SULFUR DIOXIDE MONITORING AND ANALYSIS OF THE IMPACT OF FUEL SULFUR CONTENT REGULATION

JAMES BAY, VICTORIA, BRITISH COLUMBIA

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EXECUTIVE SUMMARY

Previous studies[1,2] have established that short term peaks of sulfur dioxide (SO_2) associated with cruise ship emissions in the James Bay neighbourhood could reach or exceed the current World Health Organization (WHO) 10-minute and 24-hour guidelines for ambient SO_2 (500 μg/m^3 and 20 μg/m^3 respectively). [3] Since 2009, the British Columbia Ministry of Environment and the Greater Victoria Harbour Authority have provided funds and partnered with Island Health, the James Bay Neighbourhood Association and researchers at the University of Victoria Geography Department to monitor and analyse local SO_2 levels.

The objective of this report is to compare measured levels of SO_2 in 2014 and 2015 to current guidelines, and to provide an analysis of SO_2 levels in light of increasingly stringent regulations on marine fuel sulfur content since 2009.

Overall, air quality guidelines were infrequently exceeded at the air quality monitoring Station in James Bay and at the regional air quality monitoring Station located at Topaz Avenue, approximately 4.5 km downwind of the cruise ship terminal:

- The World Health Organization 10-minute average guideline of 500 μg/m^3 was not exceeded at either Station in 2014 or 2015.
- The British Columbia Interim 1-hour average guideline of 200 μg/m^3 (based on the 99th percentile value of daily 1-hour maximums) was not exceeded at either Station in 2014 and 2015, although when considering data only from the cruise ship season, the guideline was exceeded in James Bay in 2014 (202 μg/m^3).
- The World Health Organization daily (24-hour average) guideline of 20 μg/m^3 was exceeded twice at each Station in 2014, but not at any time in 2015.
- In general, more than 99 percent of hours on record at both Stations fall within the Island Health risk category of 'Good' category (92 μg/m^3 or less). In 2014, eleven hours in James Bay had SO_2 levels in the 'Moderate' category (93 to 197 μg/m^3) and 3 in the 'Unhealthy for sensitive groups' category (198 to 485 μg/m^3), while 4 hours were in the 'Moderate' category at Topaz Station. All hours in 2015 were in the 'Good' category at both Stations.

[1] James Bay Air Quality Study Phase I (Feb 2008) and James Bay Air Quality Study Phase II (Feb 2009). http://www.viha.ca/mho/air_quality.htm

[2] James Bay Air Quality Study Phase III: MAML – Mobile Air Monitoring Laboratory Data Collection Report – James Bay Air Quality Study June – August 2009 (Jan 2010). http://www.viha.ca/mho/air_quality.htm

[3] WHO (World Health Organization), 2006. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide – Global Update 2005. Summary of risk assessment. Available at: http://www.who.int/phe/health_topics/outdoorair_aqg/en/

While the number of cruise ships calling at Ogden Point has been increasing, SO_2 levels of concern have been decreasing since peaking in 2009 in James Bay. The same is true for Topaz Station, although there is some variation over time.

Normal 10-minute, hourly and daily SO_2 levels were established by identifying all measured data over a number of years without cruise ships present, and all SO_2 levels recorded above the normal maximums were analysed. The results show that:

- The number of 10-minute averages above normal has decreased from 463 in 2009 to 14 in 2015 in James Bay, and from 267 to 40 at Topaz Station.
- The number of hourly averages above normal has decreased from 120 in 2009 to 7 in 2015 in James Bay, and from 61 to 4 at Topaz Station.
- The number of daily averages above normal has decreased from 25 in 2009 to zero in 2015 in James Bay, and from 9 to zero at Topaz Station.

The regulation of sulfur content in marine fuels has become increasingly stringent over time, first dropping from 1.5% to 1% in 2010, then to 0.1% in 2015. Cruise ships are required to use fuels that comply with the sulfur content limit, or to use control technologies that reduce emissions to a level consistent with using compliant fuel. The analyses presented in this report support the conclusion that the regulation has been effective in reducing ambient levels of SO_2 related to cruise ship emissions in the Victoria region.

1. Background and Objectives

1.1 Introduction

The breakwater and docks at Ogden Point in Victoria (Figure 1) were constructed in 1914-1917, establishing a deep-water port facility to service commercial and industrial activities.[4] Grain and forest products were shipped for many years, although activity dwindled by the early 1980s,[5] and a fish processing plant operated from the late 1920s to 1990.[6] Passenger vessels also used the terminal, and in the 1990s, between 20 and 50 ships arrived annually. Since 2000, the main activity at Ogden Point is passenger ships. The number of cruise passengers arriving at Ogden Point increased from around 50,000 per year in 2000, to over 400,000 per year by 2009. In 2015, 227 cruise ships visited Victoria, bringing 533,000 passengers (Figure 2).[7]

Predominant winds tend to blow from the southwest quadrant during the cruise ship season, from the terminal across the primarily residential neighbourhood of James Bay, as shown in Figure 1 (using 2012 winds as an example). Depending on weather conditions, emissions from cruise ships approaching and departing from the terminal can be detected in the James Bay area.

In 2006, residents of James Bay approached the Vancouver Island Health Authority (now Island Health) with concerns about local air quality. Since then, the British Columbia Ministry of Environment (BC MoE) has been working collaboratively with Island Health (IH), the Greater Victoria Harbour Authority (GVHA), the James Bay Neighbourhood Association (JBNA), and researchers at the University of Victoria's Geography department, to identify and characterize emissions sources and pollutants of concern. Long-term data have been collected at four monitoring Stations in the region from 2006 onward (Figure 3). The BC MoE monitoring Station at Topaz Avenue has been in operation for several decades and is part of the National Air Pollution Surveillance (NAPS) network. With shared funding from study partners (IH and GVHA), monitoring with the BC MoE Mobile Air Monitoring Laboratory (MAML) was conducted in 2009, and at a location[8] on Erie Street from 2011 onward.

[4] Victoria Heritage Foundation: http://www.victoriaheritagefoundation.ca/HReg/JamesB/Dallas187.html
[5] ibid
[6] Ogden Point Enhancement Society: http://www.ogdenpoint.org/about-opes/our-history/
[7] ibid
[8] This site was moved from a 2nd floor rooftop to a 5th floor rooftop approximately 100m westward prior to the cruise ship season in 2014,

Figure 1. Study Area and Predominant Wind Direction (May-September 2012)

Figure 2. Cruise Ship Traffic at Ogden Point 2000 - 2015

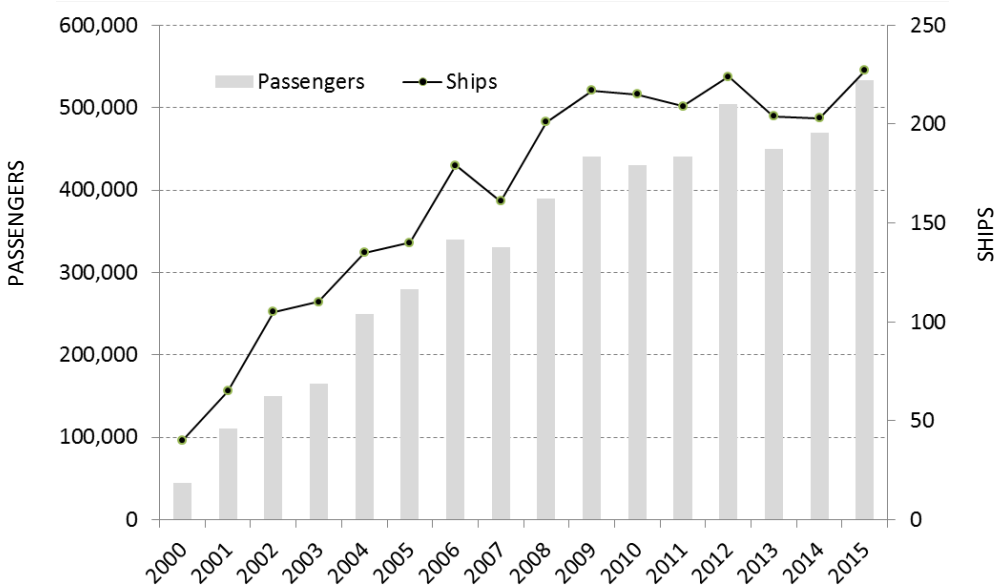
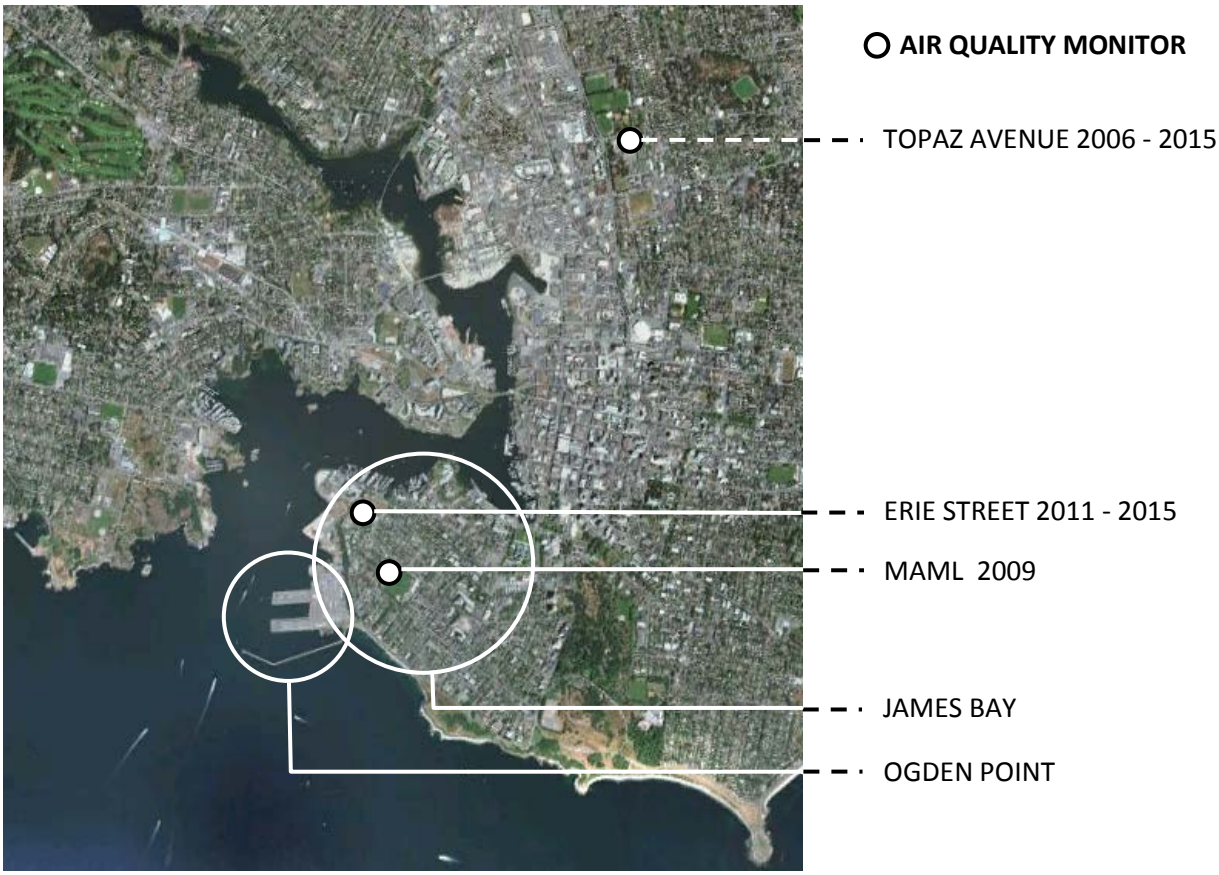


