167839	0.02426080	0.03072197
Antimony Sb	0.00029415	0.00021075	0.00025225	0.00023829	0.00035840	0.00021944
Arsenic As	0.00050425	0.00018265	0.00046245	0.00026632	0.00053760	0.00028802
Barium Ba	0.00252126	0.00133474	0.00210205	0.00110734	0.00344614	0.00233158
Beryllium Be	<	<	<	<	<	<
Boron B	0.01260628	0.02950474	0.01961911	0.04625606	0.01378455	0.04526004
Cadmium Cd	0.00007003	0.00007025	0.00007007	0.00005607	0.00008271	0.00002743
Calcium Ca	0.11065511	0.17421848	0.07567371	2.46698999	0.11854711	0.22355716
Chromium Cr	0.00182091	0.00238848	0.00168164	0.00224272	0.00220553	0.00205727
Cobalt Co	0.00008404	<	0.00007007	<	0.00008271	<
Copper Cu	0.00168084	0.00115209	0.00168164	0.00135965	0.00220553	0.00150867
Iron Fe	0.02521256	0.03231472	0.01961911	0.03784587	0.03997519	0.05211762
Lead Pb	0.00154077	0.00133474	0.00140136	0.00140170	0.00179199	0.00098749
Magnesium Mg	0.02801395	0.03231472	0.02802730	0.06587985	0.03446137	0.04526004
Manganese Mn	0.00067233	0.00102564	0.00057456	0.00131760	0.00089600	0.00090520
Molybdenum Mo	0.00019610	0.00012645	0.00018218	0.00014017	0.00026191	0.00019201
Nickel Ni	0.00462230	0.00182648	0.00434423	0.00182221	0.00454890	0.00260588
Phosphorus P	<	0.01123990	<	0.01541869	0.01102764	0.01234365
Potassium K	0.07983976	0.04074464	0.06166006	0.03504247	0.06478737	0.04937459
Selenium Se	0.00015408	0.00012645	0.00016816	0.00016820	0.00019298	0.00019201
Silver Ag	<	<	0.00002803	<	0.00002757	<
Sodium Na	0.18629277	0.21917808	0.20880337	0.27753637	0.24122958	0.36619487
Strontium Sr	0.00077038	0.00040745	0.00068667	0.00130358	0.00085464	0.00049375
Tellurium Te	<	<	<	<	<	<
Thallium Tl	<	<	<	<	<	<
Tin Sn	0.00140070	0.00196698	0.00138735	0.00091110	0.00165415	0.00192012
Titanium Ti	0.00098049	0.00125044	0.00078476	0.00112136	0.00151630	0.00164582
Vanadium V	0.00980488	0.00393397	0.00952928	0.00420510	0.01061410	0.00507461
Zinc Zn	0.00882439	0.01236389	0.00630614	0.14858008	0.00937349	0.01440092
Zirconium Zr	<	<	<	<	<	<

