Air Quality in Port Alberni

A Summary of Trends and Patterns in Meteorology, and Common Air Pollutants

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MONITORING, ASSESSMENT AND STEWARDSHIP

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Executive Summary

Historical and recent measurements of ambient air quality and meteorological data from monitoring stations in and around the City of Port Alberni were examined in this report. The air pollutants that were considered include NO_2, SO_2, O_3, $PM_{2.5}$ and PM_{10}[1].

The mountainous terrain around Port Alberni inhibits air circulation which can reduce the ability of the atmosphere to disperse pollutants. The valley location of Port Alberni also makes it susceptible to the frequent formation of temperature inversions, particularly during the colder months. An analysis of meteorological data for Port Alberni from October 2012 to January 2015 indicated that mean wind speeds were lowest in the winter and highest in the summer, and that calm wind conditions (when wind speed is below 0.5 m/s) were most frequent during the fall and winter months (up to 45% of the time). Drainage flows also appear to be an important feature in Port Alberni and can bring emissions from sources located at higher elevations to residential areas located in the valley bottom.

There were no exceedances of the BC AAQO[2] for PM_{10}, NO_2, O_3, or SO_2 during the period examined while there were occasional exceedances of the BC AAQO for $PM_{2.5}$ at both fine particulate monitoring locations in the airshed. Air quality was generally good (low pollutant concentrations) at both $PM_{2.5}$ monitoring locations during the warm months but degraded during the fall and winter. While annual average $PM_{2.5}$ concentrations were the same for the two locations, more frequent daily exceedances of the BC AAQO occurred at the Alberni Elementary School site in North Port, and extreme values were higher in magnitude. Analysis suggests that wood smoke sources (open burning and residential wood stoves) play a significant role during these episodes.

Concentrations of O_3 measured in 2014/15 are similar to those collected at the BC Hydro site 13 years ago and any differences are within the range of what might be expected due to differences in meteorology and NOx concentration/source influences, between the periods examined.

A comparison of the hourly mean NO_2 values recorded at the BC Hydro and Fire Hall stations over the same 8 month periods (June to January) indicated a decrease in average concentrations over the 13 years between measurements in Port Alberni. This is consistent with declines in ambient NO_2 concentrations across Canadian monitoring networks and can likely be attributed to reductions in vehicle emissions over this time.

Analysis of the SO_2 data sets from Alberni Elementary School and the Fire Hall site in 2014/15 showed that there are slightly higher concentrations measured at the Alberni Elementary site. Seasonally, SO_2 concentrations are similar at both sites during the spring and fall, higher at the Alberni Elementary site during the summer and higher at the Fire Hall site in the winter. The data collected at two locations in Port Alberni suggest that the Alberni Elementary School site is well located to capture potential SO_2 impacts from industrial and mobile sources in the valley.

There is a need to develop strategies to manage and mitigate sources of wintertime $PM_{2.5}$ (e.g. wood smoke) in the Alberni Valley.

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[1] Nitrogen dioxide, sulphur dioxide, ozone, particulate matter with a diameter of 2.5 micrometers and less, and particulate matter with a diameter of 10 micrometers and less.

[2] Ambient Air Quality Objective

1 Introduction

This report discusses trends and patterns in ambient air quality in Port Alberni based on data sets gathered from three stationary monitoring locations, a year-long Mobile Ambient Air Laboratory (MAML) project, and a two month mobile nephelometer monitoring study. Meteorological information from co-located sensors at two of the three ambient air monitoring stations was also examined along with data from three federal climate stations in the area. Ambient air quality data was analyzed for patterns and trends from 1998 to 2014.

Some of the key questions considered in this report include:

- What are the meteorological patterns in the valley?
- Are Common Air Contaminant (CAC) concentrations in the city meeting provincial air quality objectives, and which pollutants, if any, are of concern?
- What are the trends and patterns in CAC concentrations? What emission sources are important?
- How do fine particulate concentrations compare between two different locations in the city?
- How do fine particulate concentrations vary spatially over the city during the winter months?
- How do SO_2 concentrations compare between two different locations in the city?
- How do current O_3 and NO_2 concentrations compare to historically measured concentrations?

1.1 Site Geography

Port Alberni is located on central Vancouver Island British Columbia, 195 km north of Victoria. It lies near sea level at the head of Alberni inlet in a valley almost entirely encompassed by mountains (Figure 1). Prominent nearby topographical features include the Beaufort Range to the northwest, the highest point of which is Mt. Joan at 1156 m, and Mount Arrowsmith to the east, at 1819 m elevation. Winds tend to follow the river valley, with dominant directions from the southwest and northeast, moving in and out of the valley via Alberni inlet.