Figure 3. Monitoring Locations



1.2 Previous Reports

Previous studies[9,10] have identified sulfur dioxide (SO_2) as an air pollutant of local concern associated with the use of sulfur-containing fuels by cruise ships, and established that short term peaks in the James Bay neighbourhood could reach or exceed the current World Health Organization (WHO) 10-minute and 24-hour guidelines[11] for ambient SO_2 (500 $\mu g/m^3$ and 20 $\mu g/m^3$ respectively)[12]. In accordance with recommendations made by IH in

[9] James Bay Air Quality Study Phase I (Feb 2008) and James Bay Air Quality Study Phase II (Feb 2009). http://www.viha.ca/mho/air_quality.htm

[10] James Bay Air Quality Study Phase III: MAML – Mobile Air Monitoring Laboratory Data Collection Report – James Bay Air Quality Study June – August 2009 (Jan 2010). http://www.viha.ca/mho/air_quality.htm

[11] WHO (World Health Organization), 2006. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide – Global Update 2005. Summary of risk assessment. Available at: http://www.who.int/phe/health_topics/outdoorair_aqg/en/

[12] The WHO guideline for SO_2 is relatively new and is substantially more restrictive than the Provincial Air Quality Objectives. MoE has begun the process of developing new provincial guidelines to reflect current standards and science but this process takes time. VIHA has used the

2010[13], the GVHA partnered with the BC MoE to establish a community monitoring site in the James Bay neighbourhood (referred to as the Erie Station in this report) to measure levels of SO_2 from 2011 to present. The Erie site was selected after considering the results of previous dispersion modelling work and also taking into account security, power, temperature controlled environment, and communications requirements. Previous studies and reports include:

Phase 1 Report on the Results of Field Monitoring in 2007[14]

Phase 2 Report on the Results of CALPUFF Air Quality Dispersion Modelling 2007[15]

MAML - Mobile Air Monitoring Laboratory Data Collection Report 2009[16]

Sulfur Dioxide Levels - 2011 James Bay[17]

Sulfur Dioxide Levels - 2012 James Bay[18]

Sulfur Dioxide Levels - 2013 James Bay[19]

1.3 Objectives of this Report

This report provides an analysis of SO_2 levels in 2014 and 2015, in relation to current ambient air quality guidelines (Table 1). In addition, analyses of changes in SO_2 levels related to the regulation of marine fuel sulfur content are included.

WHO guideline in their health assessment as it better reflects current understanding of health effects of SO_2.

[13] Health Review and Response to James Bay Phase III Air Quality Monitoring (June 2010). http://www.viha.ca/mho/air_quality.htm

[14] James Bay Air Quality Study Team (2008). James Bay Air Quality Study Phase I. Report on the Results of Field Monitoring in 2007. Prepared for the Vancouver Island Health Authority.

[15] James Bay Air Quality Study Team (2009). James Bay Air Quality Study Phase II Report on the Results of CALPUFF Air Quality Dispersion Modelling 2007. Prepared for the Vancouver Island Health Authority.

[16] Poplawski K and Setton E. (2010). MAML – Mobile Air Monitoring Laboratory Data Collection report – James Bay Air Quality Study June – August 2009. Prepared for the Vancouver Island Health Authority and the British Columbia Ministry of Environment.

[17] Setton E. and Poplawski K. Sulfur Dioxide Levels – 2011 James Bay, Victoria, British Columbia. August 2012. Prepared for the British Columbia Ministry of Environment.

[18] Setton E, Poplawski K and Ma C. (2013). Sulfur Dioxide Levels – 2012 James Bay, Victoria, British Columbia. Prepared for the British Columbia Ministry of Environment.

[19] Setton E and Poplawski K. (2014). Sulfur Dioxide Levels – 2013 James Bay, Victoria, British Columbia. Prepared for the British Columbia Ministry of Environmnent.

Table 1. Current air quality guidelines for sulfur dioxide

Period	Organization		Level (μg/m^3)
10-minute average	World Health Organization guideline		500
1-hour average*	BC Ministry of Environment Interim Objective		200
1-hour average	Island Health Risk Guide	Good	92 or less
		Moderate	93 to 197
		Unhealthy for sensitive groups	198 to 485
		Unhealthy	486 and higher
24-hour average	World Health Organization		20
Maximum Acceptable Annual hourly average	Canada		30

* calculated as the 99th percentile of the daily maximum 1-hour average over one calendar year.

2. Methods

Analyses of SO_2 levels for 2014 and 2015. Raw 10-minute SO_2 data from Topaz and Erie Stations were provided by BC MoE staff. The 10-minute data were adjusted to account for instrument drift using the same adjustment levels applied to the 1-hour data, as supplied by the BC MoE. Remaining negative values in the raw data were deleted after adjustment, or when no adjustment value was provided.

All 1-hour and 24-hour SO_2 data from Topaz and Erie Stations for 2014 and 2015 were downloaded from the BC MoE website and adjusted from Pacific Standard Time to Pacific Daylight Savings Time.[20]

All instruments were maintained and calibrated by MoE staff. Instrument calibration and audit records for Topaz and Erie Stations are available on request to BC MoE.

All measured levels were converted from parts per billion (ppb) to micrograms per cubic meter ($\mu g/m^3$) as follows:

SO_2 ppb * 2.62 = SO_2 ($\mu g/m^3$)

Analyses of changes in air quality over time. For the analyses presented in Section 4, we relied on SO_2 data used for previous reports as well as the 2014 and 2015 SO_2 data described above. In addition, hourly and 24-hour average data for nitric oxide (NO), nitrogen dioxide (NO_2) and fine particulates ($PM_{2.5}$) measured at Topaz Station from 2006 onward were downloaded from the BC MoE website and adjusted from Pacific Standard Time to Pacific Daylight Savings Time.[21]

Measured levels of NO and NO_2 were converted from parts per billion (ppb) to micrograms per cubic meter ($\mu g/m^3$) as follows:

NO ppb * 1.3 = NO ($\mu g/m^3$)

NO_2 ppb * 1.9 = NO_2 ($\mu g/m^3$)

Fine particulates ($PM_{2.5}$) were reported by MoE in ($\mu g/m^3$) and did not require conversion; however, two kinds of instruments were used to measure $PM_{2.5}$ at Topaz Station. From 2006 to 2009, $PM_{2.5}$ was measured with a TEOM (Tapered Element Oscillating Microbalance) instrument. In 2009, a transition occurred to a Federal Equivalency Method Beta Attenuation Mass (FEM BAM) 1020 instrument in order to more accurately measure

[20] Data download at http://envistaweb.env.gov.bc.ca/
[21] Ibid.

$PM_{2.5}$ during the winter months.[22] For this report, the TEOM data were used for 2006 to 2009, and the FEM BAM 1020 data were used from 2010 onward.

Cruise ship arrivals and departures (recorded as first line and last line in Pacific Daylight Savings Time) for 2006 to 2015 from Western Stevedoring Company Ltd. and were used to identify data from periods without and without cruise ships present. Monitoring data were coded as 'cruise ship present' using the arrivals and departures data as follows:

- All 10-minute averages on a given day were coded as 'cruise ship present' if a ship had a recorded first or last line at any point within the 24-hour period. Given frequent departures near midnight and the possibility of higher SO_2 levels immediately after last line but technically on the following day, un-coded data were sorted from high to low, and beginning with the highest 10 minute level, were checked against the cruise ship schedule and coded as 'cruise ship present' if within 1 hour of a departure. All remaining 10-minute intervals were coded as 'cruise ship not present' and used to identify the normal maximum measured without cruise ships present.
- Hourly data were coded as 'cruise ship present' if a ship had a recorded first or last line at any point within the hour. All un-coded data were then sorted from high to low, and beginning with the highest hourly level, each was checked against the schedule and coded as 'cruise ship present' if within 1 hour +/- of an arrival or departure, to account for emissions while manoeuvering near dock. This was repeated until the highest level was encountered at which no cruise ship was present +/- 2 hours of arrival or departure. All remaining hourly intervals were coded as 'cruise ship not present' and used to identify the normal maximum measured without cruise ships present.
- 24-hour data were coded as 'cruise ship present' if a ship had a recorded first or last line at any point within the 24-hour period. All remaining 24-hour intervals were coded as 'cruise ship not present' and used to identify the normal maximum measured without cruise ships present.

Wind speed and direction data for Topaz Station were downloaded from the BC MoE website.[23] Ogden Point wind speed and direction data were provided by the Greater Victoria Harbour Authority.

[22] Senes Consultants. 2014. Air Quality in the Capital Regional District 2012. Prepared for the BC Ministry of Environment. http://www.bcairquality.ca/reports/pdfs/crd_2012_report.pdf
[23] Data download at http://envistaweb.env.gov.bc.ca/

3. SO_2 Levels

3.1 Ten-minute SO_2 Levels

The World Health Organization (WHO) 10-minute guideline of 500 μg/m^3 has been exceed four times during the years included in this report: three times in 2009 when SO_2 was being measured by the BC MoE MAML, and once in 2012, at Erie Station (Table 2). Ten-minute levels above 50% of the guideline occurred more frequently in James Bay (17 times) than at Topaz Station (2 times) (Table 3). Details for the 17 intervals reported in 2014 at Erie Station are provided in Table 4.

Health Canada has recently completed an assessment of the health effects of exposure to SO_2.[24] Based on extensive reviews of epidemiological studies, the assessment recommends that:

> "the current National Ambient Air Quality Objectives be revised or new Ambient Air Quality Objectives or Standards be introduced with consideration of the following: 1. The strongest evidence of causality was between short term SO_2 exposures and respiratory morbidity, based largely on the 5-10 minute controlled human exposure studies. A 10-min human health reference concentration of 67 ppb [175 μg/m^3] has been identified in the assessment. " (pg. 123)

This suggests that a future Canadian 10-minute guideline could be lower than the current World Health Organization's 10-minute guideline of 500 μg/m^3. If a 10-minute guideline level of 175 μg/m^3 was in fact adopted, it would have been exceeded 45 times in James Bay in 2014, and only twice in 2015; while at Topaz Station, it would have been exceeded five times in 2014, and at no time in 2015.

Table 2. Number of 10-minute intervals at or above WHO guideline
(during cruise season May 1st to Sept 30th)

	SO_2 (μg/m^3)						
	2009	2010	2011	2012	2013	2014	2015
MAML/Erie Station	3*	NA**	0	1	0	0	0
Topaz Station	0	NA**	0	0	0	0	0

* SO_2 was measured at MAML Station May 26th to August 24th only.

**SO_2 was not measured in James Bay in 2010 so no data are provided for this year.

[24] Health Canada (2016). Human Health Risk Assessment for Sulphur Dioxide Analysis of Ambient Exposure to and Health Effects of Sulphur Dioxide in the Canadian Population. Available at http://publications.gc.ca/collections/collection_2016/sc-hc/H144-29-2016-eng.pdf

Table 3. Number of 10-minute average levels above 50% of WHO Guideline
(during cruise season May 1st to Sept 30th)

	SO_2 ($\mu g/m^3$)						
	2009	2010	2011	2012	2013	2014	2015
MAML/Erie Station	59*	NA**	17	6	1	17	0
Topaz Station	1	NA**	0	2	0	0	0

* Measured at MAML Station

**SO_2 was not measured in James Bay in 2010 so no data are provided for this year.

Table 4. 10-minute average levels above 50% of WHO guideline – Erie Station 2014

Date	Time	SO_2 ($\mu g/m^3$)	Ships Present (up to 1 hour +/-)
09/05/2014	8:00 PM	292	GOLDEN PRINCESS, WESTERDAM, ZUIDERDAM
	8:10 PM	408	
	8:40 PM	362	
	8:50 PM	492	
	9:00 PM	334	
30/05/2014	6:50 PM	253	GOLDEN PRINCESS, WESTERDAM, NORWEGIAN JEWEL
11/07/2014	7:00 PM	317	GOLDEN PRINCESS, WESTERDAM, NORWEGIAN JEWEL
	7:10 PM	451	
12/07/2014	6:30 PM	285	AMSTERDAM, NORWEGIAN PEARL, GRAND PRINCESS
26/07/2014	2:20 PM	471	STAR PRINCESS
	2:30 PM	327	
15/08/2014	6:50 PM	329	GOLDEN PRINCESS, WESTERDAM, NORWEGIAN JEWEL
29/08/2014	7:10 PM	271	GOLDEN PRINCESS, WESTERDAM, NORWEGIAN JEWEL
	8:00 PM	276	
	8:10 PM	300	
	8:20 PM	325	
09/09/2014	10:30 PM	295	CARNIVAL MIRACLE

3.2 Hourly SO_2 Levels

The BC Interim Objective for SO_2 is 200μg/m^3, measured as the 99th percentile of the daily maximum hourly averages over a full year; however, SO_2 was measured only during the cruise ship season at MAML Station (2009) and Erie Station (2011-2014) in James Bay. In this report, the 99th percentile of daily maximum hourly averages has been calculated using data only from the cruise ship season to facilitate comparisons between years and monitoring sites. In addition, when possible, the 99th percentile of daily maximum hourly averages are provided for both the cruise ship season and the entire year: Topaz Station (2006 – 2015) and Erie Station (2015)(Table 5).