Table D-7. Metals Analysis – September 18th – 23rd – Mass by Volume

Metal	Amount (micrograms/cubic metre) (< indicates no detectable levels)					
	Site F-1 Cruise	Site F-1 No Cruise	Site F-2 Cruise	Site F-2 No Cruise	Site F-3 Cruise	Site F-3 No Cruise
Aluminum	0.02179265	0.13846058	0.01848955	0.04276787	0.01238679	0.02958886
Antimony Sb	0.00014125	0.00018627	0.00005080	0.00016609	<	0.00020692
Arsenic As	0.00038339	0.00022766	0.00046732	0.00014533	0.00099500	0.00028968
Barium Ba	0.00082731	0.00134528	0.00067050	0.00105882	0.00069041	0.00128287
Beryllium Be	<	<	<	<	<	<
Boron B	0.01614270	0.01655732	0.02438182	0.08512052	0.00812249	0.02069151
Cadmium Cd	0.00002018	0.00004139	0.00004064	0.00006228	0.00002031	0.00004138
Calcium Ca	0.13519512	0.23594180	0.25194547	0.15986049	0.21321529	0.17587784
Chromium Cr	0.00201784	0.00269056	0.00223500	0.00228372	0.00284287	0.00268990
Cobalt Co	<	<	<	<	<	<
Copper Cu	0.00086767	0.00184200	0.00089400	0.00122491	0.00069041	0.00186224
Iron Fe	0.01816054	0.05588095	0.01422273	0.03114165	0.01624497	0.03724472
Lead Pb	0.00112999	0.00206966	0.00128005	0.00141175	0.00113715	0.00204846
Magnesium Mg	0.08071351	0.04967196	0.10971819	0.04775053	0.08731674	0.04759047
Manganese Mn	0.00036321	0.00142807	0.00034541	0.00089273	0.00042643	0.00115872
Molybdenum Mo	0.00010089	0.00024836	0.00010159	0.00024913	0.00010153	0.00028968
Nickel Ni	0.00242141	0.00248360	0.00243818	0.00170241	0.00203062	0.00167601
Phosphorus P	<	0.02069665	0.03657273	0.01660888	0.01624497	0.01862236
Potassium K	0.04842810	0.06002028	0.06501818	0.06020720	0.05076554	0.05172878
Selenium Se	0.00014125	<	<	<	<	<
Silver Ag	<	<	0.00004064	<	<	<
Sodium Na	0.62956536	0.32286773	0.90212731	0.44221147	0.64776835	0.29175029
Strontium Sr	0.00050446	0.00045533	0.00075177	0.00035294	0.00056857	0.00041383
Tellurium Te	<	<	<	<	<	<
Thallium Tl	<	<	<	<	<	<
Tin Sn	0.00046410	0.00153155	0.00589227	0.00145328	0.00040612	0.00142771
Titanium Ti	0.00042375	0.00151086	0.00052827	0.00103806	0.00046704	0.00140702
Vanadium V	0.00524638	0.00351843	0.00447000	0.00332178	0.00527962	0.00351756
Zinc Zn	0.00484281	0.01034832	0.00304773	0.00809683	0.00324899	0.00786277
Zirconium Zr	<	<	<	<	<	<

Table D-8. Vanadium and Nickel Levels in $PM_{2.5}$ at Topaz Station - 2006

Dichotomous Sampler Concentrations (µg/m3) at VICTORIA - 923 TOPAZ NAPS No. 100304

Date	Category	Vanadium	Detection Limit.	Nickel	Detection Limit
23-Jan-06	off season	0.0020	0.0027	0.0049	0.0043
29-Jan-06	off season	--	0.0027	0.0070	0.0045
04-Feb-06	off season	0.0005	0.0029	0.0033	0.0048
10-Feb-06	off season	0.0007	0.0030	0.0054	0.0049
22-Feb-06	off season	0.0044	0.0027	0.0079	0.0047
28-Feb-06	off season	0.0013	0.0035	0.0016	0.0052
06-Mar-06	off season	--	0.0032	0.0067	0.0046
12-Mar-06	off season	--	0.0025	0.0076	0.0045
18-Mar-06	off season	0.0003	0.0029	0.0074	0.0047
24-Mar-06	off season	0.0015	0.0028	**0.0087**	0.0046
11-May-06	cruise ship present	0.0007	0.0031	0.0069	0.0045
17-May-06	no cruise ships	0.0065	0.0037	0.0093	0.0049
23-May-06	no cruise ships	0.0050	0.0034	0.0088	0.0048
29-May-06	no cruise ships	0.0025	0.0031	0.0084	0.0047
04-Jun-06	no cruise ships	0.0027	0.0033	**0.0111**	0.0048
10-Jun-06	cruise ship present	0.0143	0.0039	**0.0176**	0.0051
16-Jun-06	cruise ship present	0.0077	0.0024	0.0055	0.0041
22-Jun-06	cruise ship present	0.0021	0.0031	0.0060	0.0042
28-Jun-06	no cruise ships	0.0119	0.0116	--	0.0026
04-Jul-06	no cruise ships	**0.0144**	0.0117	--	0.0026
10-Jul-06	no cruise ships	0.0148	0.0116	--	0.0026
16-Jul-06	no cruise ships	0.0000	0.0124	--	0.0026
22-Jul-06	cruise ship present	**0.0209**	0.0119	0.0061	0.0026
28-Jul-06	cruise ship present	0.0184	0.0115	--	0.0025
03-Aug-06	cruise ship present	--	0.0123	--	0.0026
21-Aug-06	no cruise ships	--	0.0125	--	0.0026
27-Aug-06	no cruise ships	--	0.0126	--	0.0026
02-Sep-06	cruise ship present	--	0.0126	--	0.0026
08-Sep-06	cruise ship present	--	0.0128	--	0.0027
14-Sep-06	cruise ship present	--	0.0125	--	0.0026
20-Sep-06	no cruise ships	--	0.0126	--	0.0026
26-Sep-06	no cruise ships	--	0.0122	--	0.0026
02-Oct-06	no cruise ships	--	0.0122	--	0.0025
08-Oct-06	no cruise ships	--	0.0123	--	0.0026
14-Oct-06	cruise ship present	--	0.0123	--	0.0026
20-Oct-06	no cruise ships	--	0.0121	--	0.0025
26-Oct-06	no cruise ships	--	0.0125	--	0.0026
01-Nov-06	off season	--	0.0125	--	0.0025
07-Nov-06	off season	--	0.0126	--	0.0026
13-Nov-06	off season	--	0.0124	--	0.0026
25-Nov-06	off season	0.0032	0.0024	0.0007	0.0045
01-Dec-06	off season	0.0046	0.0027	0.0012	0.0045
07-Dec-06	off season	0.0010	0.0023	0.0042	0.0041
13-Dec-06	off season	0.0018	0.0029	0.0060	0.0047
19-Dec-06	off season	0.0030	0.0029	0.0055	0.0048
25-Dec-06	off season	**0.0062**	0.0027	0.0043	0.0044
31-Dec-06	off season	0.0014	0.0026	--	0.0042
Average cruise		0.0107		0.0084	
Average no cruise		0.0072		0.0094	
Average off season		0.0023		0.0051	
Average All samples		0.0055		0.0065	