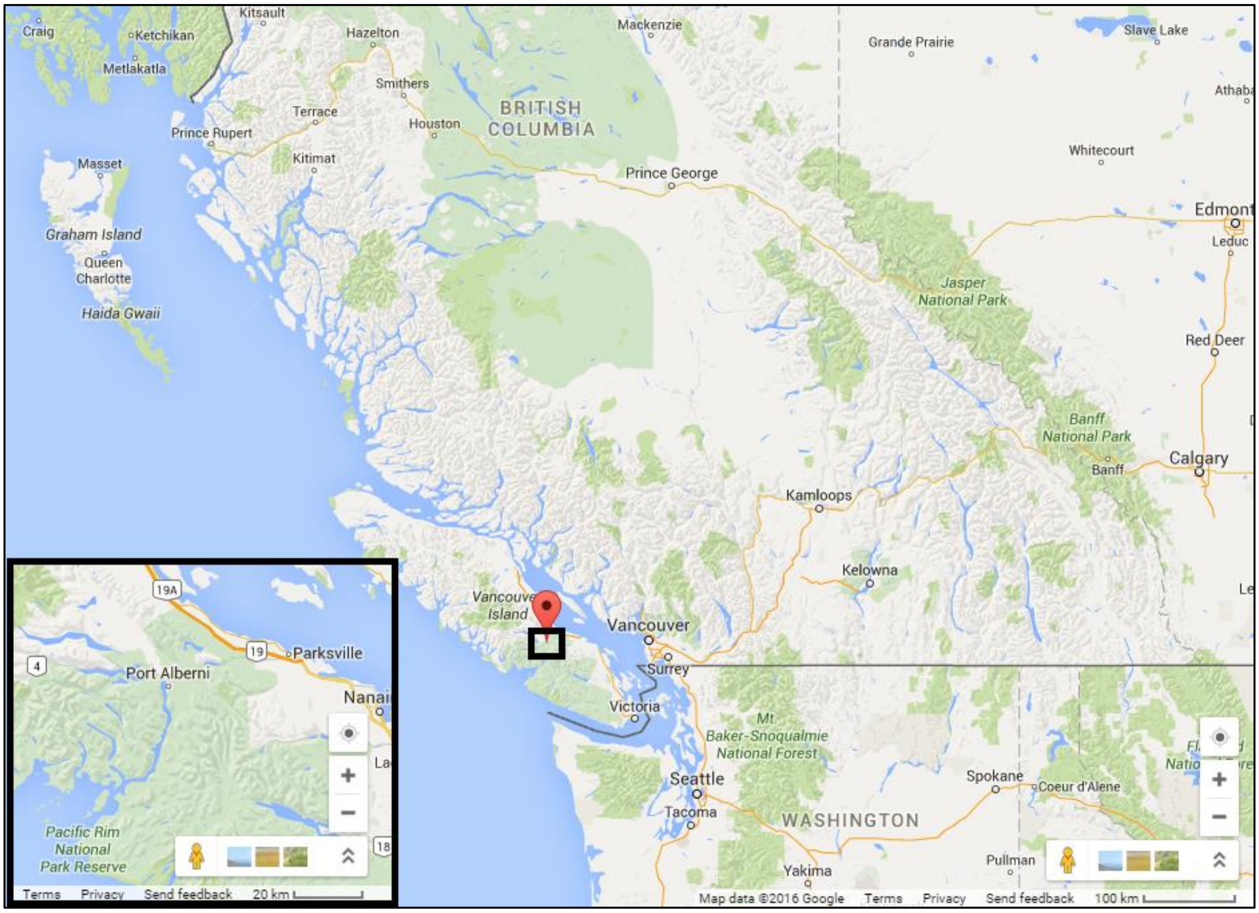

Figure 1: Location map for Port Alberni, BC.

The mountainous terrain around Port Alberni inhibits air circulation which can reduce the ability of the atmosphere to disperse pollutants. The valley location of Port Alberni also makes it susceptible to the frequent formation of temperature inversions, particularly during the cooler months. During a temperature inversion, cold air at the surface is trapped by warmer air aloft, resulting in poor vertical mixing and stagnation. High levels of air pollutants can accumulate in the valley bottom during extended periods of stagnation.