The 99th percentile of daily 1-hour maximums has varied at Erie Station, but was substantially lower in 2015 compared to previous years. At Topaz Station, the highest values occurred in 2008 and 2009, while the lowest values have occurred in 2011, 2013, and 2015. Notably, the BC Interim Objective was not exceeded at Topaz Station in any year, regardless of the period analyzed (cruise ship season only versus full year).

Table 5. Annual 99th percentile of daily maximum 1-hour average SO_2 levels 2006- 2015
(during cruise season May 1st to Sept 30th)

	SO_2 (μg/m^3)									
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Erie Station (May 1 – Sept 30)	--	--	--	**413***	--	**204**	175	133	**202**	48
Erie Station (full year)										46
Topaz Station (May 1 – Sept 30)	69	71	121	128	112	60	80	39	108	47
Topaz Station (full year)	60	53	106	116	78	51	72	37	42	51

* SO_2 was measured at MAML Station May 26th to August 24th only. This level would likely be lower if more data were available.

Island Health (formerly Vancouver Island Health Authority) has defined risk categories for ambient SO_2 levels (Appendix A). In general, more than 99 percent of the hours on record at all Stations fall within the 'Good' category (Tables 6 and 7). In James Bay, 2009 had the highest number of hours in the 'Moderate' and 'Unhealthy for Sensitive Groups' categories. In 2015, all hours recorded at Erie Station were in the 'Good' category. Topaz Station has occasionally had hours in the 'Moderate' category, with the highest number of hours seen in 2008 and 2009.

Table 6. Hourly SO_2 levels by Health Risk Guide Categories – MAML and Erie Stations
(during cruise season May 1st to Sept 30th)

		Number of Hours (May 1 – Sept 30)			
	Valid Hours (May 1 – Sept 30)	Good	Moderate	Unhealthy for Sensitive Groups	Unhealthy
		0 to 92 μg/m^3	93 to 198 μg/m^3	198 to 485 μg/m^3	> 485 μg/m^3
2009*	2,012	1,944	37	31	0
2010	**				
2011	3,415	3,463	19	2	0
2012	3,561	3,574	11	2	0
2013	3,636	3,574	8	0	0
2014	3,568	3,554	11	3	0
2015	3,528	3,528	0	0	0

* Measured at MAML Station May 26th to August 24th only.

**SO_2 was not measured in James Bay in 2010 so no data are provided for this year.

Table 7. Hourly SO_2 levels by Health Risk Guide Categories – Topaz Station
(during cruise season May 1st to Sept 30th)

		Number of Hours (May 1 – Sept 30)			
	Valid hours (May 1 – Sept 30)	Good	Moderate	Unhealthy for Sensitive Groups	Unhealthy
		0 to 92 μg/m^3	93 to 198 μg/m^3	198 to 485 μg/m^3	> 485 μg/m^3
2006	3,672	3,672	0	0	0
2007	3,672	3,672	0	0	0
2008	3,672	3,663	9	0	0
2009	3,672	3,662	10	0	0
2010	3,672	3,667	5	0	0
2011	3,672	3,672	0	0	0
2012	3,672	3,671	1	0	0
2013	3,672	3,672	0	0	0
2014	3,490	3,486	4	0	0
2015	3,499	3,499	0	0	0

3.3 Daily SO_2 Levels

The World Health Organization guideline of 20 ug/m^3 has been exceeded a number of times during the years included in this report (Table 8). Most notably, the highest number of days exceeding this guideline was observed at MAML Station in 2009, between May 26th and August 24th of that year. In all other years at Erie Station, only a few days exceeded the guideline, with the exception of 2015 when no 24-hour average level was above 20 ug/m^3.

All days with 24-hour average levels above the guideline were associated with the presence of cruise ships. As previous reports have shown, the days on which the guideline was exceeded at stations in James Bay (MAML or Erie) are often not the same days when the guideline was exceeded at Topaz Station, suggesting weather conditions play a role in where peak SO_2 levels are experienced.[25] As an example, Tables 9 and 10 show the dates and cruise ships present on the days the guideline was exceeded in 2014 at Erie Station and Topaz Station respectively.

Table 8. Number of 24-hour averages at or above the WHO guideline
(during cruise season May 1st to Sept 30th)

	SO_2 ($\mu g/m^3$)									
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
MAML/Erie Station	--	--	--	14*	--	2	3	1	2	0
Topaz Station	0	1	1	4	3	0	0	0	2	0

* Measured at MAML Station May 26th to August 24th only.

Table 9. 24-hour average levels at or above guidelines – ERIE Station 2014

Date	SO_2 (ug/m3)	Ships Present
5/9/2014	24	GOLDEN PRINCESS, WESTERDAM, ZUIDERDAM
7/26/2014	20	STAR PRINCESS, GRAND PRINCESS, AMSTERDAM

Table 10. 24 hour average levels at or above guidelines – TOPAZ Station 2014

Date	SO_2 (ug/m3)	Ships Present
7/11/2014	23	GOLDEN PRINCESS, WESTERDAM, NORWEGIAN JEWEL
7/12/2014	22	AMSTERDAM, NORWEGIANPEARL, GRAND PRINCESS

[25] Setton E. and Poplawski K.(2012). Sulfur Dioxide Levels – 2011 James Bay, Victoria, British Columbia. August 2012. Prepared for the British Columbia Ministry of Environment.

3.4 Annual SO_2 Levels

New Canadian ambient air quality standards for SO_2 are currently in development. The previous Canadian standard for annual average hourly SO_2 is a maximum desirable level of 30 ug/m^3. Based on data from the cruise ship season only, the highest annual average hourly SO_2 level recorded at any Station during the years included in this report is 12 μg/m^3, observed at MAML Station in 2009 (Table 11). This would be lower if a full year of data were available. Similarly, a high of 4.9 μg/m^3 was observed at Topaz Station in 2009 during the cruise ship season. The lowest level observed was at Erie Station in 2015, based on a full year of data.

Table 11. Annual average hourly SO_2 2006- 2015
(during cruise season May 1st to Sept 30th)

	SO_2 (μg/m^3)									
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Erie Station (May 1st –Sept 30th)	--	--	--	12*	--	4.2	3.4	2.8	2.7	0.8
Erie Station (full year)										0.6
Topaz Station (May 1st – Sept 30th)	2.5	1.4	4.3	4.9	4.1	3.0	3.5	2.2	2.6	2.9
Topaz Station (full year)	2.1	1.4	3.4	3.4	3.2	3.3	2.7	2.2	2.6	2.9

* SO_2 was measured at MAML Station May 26th to August 24th only.

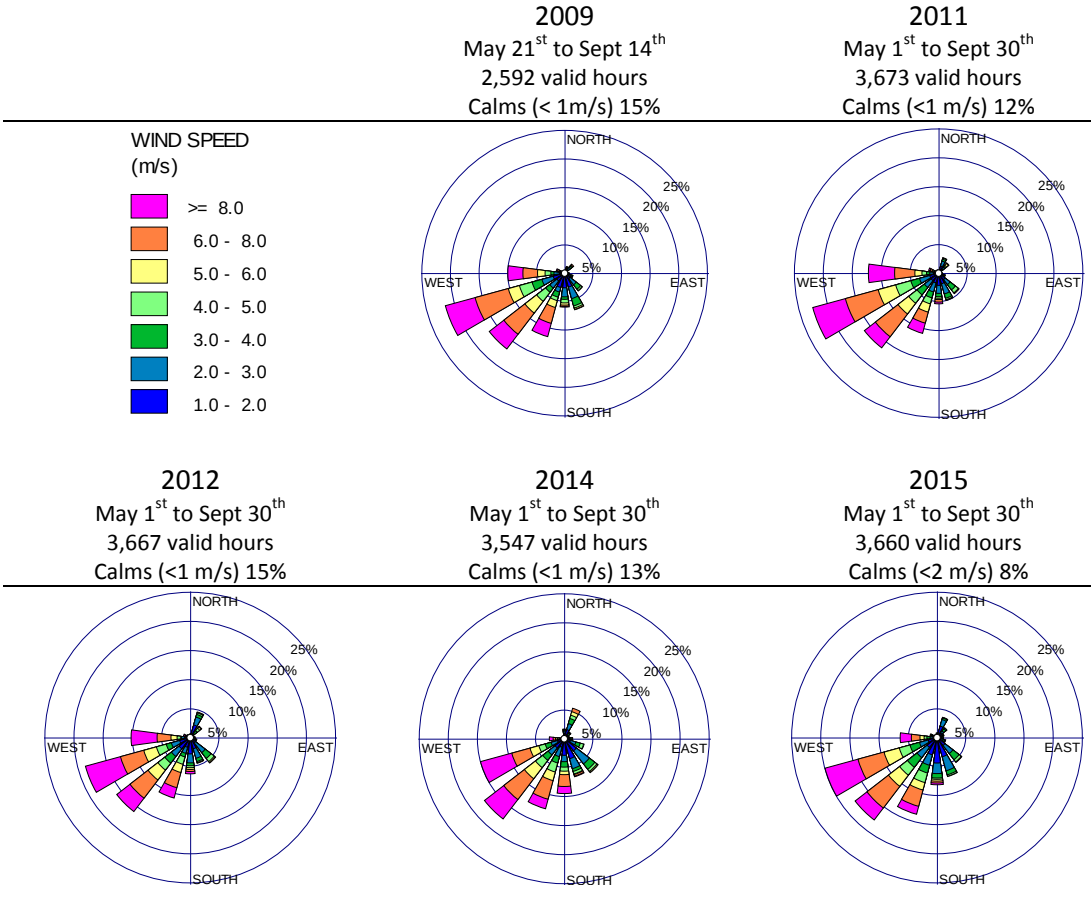
4. Annual Changes in Air Quality 2006 - 2015

Air quality is improving in the James Bay neighbourhood, with respect to SO_2 related to cruise ship emissions. In addition to changes in Station locations in James Bay, this may be influenced by changes in wind speed and direction and/or to increasingly stringent regulatory limits on fuel sulfur content for ocean-going vessels, including cruise ships.