Bold denotes maximum level in category, data provided by BC Ministry of Environment

APPENDIX E. TECHNICAL DETAILS: VOLATILE ORGANIC COMPOUNDS SAMPLING

Measurement Approach

Membrane introduction mass spectrometry (MIMS) is a powerful technique with demonstrated capabilities as an on-line monitor. It has been reviewed several times in the recent literature, including environmental and process control applications[49] [50] [51]. MIMS uses a semi-permeable membrane to introduce analyze mixtures from samples (air, water, slurries etc.) to a mass spectrometer, where they can be resolved based upon their masses, or by using advanced techniques such as tandem mass spectrometry (MS/MS). The advantage of using this approach over conventional analytical techniques is that the sample can be directly measured in a continuous fashion (via flowing the sample past the membrane). This eliminates sample preparation and chromatographic resolution, giving an effective analytical duty cycle that is limited only by the analyte transport rates through the membrane. The membrane rejects the bulk sample, and by using a hydrophobic membrane material such as polydimethylsiloxane (PDMS, or Silicone™), hydrophobic organic analytes are actually concentrated in the membrane from the sample in an online fashion. MIMS has been shown to have detection limits in the parts-per-trillion (pptrv) for volatile organic compounds (VOCs) in air[52], and by heating the membrane, semi-volatile organic compounds can also be detected[53]. Although the study presented in this report deals primarily with VOC measurements, we have developed a substantially improved MIMS interface that allows both VOC and SVOC measurements at pptrv levels with one interface[54]. The work presented in this report used an in-house constructed MIMS-MS/MS system to monitor atmospheric contaminants in real-time at field locations in the Victoria, BC harbour airshed and environs obtained over two field studies in the summer of 2007.

[49] R. C. Johnson, R. G. Cooks, T. M. Allen, M. E. Cisper and P. H. Hemberger, *Mass Spectrom. Rev.*, 2000, **19**, 1-37
[50] R. A. Ketola, T. Kotiaho, M. E. Cisper and T. M. Allen, *J. Mass Spectrom.*, 2002, **37**, 457-476.
[51] A. M. Llamas, C. B. Ojeda and F. S. Rojas, *Appl. Spectrosc. Rev.*, 2007, **42**, 345-367
[52] M. E. Cisper, C. G. Gill, L. E. Townsend and P. H. Hemberger, *Anal.Chem.*, 1995, **67**, 1413-1417.
[53] T. M. Allen, M. E. Cisper, P. H. Hemberger and C. W. Wilkerson, Jr., *Int. J. Mass Spectrom.*, 2001, **212**, 197-204.
[54] A. J. Thompson, A. S. Creba, R. M. Ferguson, E. T. Krogh and C. G. Gill, *Rapid Commun. Mass Spectrom.*, 2006, **20**, 2000-2008.

Methods

The MIMS-MS/MS system used for this work has been described elsewhere[55]. Briefly, a capillary hollow fibre polydimethylsiloxane (PDMS) membrane was mounted co-axially inside 0.25" OD stainless steel flow cell interface. Helium carrier gas (99.999% pure) was continuously passed through the center of the membrane (1.0 mL /min) for all experiments to carry analytes to the mass spectrometer. The MIMS interface was mounted inside a temperature controlled oven (70^{o}C). In addition, a 5.0 m X 0.25" OD stainless steel sample pre-heating coil and a small permeation cell were also placed in the oven, connected in-line and upstream of the interface. The permeation cell provided a continuous, trace infusion of toluene-d8 internal standard, allowing continuous, on-line quantitation throughout all real-time measurement runs. A quadrupole ion trap tandem mass spectrometer (Thermo-Fisher GCQ™) was used to obtain the presented MIMS-MS/MS data. Figure E.1 is a schematic diagram of the MIMS-MS/MS apparatus. For the field studies, we used this system installed in a mobile laboratory equipped with on-board AC power (provided at cost by CANTEST Ltd., Burnaby, BC) to allow measurements from both fixed and mobile locations. The sample inlet stream was positioned on the exterior of this vehicle at 2.5 m height, opposite the exhaust to minimize inadvertent sampling of the emissions from the vehicle during motion and the generator when at fixed locations. To further reduce any potential contamination from the generator exhaust, a 5m flexible exhaust pipe was used to direct these emissions downwind during fixed location deployments.

To quantify analytical signals obtained by this work, instrumental response factors were obtained for all analytes using the system shown in Figure E.1.

Target analytes for this study included the BTEX suite (benzene, toluene, ethylbenzene and xylenes) and naphthalene, known to be present during fossil fuel use. Gaseous standards of the analytes were prepared by using gravimetrically calibrated permeation tubes in a 99.999% pure dilution airflow (via a model 450 VICI Metronics Dynacalibrator™ System). Table E.1 gives the relevant MS/MS transitions used by the mass spectrometer and the permeation rates of the analyte tubes. All analytical signals were background subtracted based upon a baseline determined using UHP (99.999% pure) air. It is known that calibration of toluene and/or benzene in the presence of ethylbenzene and xylene can yield a positive analytical bias. This can be somewhat corrected by using chemical ionization in the mass spectrometer, or through numeric deconvolution via experimentally determined interference factors[56]. Because this study was designed to look for trends in temporal variations of the analytes rather than to

[55] A. J. Thompson, A. S. Creba, R. M. Ferguson, E. T. Krogh and C. G. Gill, *Rapid Commun. Mass Spectrom.*, 2006, **20**, 2000-2008.

[56] R. M. Ferguson, A. S. Creba, A. J. Thompson, D. Kim, C. D. Simpson, C. W. LeBlanc, E. T. Krogh and C. G. Gill, Pacifichem 2005, Honolulu, HI, 2005.

provide absolute quantitation, the reader is cautioned to use the observed trends rather than specific concentrations, especially in the case of benzene and toluene. Because a suitable naphthalene permeation tube was not available at the time of the study, surrogate standards prepared in aqueous solution were used to determine an approximate response factor for this work (this is possible because MIMS works equally well for both aqueous and gas phase samples).

Figure E.1 Schematic diagram of MIMS-MS/MS system. The depicted apparatus was used for in lab system calibrations. The Dynacalibrator was removed during field deployments to minimize power consumption.