4.1 Wind Speed and Direction – Ogden Point

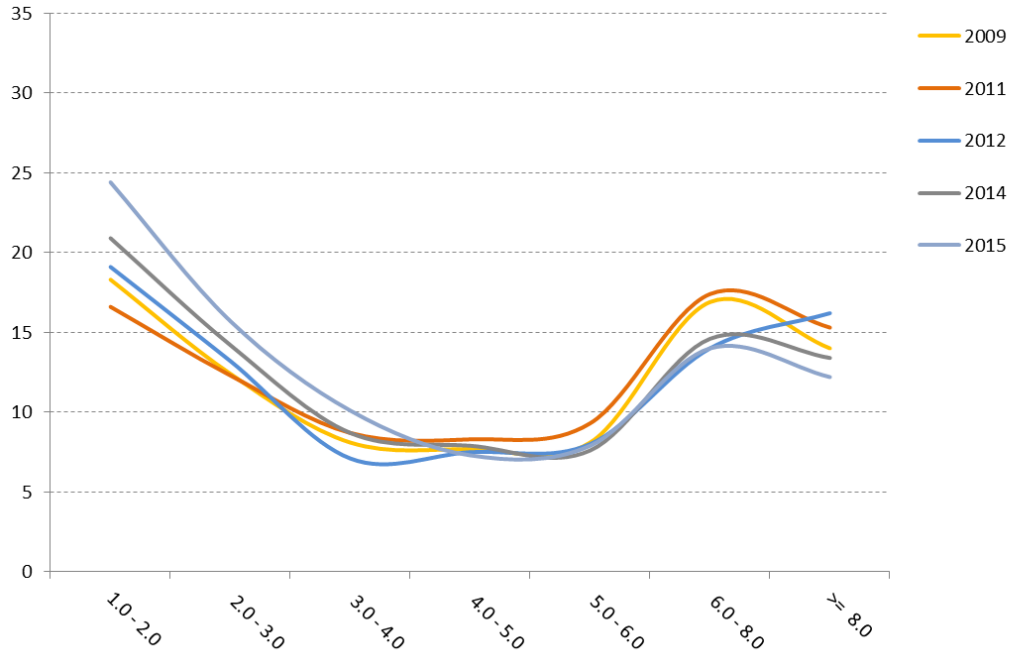
Wind speed and direction were relatively similar from 2009 to 2014 at Ogden Point (Figures 4 and 5). It is unlikely that the decrease in SO_2 levels measured in 2015 at Erie Station is due to changes in wind speed and direction. Wind speed and direction were also similar from 2009 to 2015 at Topaz Station (Figures 6 and 7).

Figure 4. Wind speed and direction - Ogden Point (May 1st to September 30th)



NOTE: SO_2 data not collected in 2010; 2013 omitted due to equipment failure

Figure 5. Percent of hours by wind speed- Ogden Point (May 1st to September 30th)



Wind Speed (m/s)	Percent of hours (May 1st – September 30th)				
	2009	2011	2012	2014	2015
Calms < 1.0	15	12	15	13	8
1.0 - 2.0	18	17	19	21	24
2.0 - 3.0	12	12	12	14	16
3.0 - 4.0	8	9	7	9	10
4.0 - 5.0	8	8	8	8	7
5.0 - 6.0	8	9	8	8	8
6.0 - 8.0	17	17	14	15	14
>= 8.0	14	15	16	13	12

Figure 6. Wind speed and direction - Topaz Station (May 1st to September 30th)

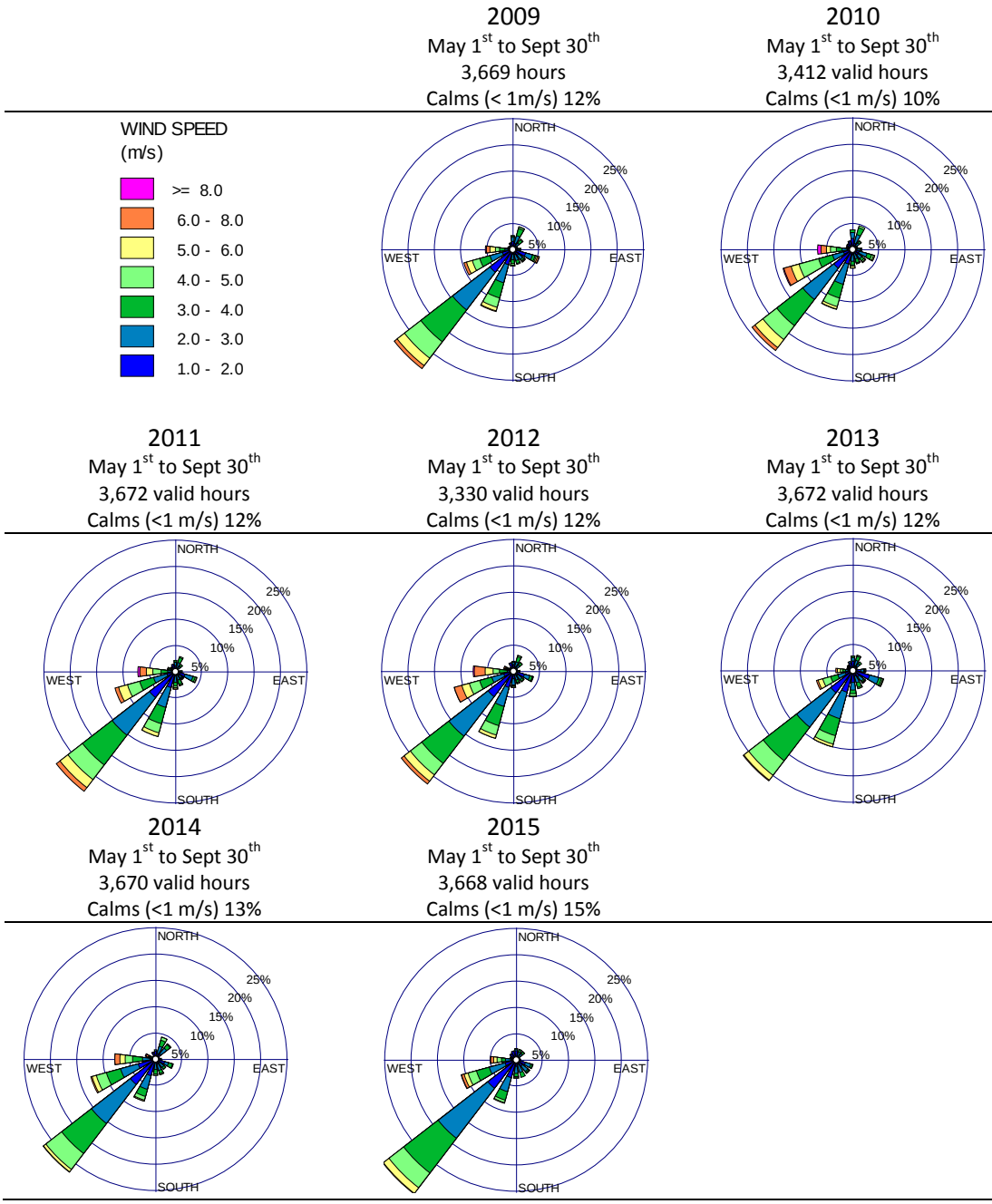
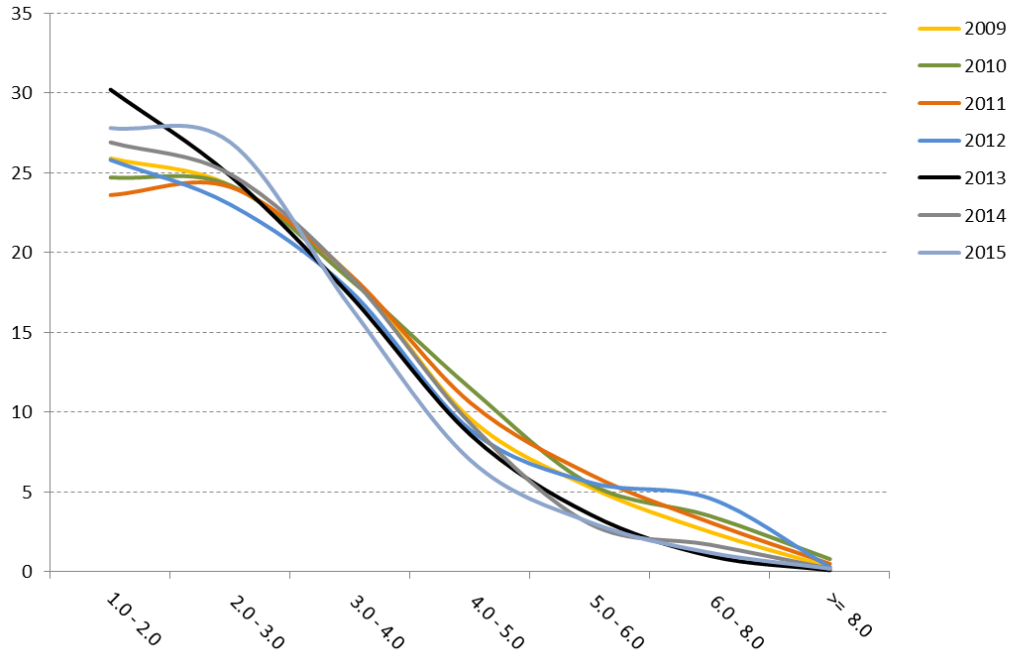


Figure 7. Percent of hours by wind speed- Topaz (May 1st to September 30th)



Wind Speed (m/s)	Percent of hours (May 1st – September 30th)						
	2009	2010	2011	2012	2013	2014	2015
Calms < 1.0	12	10	12	12	12	13	15
1.0 - 2.0	26	25	24	26	30	27	28
2.0 - 3.0	24	24	24	23	25	25	27
3.0 - 4.0	19	18	19	18	17	19	17
4.0 - 5.0	10	12	11	9	9	9	7
5.0 - 6.0	5	6	6	6	4	3	3
6.0 - 8.0	3	4	3	5	1	2	1
>= 8.0	0.3	1	0.5	0.3	0.1	0.2	0.2

4.2 Fuel Sulfur Content Regulations

In Canada, marine emissions to air currently fall under the International Maritime Organization (IMO) MARPOL Annex VI, which came into force on May 19, 2005. Specifically, fuel sulfur content is limited to 3.5 percent (35,000 ppm) globally as of January 1, 2012, with a reduction to 0.5 percent (5,000 ppm) to take place January 1st, 2020, subject to a feasibility review to be completed no later than 2018.[26]

Annex VI also allows for the establishment of emission control areas (ECAs), within which fuel sulfur content is further limited. Canada and the United States jointly applied to the IMO to establish the North American ECA, covering navigable waters within approximately 200 nautical miles of the coast. The North American ECA was adopted in March 2010, and although not enforceable at that time, fuel sulfur content was limited to 1.5 % (15,000 ppm). On August 1st, 2012, fuel sulfur content was further limited to 1 percent (10,000 ppm), and an additional reduction to 0.1 percent (1,000 ppm) came into effect as of January 1st, 2015 (Figure 5).[27]

Overall, this new regulatory environment is expected to reduce SO_2 emissions from ocean-going vessels by as much as 96 percent,[28] as there is a direct relationship between the sulfur content of the fuel and the amount of SO_2 produced in emissions. The US EPA notes:

> "Sulfur oxides (SO_X) emissions are generated during oil combustion from the oxidation of sulfur contained in the fuel. The emissions of SO_X from conventional combustion systems are predominantly in the form of SO_2. Uncontrolled SO_X emissions are almost entirely dependent on the sulfur content of the fuel and are not affected by boiler size, burner design, or grade of fuel being fired. On average, more than 95 percent of the fuel sulfur is converted to SO_2, about 1 to 5 percent is further oxidized to sulfur trioxide (SO_3), and 1 to 3 percent is emitted as sulfate particulate." [29]