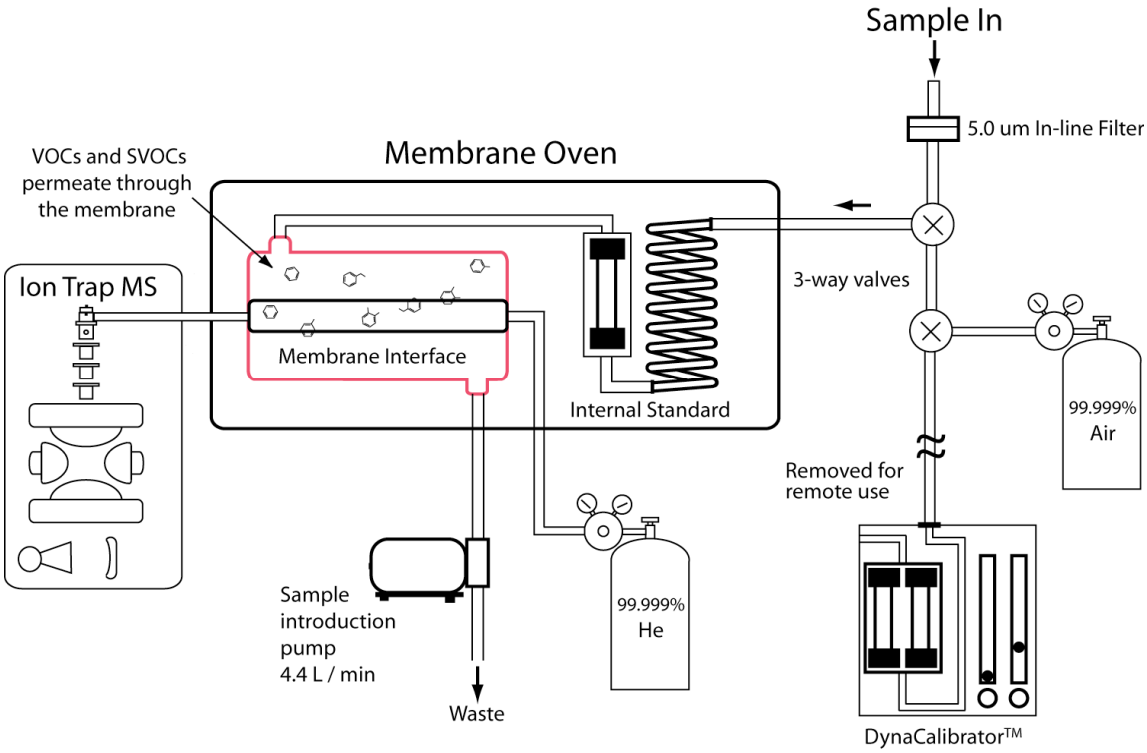


Table E.1 Analyte permeation tube emission rates and MS/MS transitions used

Target Molecules	Permeation Rate (ng/min)	MS/MS Transitions
Benzene	321	78 → 50, 51, 52
Toluene	189	91 → 65
Ethylbenzene	-	106 → 77, 79, 91
Xylenes	838	106 → 77, 79, 91
Naphthalene[a]	-	128
Toluene-d8*	589	100 → 70

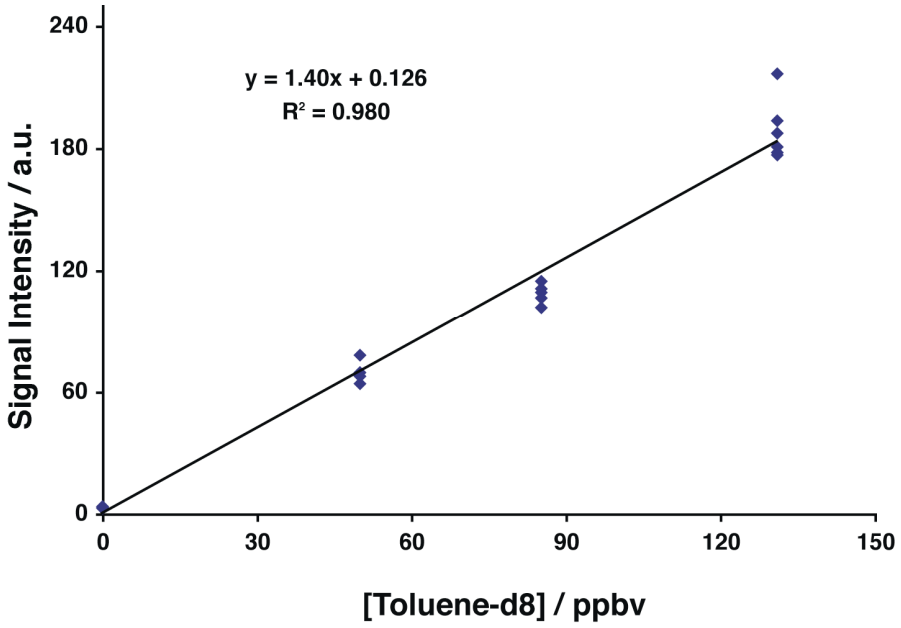
*Deuterated Internal Standard

[a] Selected Ion Monitoring Mode only

Note: Ethylbenzene and xylene are structural isomers and are not resolvable by the MS/MS techniques used.

To rule out major variations in analytical signals due to matrix effects, the variation of the internal standard signal was studied over a multi-day period by assessing calibration reproducibility for binary mixtures of the different analytes. The pooled calibration plot for the internal standard is given in Figure E.2. The results suggest multi-day calibration can be achieved for a variety of analytes, with an estimated bias of approximately +/- 12% regardless of the analyte species present in a given calibration mixture.

Figure E.2 Pooled calibration data for toluene D-8 obtained over 5 days for separate binary mixtures of each analyte in 99.999% pure air



The data used to generate the overall toluene-d8 response were also utilized to determine MIMS-MS/MS instrumental response factors for all analytes in binary mixtures over a range of (ppbv) concentration levels relative to the continuously infused toluene-d8 internal standard. Response factors were calculated in the standard manner (Equation 1) at different ppbv concentration levels using steady state MIMS-MS/MS signals and then averaged to give overall response factors (Table E.2).

$$RF = \frac{Signal_X / [X]}{Signal_{Toluene_{D-8}} / [Toluene_{D-8}]} \quad (1)$$

Table E.2 Experimentally determined response factors (RF) for a variety of gas phase analytes versus Toluene-d8 in 99.999% pure air.

Compound	Response Factor (RF)
Benzene	1.28
Toluene	2.36
Xylenes[b]	0.96
Naphthalene*	2.10

*obtained using aqueous standards

[b]used for the combined ethylbenzene/xylene trace (not resolvable by MS/MS)

APPENDIX F. PRECIPITATION TRENDS

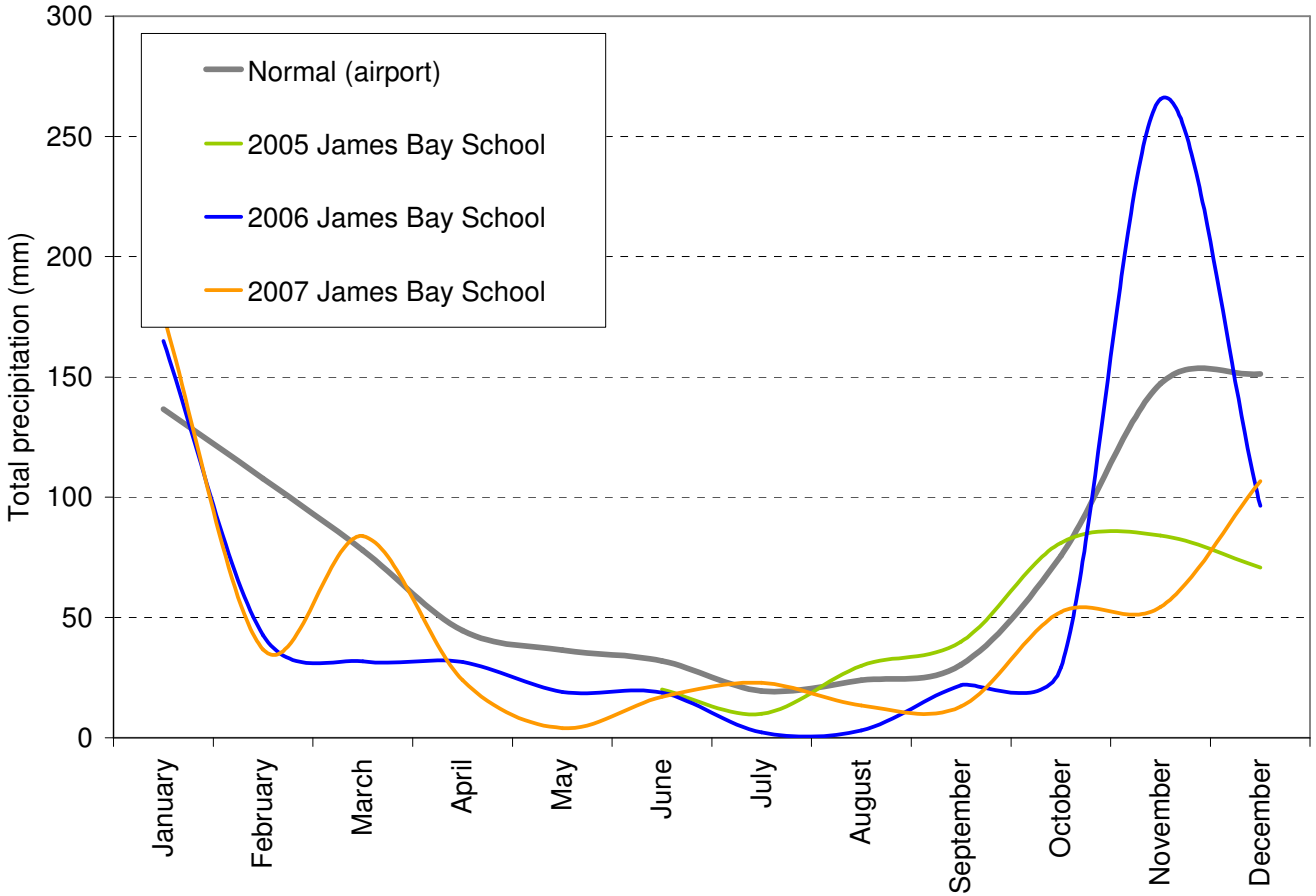
Table F-1. Precipitation trends -average monthly precipitation (mm)