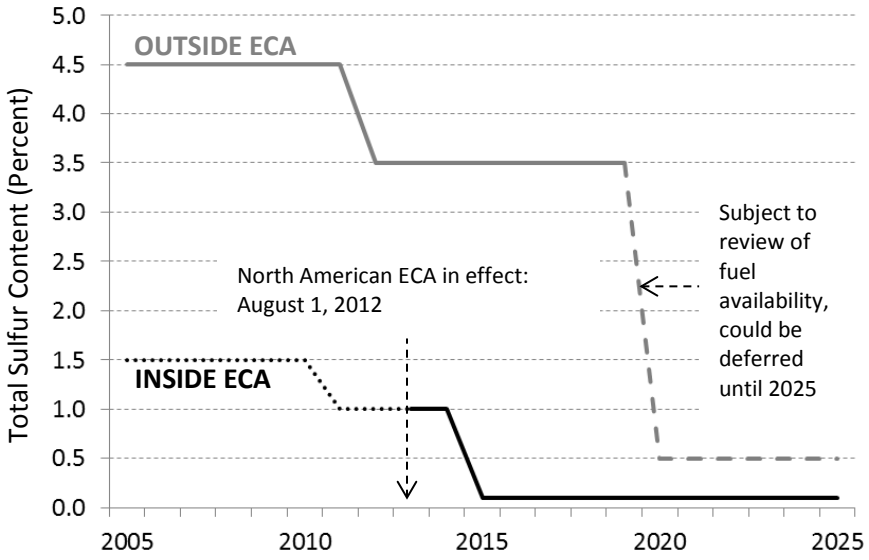
[26] International Maritime Organization. Sulfur Oxides (SOx) – Regulation 14. http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Sulfur-oxides-(SOx)-%E2%80%93-Regulation-14.aspx

[27] Transport Canada. Regulations for Vessel Air Emissions: 2015 Sulfur Emissions Standards – SSB No.:08/2014. http://www.tc.gc.ca/eng/marinesafety/bulletins-2014-08-eng.htm

[28] Government of Canada. Canada Gazette Vol. 146, No. 29 – July 21, 2012. Archived content. http://gazette.gc.ca/rp-pr/p1/2012/2012-07-21/html/reg2-eng.html#archived

[29] AP-42 (5th Edition) Vol 1: 1.3 Fuel Oil Combustion (Supplement E September 1999, corrected May 2010) https://www3.epa.gov/ttn/chief/ap42/ch01/final/c01s03.pdf

Figure 5. Fuel Oil Sulfur Limits



The switch to cleaner fuels or equivalent emissions control technology did not occur exactly on the specified dates. In Canada, the regulation became enforceable on January 1, 2013. Prior to this, cruise ships were not obligated to meet the ECA requirements, although it is generally reported by the Cruise Lines International Association that companies operating cruise ships on the west coast of North America have been complying with the fuel sulfur content limits since the North American ECA was adopted in 2010.[30] If this is the case, SO_2 levels measured in 2009 would indicate the impact of 1.5 percent sulfur content fuel; levels measured in 2010 to 2014 would indicate the impact of 1.0 percent sulfur content fuel; and levels measured in 2015 would indicate the impact of 0.1 percent sulfur content fuel.

In addition to the use of fuel meeting sulfur content regulations, as of May 2013 regulations have allowed for the use of scrubbers, alternative fuels, other technology and regional fuel averaging regimes to meet the emissions standards. More specifically, this policy allows for "the continued use of residual fuel…if the vessel is to be fitted with new technology or modified to use of alternative fuels that will result in improved air emissions within 3 years. This would require an exemption issued under Regulation 3 of MARPOL."[31]

Under this regulation, Carnival Corporation applied for flexibility while they developed new technology that would allow for using lower cost higher sulfur fuels, while still meeting the emission standard for SO_2 as well as realizing reductions in particulate matter ($PM_{2.5}$) and

[30] Personal communication, April 7th, 2016. Donna Spalding, Director Administration, Cruise Lines International Association – North West & Canada.
[31] New Regulations for Vessel Air Emissions: Proposing Alternative Compliance Options - SSB No.: 02/2013. https://www.tc.gc.ca/eng/marinesafety/bulletins-2013-02-eng.htm

black carbon emissions.[32] Information provided by Environment Canada[33] indicates that four cruise ships scheduled to arrive during the 2016 season have installed scrubbers. Assuming these four ships had scrubbers installed in time for the 2015 season, they would account for 42 out of the 206 cruise ship arrivals in that year (20.4 percent).

4.4 Approach to evaluating changes in air quality due to regulation

Previous studies have shown that elevated levels of SO_2 are relatively infrequent, usually occurring as short-term episodes over several hours.[34] Between episodes, SO_2 in the James Bay neighbourhood quickly returns to a general background level in the absence of any other major sources. Given the gradual shift to lower emissions via cleaner fuel or use of scrubbers, there should be fewer and fewer episodes of elevated SO_2 levels in the region. This report focuses on identifying and analysing these episodes on an annual basis from 2009 to 2015.

In order to identify episodes of elevated SO_2 associated with cruise ships, background levels of SO_2 were established first. In James Bay, data from days without cruise ships present between May 1st and September 30th in 2009, 2011, 2012 and 2013 were combined and the maximum observed was used as the upper bound of 'normal' levels. This was done for 10-minute, hourly and 24-hour averaging times. For Topaz Station, the same procedure for identifying the normal maximum was applied for 2011, 2012 and 2013 for 10-minute SO_2 data, and for 2006 – 2013 inclusive for hourly and 24-hour average SO_2, nitric oxide (NO), nitrogen dioxide (NO_2) and fine particulates ($PM_{2.5}$) as a means of establishing whether the trends seen in SO_2 were unique and therefore attributable to the regulation of fuel sulfur content. Given maximum normal levels without cruise ships present, all measured levels above the normal maximums were identified and analyzed for May 1st to September 30th 2009 – 2015, excluding 2010 in James Bay when no data were collected.

[32] US EPA. Ocean Vessels and Large Ships. North American Emission Control Area. https://www3.epa.gov/otaq/oceanvessels.htm

[33] Personal Communication, May 2016. Richard Holt and Jim Ly, Transportation Division, Environment Canada.

[34] See reports listed and referenced on page 11 of this report.

4.5 Ten-minute levels

Based on almost 26,700 10-minute intervals with no cruise ships present between May 1st and September 30th, the highest 10-minute average level of SO_2 measured in James Bay (MAML or Erie Stations) was 69 μg/m^3, while at Topaz, based on more than 25,500 10-minute intervals, the highest level measured was 45 μg/m^3 (Table 12 and Figures 6 and 7). These levels incorporate all sources of SO_2 emissions, other than cruise ships. At MAML/Erie Stations, this could include occasional ocean-going vessels other than cruise ships using Ogden Point Terminal as well as other land-based transportation sources. Notably, the maximum normal level of 69 μg/m^3 measured at MAML Station in 2009 occurred when the freighter *Pac Alnath* was in port.

Table 12. 10-minute SO_2 without cruise ships present
(during cruise season May 1st to Sept 30th)

	2009	2011	2012	2013	**All Years**
MAML/Erie Station					
Number of intervals	4,084*	7,224	7,057	8,293	26,658
Maximum level (μg/m^3)	69	50	59	67	**69**
Topaz Station					
Number of intervals	4,176*	6,814	6,657	7,920	25,567
Maximum level (μg/m^3)	45	31	45	27	**45**

* Includes June 1st to August 24th only.

At MAML/Erie Station, the highest SO_2 level above normal was observed in 2012 (636 μg/m^3), although the number of 10-minute intervals above normal has decreased in each year since 2009 at MAML/Erie Station, from a high of 463 intervals to a low of 14 intervals in 2015 (Table 13). At Topaz Station, the number of SO_2 levels above normal has also decreased, from a high of 267 in 2009, down to 40 in 2015, although there has been some variation in both the number of 10-minute intervals above normal and the maximum level observed between 2009 and 2015 (Table 13).

Table 13. 10-minute SO_2 above normal
(during cruise season May 1st to Sept 30th)

	2009	2011	2012	2013	2014	2015
MAML/Erie Station						
Number of intervals	463*	198	162	160	136	14
Maximum level (μg/m^3)	590	438	636	258	492	209
Topaz Station						
Number of intervals	267	95	99	42	89	40
Maximum level (μg/m^3)	312	124	269	85	280	109

* Includes June 1st to August 24th only.

Figure 6. MAML/ Erie Station 10-Minute SO_2 levels– days without cruise ships (May 1st to September 30th)

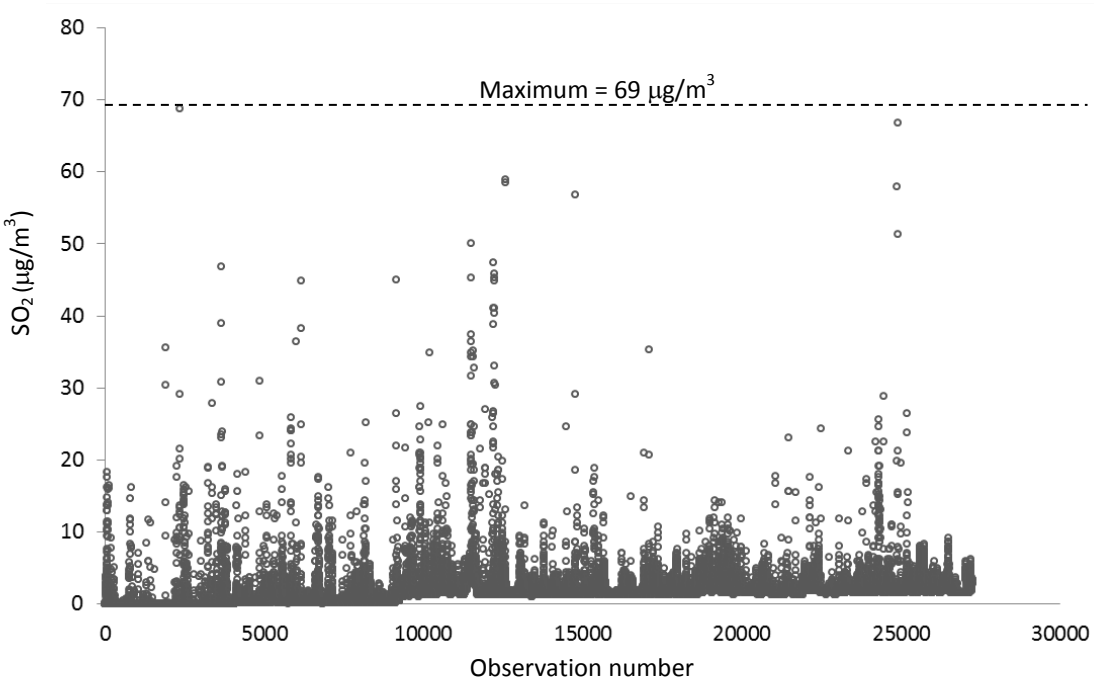
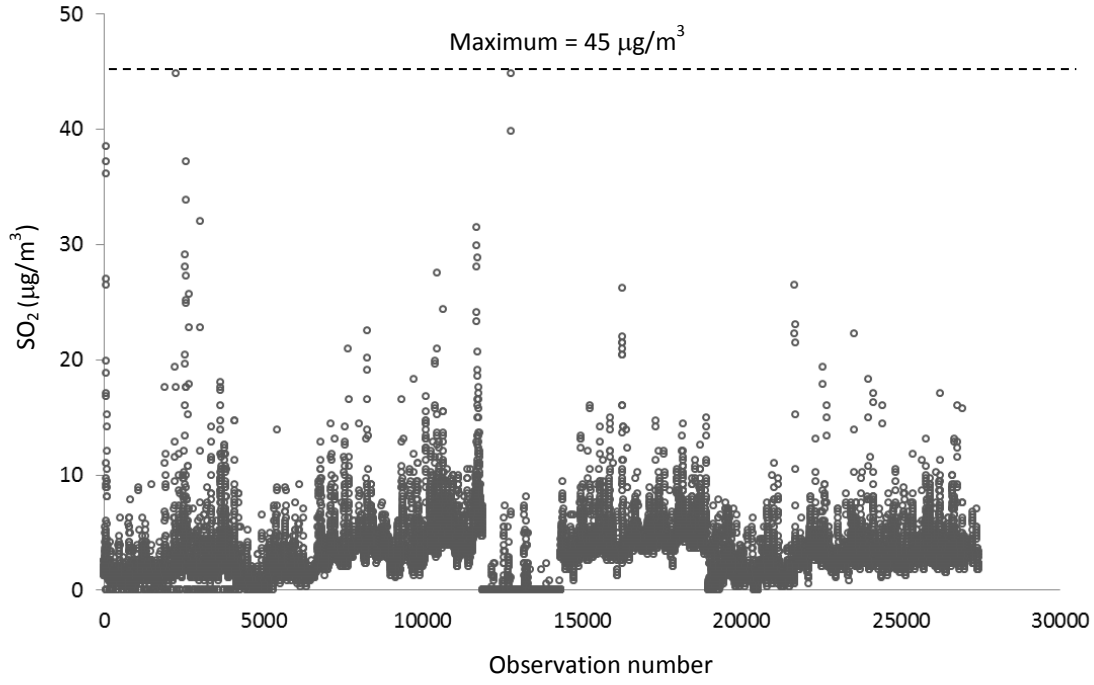


Figure 7. Topaz Station 10 Minute SO_2 levels– days without cruise ships (May 1st to September 30th)



The distribution of 10-minute SO_2 levels above normal at MAML/Erie Station shows 2015 to be a recognizable improvement over other years, with the lowest maximum, lowest number of intervals above normal, and the smallest range of levels above normal (Figure 8). At Topaz Station, 2013 has the lowest number of intervals above normal, the lowest maximum, and the smallest range, although 2015 is similar (Figure 9). It is reasonable to conclude that the number of ships operating under exemption and using higher sulfur fuels is declining, but when such a cruise ship does arrive, the magnitude of the elevated episode may be similar to pre-regulation. For example, 2014 was slightly worse than 2011.