Airport	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average (1941-2007)	144.0	98.0	75.3	43.8	33.1	30.2	18.6	25.1	33.2	84.1	138.5	148.8
Climate Normals (1977 – 2007)	136.6	107.8	78.0	44.5	36.5	32.0	19.5	23.9	30.4	75.7	147.2	151.2
2005	184.4	38.1	98.2	46.6	38	29.2	16	24.7	13.6	83	108.8	110.4
2006	222.2	67.3	47.6	42.8	35	40.6	6.9	2.4	29.7	45.6	351.9	157.1
2007	203.8	62	124.8	38.6	20	36.1	32	36.8	36.4	77.8	99.6	219.1

James Bay School	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	no data	no data	no data	no data	no data	20.1	9.9	30.0	39.9	81.0	84.1	70.8
2006	164.9	42.7	31.7	31.5	19.1	18.8	2.3	3.0	21.8	29.2	265.4	96.5
2007	175.5	36.8	83.8	23.9	4.1	17.0	22.9	13.5	13.0	52.3	54.3	106.7

S.J. Willis School (Topaz Station)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	no data	no data	no data	no data	no data	21.1	1.3	3.3	23.6	38.6	278.6	113.3
2007	205.0	72.6	98.0	27.4	8.9	20.1	25.7	14.7	14.2	55.6	63.5	142.8

Figure F-1. Average monthly precipitation at James Bay Elementary School, 2005, 2006 and 2007



APPENDIX G. NO, NO_2 AND SO_2 RESULTS FOR SHOAL POINT

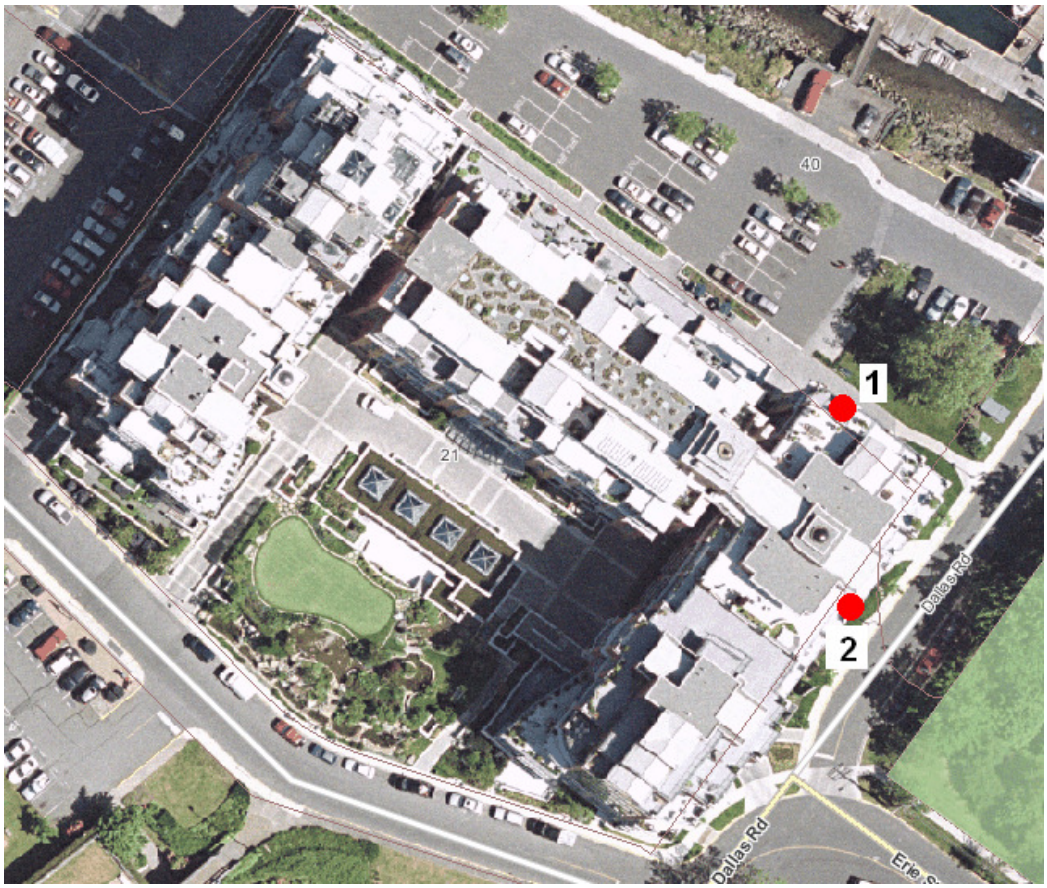
Field sampling was conducted at Shoal Point from August 8th to 22nd, 2007. Two Ogawa passive diffusion samplers were installed on the north and east side of the complex and were used to measure ambient concentrations of NO, NO_2, and SO_2 over 14 consecutive days. Shoal Point is located on the northeastern tip of James Bay, at the corner of the entrance to the Inner Harbour. The Victoria Clipper and Coho passenger ferries pass this location on their way into the harbour, as do float planes during landing and take-off.