Figure 8. MAML/Erie Station distribution of 10-Minute SO_2 levels above normal (May 1st to September 30th)

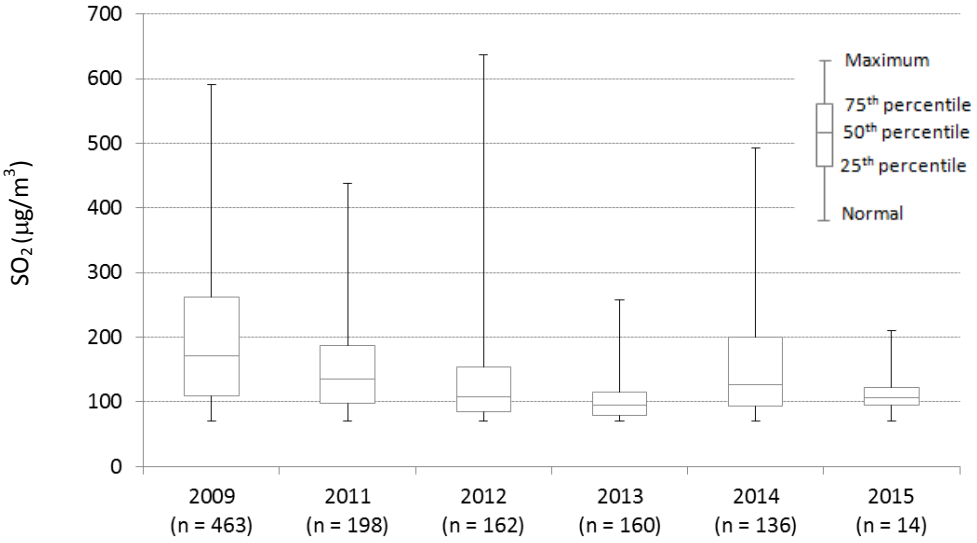
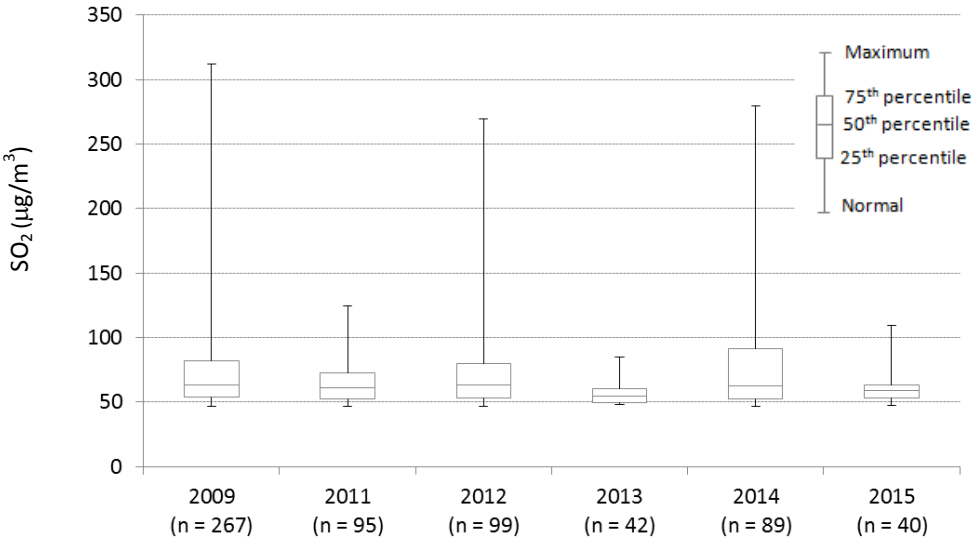


Figure 9. Topaz Station distribution of 10 Minute SO_2 levels above normal (May 1st to September 30th)



4.6 Hourly levels

Based on more than 10,000 hourly average intervals between May 1st and September 30th with no cruise ships present, the highest level of SO_2 measured in James Bay (MAML or Erie Stations) was 34 μg/m^3, while at Topaz, based on more than 21,000 hourly average intervals, the highest level measured was 44 μg/m^3 (Table 14 and Figures 10 and 11). These levels incorporate all sources of SO_2 emissions, other than cruise ships. At MAML/Erie Stations, this could include occasional ocean-going vessels other than cruise ships using Ogden Point Terminal.

Table 14. Hourly SO_2 without cruise ships present
(during cruise season May 1st to Sept 30th)

	2006	2007	2008	2009	2010	2011	2012	2013
MAML/Erie Station								
Number of intervals	--	--	--	1,350*	--	2,244	3,188	3,277
Maximum level (μg/m^3)	--	--	--	29	--	31	34	31
Topaz Station								
Number of intervals	2,737	2,970	2,777	2,583	2,547	2,563	2,562	2,602
Maximum level (μg/m^3)	29	39	34	30	44	31	21	28

* Includes June 1st to August 24th only.

At MAML/Erie Station, the highest SO_2 level above normal was observed in 2009 (448 μg/m^3), although the number of hourly intervals above normal has decreased since 2009 at MAML/Erie Station, from a high of 120 intervals to a low of 7 intervals in 2015 (Table 15). At Topaz Station, the number of hourly intervals with SO_2 levels above normal has also decreased, from a peak of 61 in 2009, down to 4 in 2015, although there has been some variation in both the number of hourly intervals above normal and the maximum level observed between 2009 and 2015 (Table 15).

Table 15. Hourly SO_2 above normal
(during cruise season May 1st to Sept 30th)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
MAML/Erie Station										
Number of intervals	--	--	--	120*	--	78	62	64	48	7
Maximum level (μg/m^3)	--	--	--	448	--	235	266	156	343	51
Topaz Station										
Number of intervals	19	12	35	61	32	9	11	2	12	4
Maximum level (μg/m^3)	76	87	144	168	123	66	126	46	129	59

* Includes June 1st to August 24th only.

Figure 10. MAML/ Erie Station Hourly SO_2 levels– days without cruise ships (May 1st to September 30th)

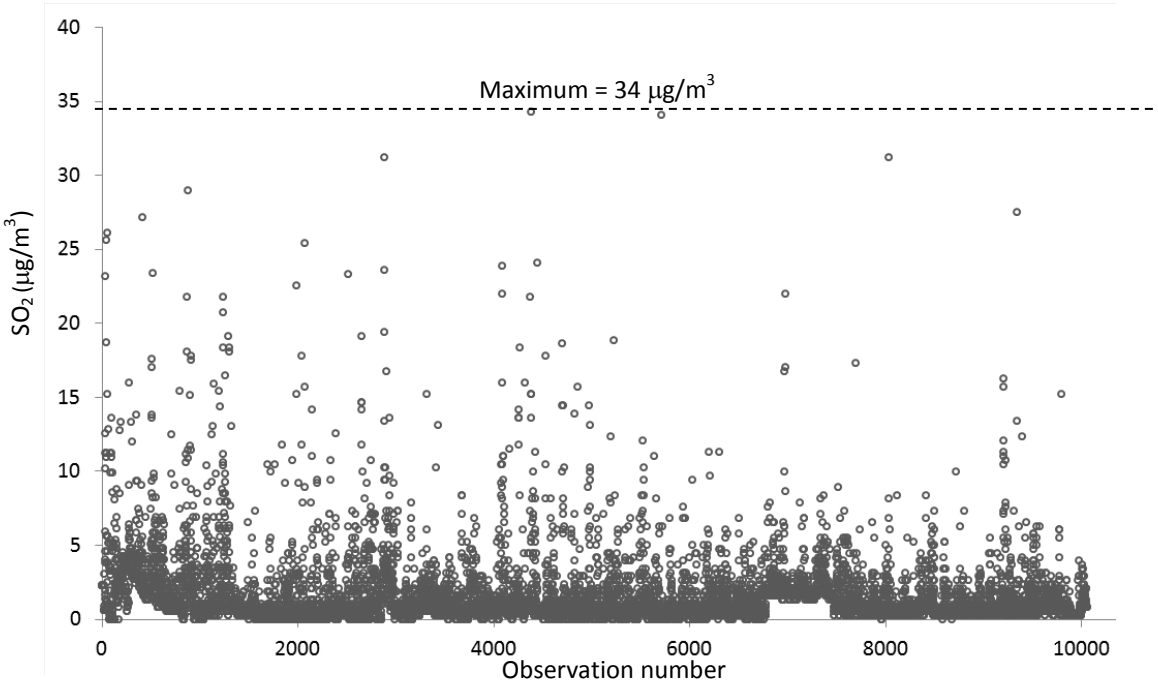
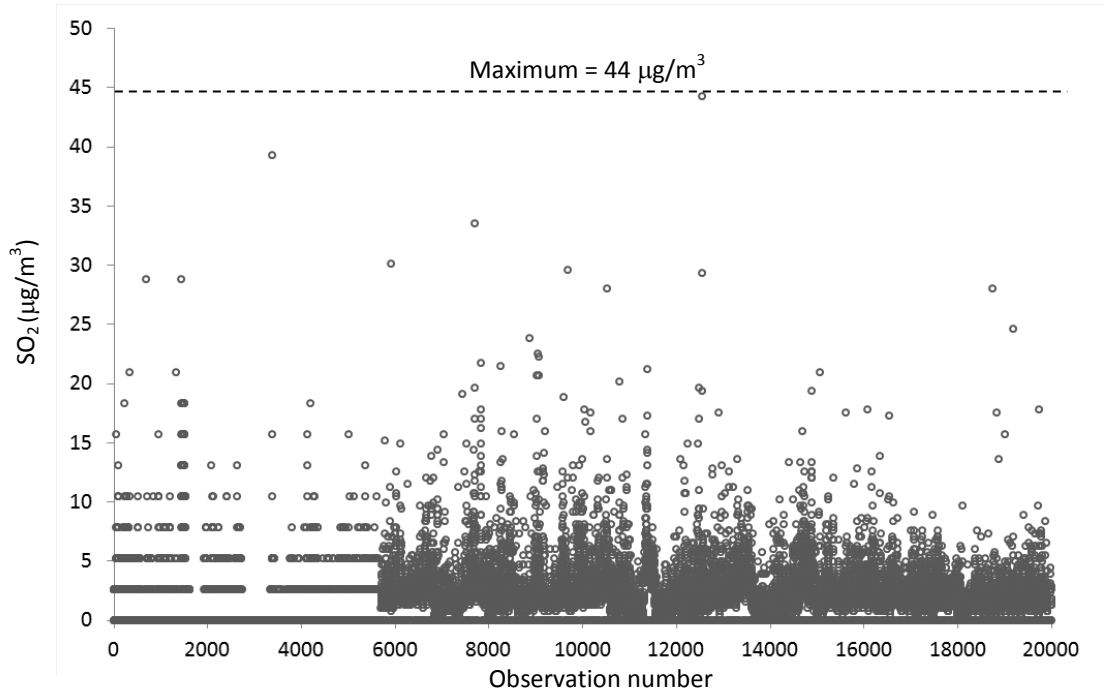


Figure 11. Topaz Station Hourly SO_2 levels– days without cruise ships (May 1st to September 30th)



Note: Data in 2006 and 2007 were rounded by BC Ministry of Environment

The distributions of hourly SO_2 levels above normal at MAML/Erie Station show 2015 has the lowest maximum and the lowest number of intervals above normal on record. Previous years, however, show more variation (Figure 12). At Topaz Station, 2013 has the fewest hourly levels above normal and the lowest maximum, but variation among years is also present (Figure 13), showing there is not yet a clear downward trend in the median (50th percentile) or other percentiles (i.e., 25th and 75th). These data suggest that the number of ships operating under exemption is likely declining, but as seen in the 10-minute levels, the magnitude of elevated episodes may be similar to pre-regulation.

Figure 12. MAML/Erie Station distribution of Hourly SO_2 levels above normal (May 1st to September 30th)

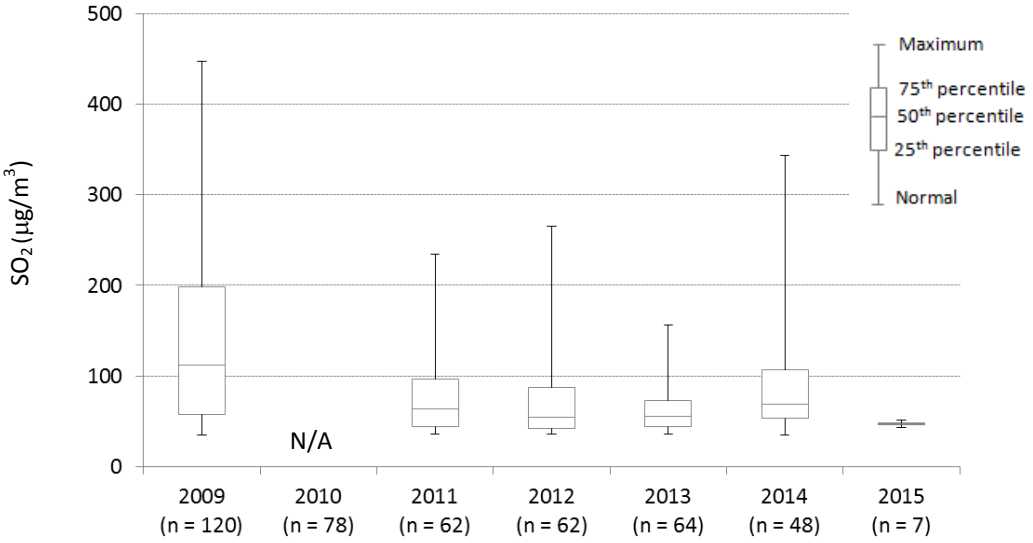
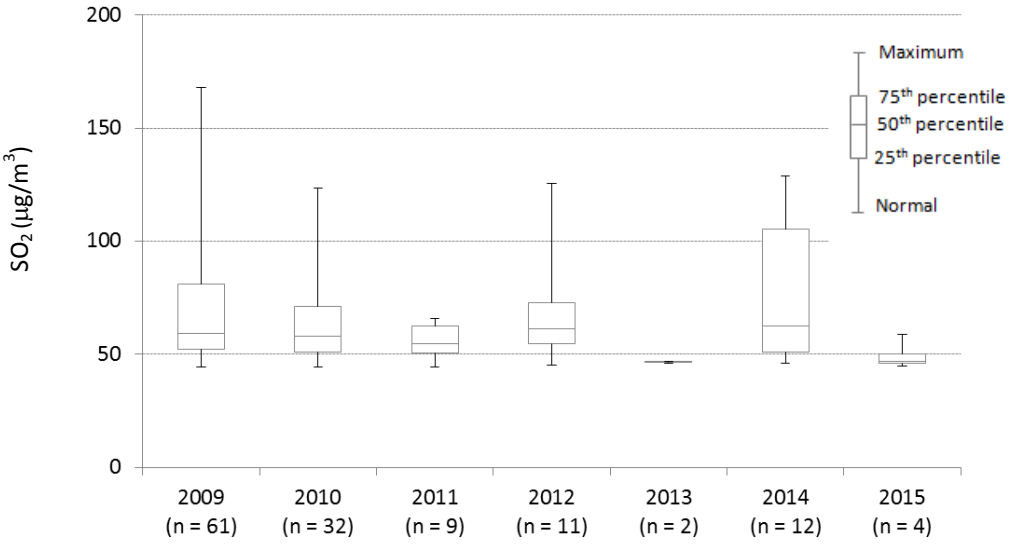


Figure 13. Topaz Station distribution of Hourly SO_2 levels above normal (May 1st to September 30th)



4.7 Daily levels

The highest 24-hour average level of SO_2 measured in James Bay (MAML or Erie Stations) was 7 μg/m^3, based on 188 days without cruise ships present between May 1st and September 30th of each year, while at Topaz Station, the highest 24-hour average level of SO_2 was 15 μg/m^3, based on 538 days with no cruise ships in port (Table 16 and Figures 14 and 15). These levels incorporate all sources of SO_2 emissions, other than cruise ships. At MAML/Erie Stations, this could include occasional ocean-going vessels using Ogden Point Terminal.

Table 16. 24-hour average SO_2 without cruise ships present (May 1st to September 30th)
(during cruise season May 1st to Sept 30th)

	2006	2007	2008	2009	2010	2011	2012	2013
MAML/Erie Station								
Number of intervals	--	--	--	29*	--	52	47	59
Maximum level (μg/m^3)	--	--	--	7	--	7	7	5
Topaz Station								
Number of intervals	61	79	69	91	50	52	47	60
Maximum level (μg/m^3)	15	5	9	9	8	8	6	5

* Includes June 1st to August 24th only.

At MAML/Erie Station, the highest 24-hour average SO_2 level was observed in 2009 (122 μg/m^3), after which maximum levels dropped, reaching a low of 7 μg/m^{3}in 2015 (Table 17). The number of daily intervals above normal was similar in 2009 and 2011, but has decreased since then, with no intervals above normal in 2015. At Topaz Station, the number of intervals above normal and maximum levels peaked in 2009, and although the number of intervals above normal has decreased since then, maximum levels have varied (Table 17).

Table 17. 24-hour average SO_2 above normal
(during cruise season May 1st to Sept 30th)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
MAML/Erie Station										
Number of intervals	--	--	--	25*	--	26	14	15	10	0
Maximum level (μg/m^3)	--	--	--	122	--	21	26	25	24	7
Topaz Station										
Number of intervals	0	1	5	9	5	1	0	0	2	0
Maximum level (μg/m^3)	15	23	24	30	25	18	12	11	23	10

* Includes June 1st to August 24th only.

Figure 14. MAML/ Erie Station 24-hour average SO_2 levels– days without cruise ships (May 1st to September 30th)

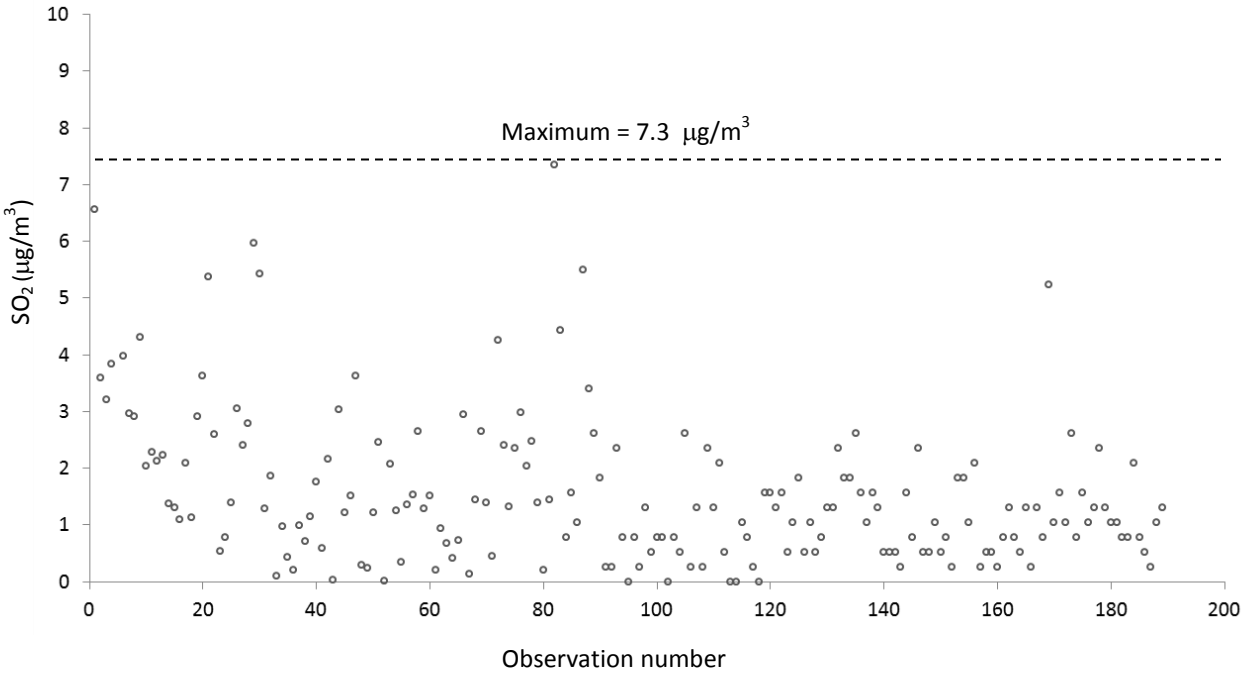
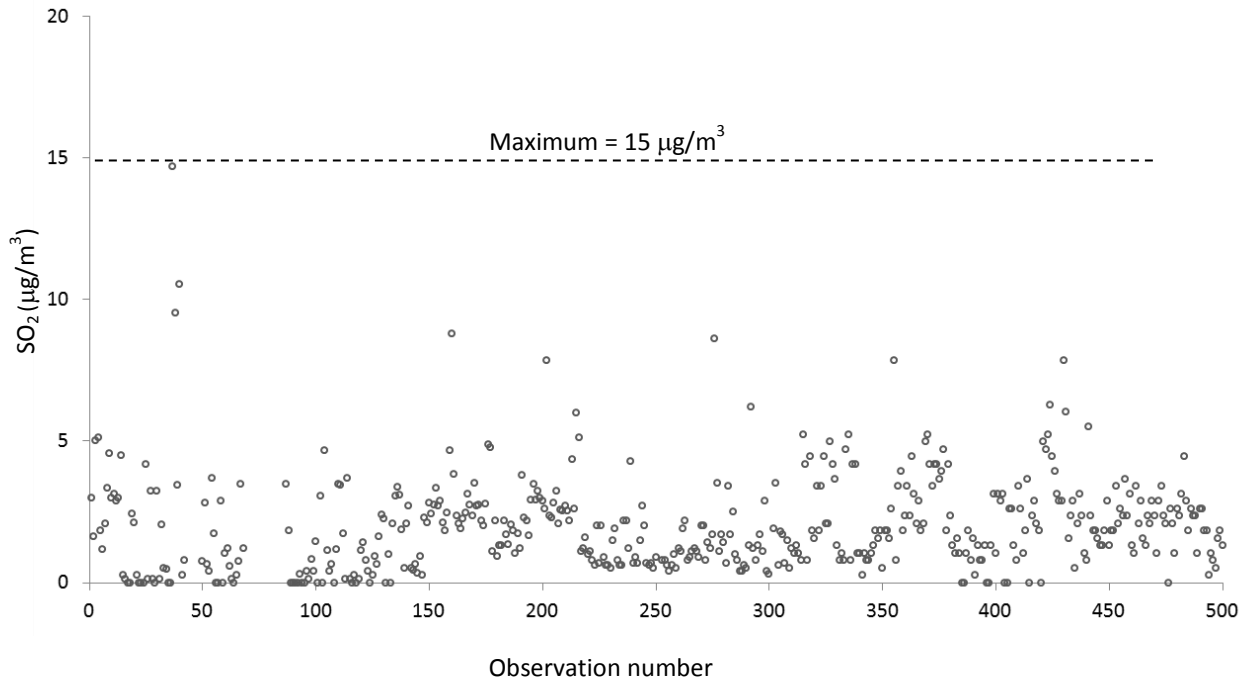


Figure 15. Topaz Station 24-hour average SO_2 levels– days without cruise ships (May 1st to September 30th)



With the exception of 2009, the distributions of 24-hour average SO_2 levels that are above normal at MAML/Erie Station are relatively similar from 2011 to 2014 inclusive. No 24-hour average levels above normal were observed in 2015 (Figure 16). Normal levels were infrequently exceeded at Topaz Station. No 24-hour average levels above normal were observed in 2012, 2013, or 2015 (Figure 17).