Sampler 1 was attached to a fourth floor balcony railing, facing Fisherman's Wharf and a parking lot. During the sampling period, large refrigeration trucks were parked in the parking lot, and ran continuously. The other sampler was attached to a sixth floor balcony on the East side of the building, directly adjacent to Dallas Rd. Heavy car and tour bus traffic are present on this road, transporting tourist traffic to the wharf. A third sampler was also used as a field blank for quality control purposes. This sampler was momentarily exposed on site and was then stored at the UVic Spatial Sciences Laboratory for the remainder of the sampling period.

Figure G-1 includes the sampler locations, monitoring results, wind speed and direction, precipitation, and presence of cruise ships during the sampling period.

Figure G-1. Shoal Point Monitoring Results – August 8th – August 22nd , 2007 (consecutive 14-day exposure)

(a) Sampling Sites:



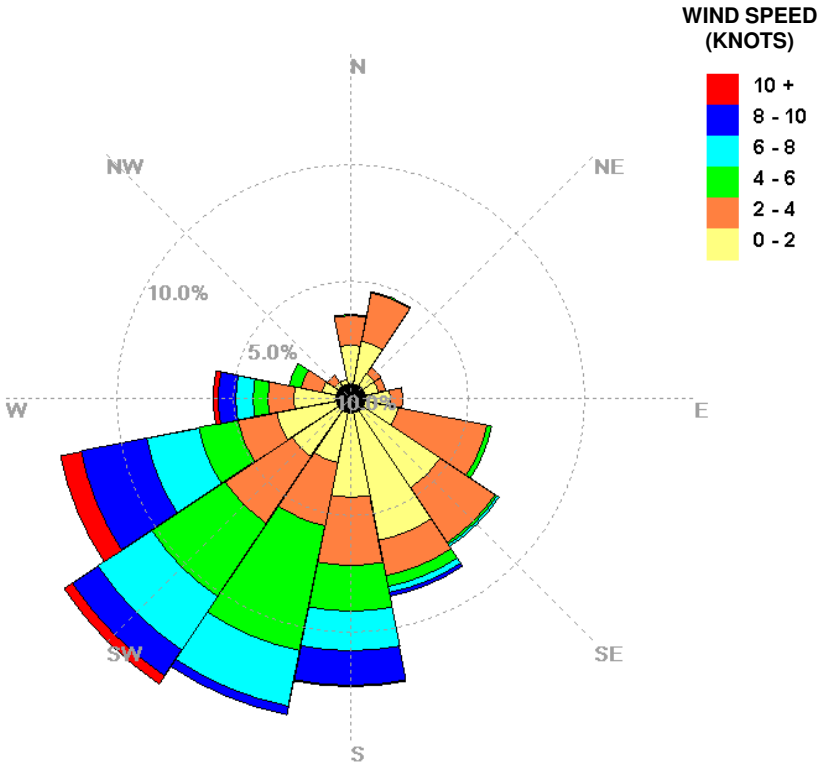
(b) Sampling results:

14-day average concentrations (µg/m^3) of NO, NO_2 and SO_2

Site	NO	NO_2	SO_2
1	16.0	18.7	2.1
2	21.6	24.6	0.0
*Field Blank	1.9	0.4	16.5

*Pollutant concentrations measured by the field blank sampler are indicative of the impact handling and transport have had on concentration levels, and were used to adjust Site 1 and 2 values as presented in the table.

(c) Windrose (Ogden Point data):



(d) Precipitation (James Bay School):

Date	Total Precipitation (mm)	Notes
August 12th	0.51	Non-cruise day
August 16th	1.02	1 cruise ship present
August 18th	0.51	3 cruise ships present
August 19th	6.35	Non-cruise day
August 21st	3.81	Non-cruise day

(e) Cruise Ship Presence:

Total sample hours: 336

	No Ships	**1 Ships**	**2 Ships**	**3 Ships**
Hours	291	23	10	12
Percent of total sample hours	87	7	3	4