Figure 16. MAML/Erie Station distribution of 24-hour average SO_2 levels above normal

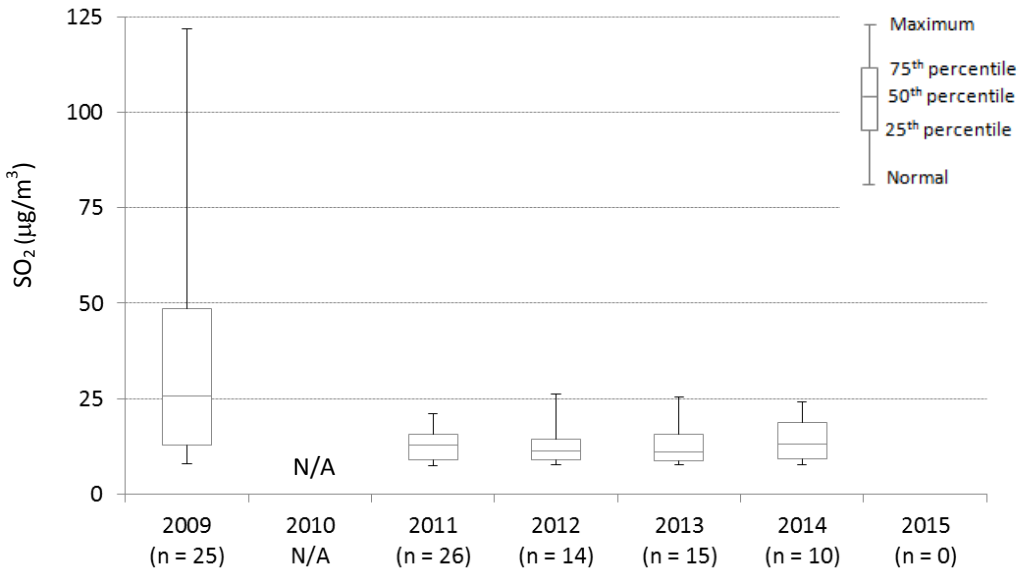
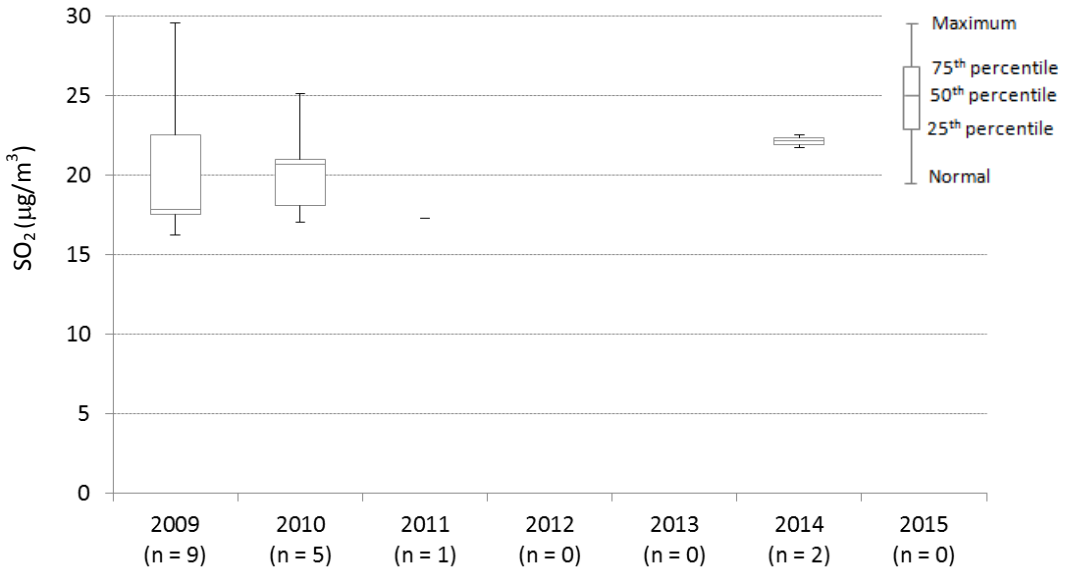


Figure 17. Topaz Station distribution of 24-hour average SO_2 levels above normal



4.8 Comparison of SO_2, NO, NO_2 and $PM_{2.5}$ at Topaz Station

The previous analyses suggest a recent decrease in SO_2 levels in the James Bay neighbourhood, most notably in 2015 when ocean-going vessels were required to use fuel with 0.1 percent sulfur content or have scrubbers installed. This trend is also apparent at Topaz Station, although not as pronounced, since this monitoring Station is further from Ogden Point Terminal and is not impacted by cruise ship emissions as frequently or at the same magnitude.

Other pollutants measured at Topaz Station do not show the same trend. After establishing the normal maximum observed without cruise ships present for NO, NO_2 and $PM_{2.5}$ (Table 18), it is clear that measured levels of these pollutants never exceed the normal maximum even when cruise ships are present, with the exception of NO_2 (1 hour in 2009) and $PM_{2.5}$ (1 hour in 2013 and 2 hours in 2015)(Table 19). In comparison, the number of hours above the normal maximum for SO_2 has decreased markedly since 2009.

There does appear to be a general decline in the maximum NO measured at Topaz Station (Table 19). As previous studies have established that NO at Topaz Station is typically unrelated to cruise ship emissions[35,36]. NO_2, which has been shown to be influenced by cruise ship emissions at Topaz Station[20,21], shows higher maximums in 2009 and 2010, but since then, maximum levels have remained relatively stable, as have the average levels. Maximum $PM_{2.5}$ levels show general variation from year to year, with no apparent trend.

In general, these analyses suggest that the changes in SO_2 levels, particularly the decreasing number of intervals above the normal maximum, are being uniquely affected and that this is the result of gradual implementation of the ECA regulation.

It was noted earlier that decreases in SO_2 and $PM_{2.5}$ were expected with the use of scrubbers; however, $PM_{2.5}$ levels have not changed much at Topaz Station since 2009. It may be that local vehicle traffic, regional impacts of forest fires, and long range transport of $PM_{2.5}$ from other countries are more dominant sources.

[35] James Bay Air Quality Study Team. 2008. James Bay Air Quality Study: Phase 1 Report on the Results of Field Monitoring in 2007. Prepared for the Vancouver Island Health Authority, Victoria, B.C.
[36] Poplawski K. and Setton E. 2010. MAML – Mobile Air Monitoring Laboratory Data Collection report – James Bay Air Quality Study – June –August 2009. Prepared for the Vancouver Island Health Authority and the BC Ministry of Environment. Victoria, B.C.

Table 18. Percentiles of Hourly NO, NO_2, $PM_{2.5}$ and SO_2 Levels – hours without cruise ships – Topaz Station

(during cruise season May 1st to Sept 30th)

Percentiles	NO ug/m^3 (*n* = 20,074)	NO_2 ug/m^3 (*n* = 20,074)	$PM_{2.5}$ ug/m^3 (*n* = 19,115)	SO_2 ug/m^3 (*n* = 20,074)
5	0	0	0	0
10	0	3	1	0
25	1	7	3	0
50	3	14	5	2
75	9	23	7	3
90	18	33	10	5
95	28	40	13	6
96	32	42	13	7
97	37	45	14	8
98	46	49	16	8
99	67	55	18	11
Normal maximum	250	97	69	44

Based on data from 2006 – 2013

Table 19. Number of Hourly NO, NO_2, $PM_{2.5}$ and SO_2 Levels above normal maximum – Topaz Station

(during cruise season May 1st to Sept 30th)

Pollutant	2009	2010	2011	2012	2013	2014	2015
NO							
Hours above normal maximum	0	0	0	0	0	0	0
Highest level (μg/m^3)	219	185	156	150	175	132	147
Average level (μg/m^3)	8	7	7	7	7	6	6
NO_2							
Hours above normal maximum	1	0	0	0	0	0	0
Highest level (μg/m^3)	100	94	83	87	71	77	80
Average level (μg/m^3)	18	18	14	17	16	15	15
$PM_{2.5}$							
Hours above normal maximum	0	0	0	0	1	0	2
Highest level(μg/m^3)	30	97	42	35	137	44	100
Average level (μg/m^3)	6	8	6	6	5	5	5
SO_2							
Hours above normal maximum	61	32	9	11	2	12	4
Highest level (μg/m^3)	168	123	66	126	46	129	59
Average level (μg/m^3)	5	4	3	3	3	3	3

Appendix A – Vancouver Island Sulfur Dioxide Health Risk Guide

Note: The Sulphur Dioxide Health Risk Guide does not replace specific advice provided to individuals by their health care professionals.

Protecting Your Health from Sulphur Dioxide

Sulphur Dioxide Concentration (ppb*)	Air Quality	At-Risk Populations**	General Population
0 - 35 Good (0 to ~90 $\mu g/m^3$)	Air quality is satisfactory, SO2 concentrations pose little or no risk	Enjoy your usual outdoor activities. Follow Dr's advice for exercise regime and condition management.	No need to modify usual outdoor activities.
36 - 75 Moderate (~90 to ~ 200 $\mu g/m^3$)	There may be a moderate health risk for a very small number of people who are unusually sensitive to SO2.	A small number of persons with asthma who are very sensitive to SO2 may experience symptoms. Follow Dr's advice for managing condition.	No need to modify usual outdoor activities.
76 - 185 Unhealthy for Sensitive Groups (~200 to ~ 480 $\mu g/m^3$)	Members of sensitive groups may experience health effects. The general public is not likely to be affected.	Increasing likelihood of respiratory symptoms such as chest tightness and breathing discomfort in people with asthma. People with asthma should consider limiting outdoor exertion or reschedule when SO2 concentrations are lower. Follow Dr's advice for managing condition.	No need to modify usual outdoor activities unless you experience symptoms of cough or wheeze when exercising.
more than 185 Unhealthy (Higher than ~ 480 $\mu g/m^3$)	**Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.**	**Children, the elderly, asthmatics and people with heart and lung disease should limit exertion outdoors or reschedule when SO2 concentrations are lower. Follow Dr's advice for managing condition.**	**At elevated SO2 concentrations, chest tightness and wheezing can occur, even with very brief exposures (minutes) in healthy people without asthma. Reschedule outdoor activity when SO2 levels are lower.**

**ppb = parts per billion*
*** At risk populations include exercising asthmatics. At higher concentrations, children, the elderly and people with chronic heart and lung conditions may experience symptoms of shortness of breath and chest tightness.*

Source: http://www.viha.ca/mho/james_bay_sulfur_dioxide_monitoring.htm