1.2 Fine Particulate Matter ($PM_{2.5}$ and PM_{10})

$PM_{2.5}$, or fine particulate, refers to particulate matter with a diameter of 2.5 micrometers (a micrometer or micron is equal to a millionth of a meter) or less. These fine particles are of particular concern from a human health perspective as they are small enough that, when inhaled, they can travel through the gas exchange portion of the lungs and into the bloodstream (Cormier et al., 2006). Short and long term exposure can cause a broad range of adverse health effects, ranging from shortness of breath and eye irritation to cardiovascular and respiratory disease, birth defects and premature death. Children, the elderly and those with pre-existing conditions are particularly at risk (Cohen et al., 2005; Laumbach, 2010; WHO, 2013). $PM_{2.5}$ can also affect visibility and is primarily produced through combustion processes and through chemical reactions in the air. These particles are mainly associated with open burning, commercial and residential heating, transportation, and commercial/industrial emissions (Metro

Vancouver, 2014; Bates and Caton, 2002). In the Alberni Valley, the main sources of $PM_{2.5}$ include: smoke from wildfires, smoke from commercial open-burning (forest harvesting, agricultural land clearing, land clearing for new property development), smoke from residential backyard burning, emissions from residential/commercial heating (wood-heat much worse than other forms of heating), vehicle emissions, marine emissions, and commercial/industrial emissions.

PM_{10}, refers to suspended particulate matter with a diameter of 10 micrometers or less. As such, PM_{10} includes $PM_{2.5}$, and therefore has some of the same potential health implications. The coarser particles with diameters between 2.5 and 10 micrometers (coarse fraction) can generally only be deposited as far as the bronchi. However, these particles can still be particularly irritating to those with pre-existing conditions (Suzuki, 2003; WHO 2013). Coarse fraction PM_{10} particles are generally produced from grinding processes and natural sources. The coarse fraction can include pollen, road dust, and dust from construction, mining, and demolition activity. PM_{10} can also increase corrosion, decrease visual air quality, and interfere with photosynthesis in plant matter, resulting in stunted growth and increased mortality (EPA, 2009; WHO, 2005).

$PM_{2.5}$ is currently monitored at the Alberni Elementary school station. $PM_{2.5}$ was also measured at the Port Alberni Fire Hall in 2014 and was examined during a mobile Nephelometer study in the winter of 2012/2013. PM_{10} was monitored at the Townsite station from 1998-2010.

1.3 Sulphur Dioxide

Sulphur oxides (SO_x) are released during the combustion of sulphur bearing fuels. Sulphur dioxide (SO_2) makes up the great majority of SO_x in the lower atmosphere. Due to a significant lowering of sulphur levels in gasoline and on-road diesel fuel, SO_2 emissions from motor vehicles have declined considerably over the past decade. Additionally, prior to August 1st 2012, sulphur content in marine fuel for ocean going vessels could have been as high as 3.5 percent along the coast of BC. After this date, marine vessels were required to use fuel with no more than 1 percent sulphur content until the end of December 2014, after which sulphur content requirements were further reduced to 0.1 percent (EPA, 2010).

Sulphur dioxide (SO_2) is a colourless, toxic gas with an irritating smell that is produced through combustion of fuels containing sulphur compounds. At high enough concentrations, it can have adverse effects on human health and damage buildings and vegetation. Inhalation can irritate the upper respiratory tract and aggravate or even cause respiratory diseases (Metro Vancouver, 2014; WHO, 2005; WHO 2013). Major sources include the oil and gas sector and pulp and paper mills, while minor sources include transportation (particularly railways, shipping, and trucking) and residential/commercial space heating. Ambient SO_2 concentrations are currently monitored at the Alberni Elementary station and were previously monitored at the Fire Hall station in 2014 and early 2015.

1.4 Nitrogen Oxides (NO and NO_2)

NO_x (nitrogen oxides) refers to NO (nitric oxide) and NO_2 (nitrogen dioxide), both of which are produced primarily through fossil fuel combustion and biomass burning, and are also released from fertilized soils. The reaction of nitrogen with oxygen results in the production of nitrogen oxides (NO_x) during fuel combustion. NO_X also reacts with other substances in the atmosphere to produce ozone, and acid rain. NOx gases can also contribute to the formation of secondary fine particles such as nitrates.

NO_2 is a reddish-brown, toxic gas with a sharp odour, the inhalation of which can cause acute and chronic respiratory disease (Godish, 1997; Metro Vancouver, 2014; WHO, 2005; WHO, 2013). NO_2 is corrosive due to its high potential for oxidation and can cause a reduction in visibility in its role as a smog-forming constituent. Major anthropogenic sources include mobile sources such as vehicle and marine vessel exhaust, and stationary sources such as industrial boilers, and residential home heating. Ambient NO and NO_2 concentrations were monitored at the BC Hydro station in 2001/2002 and at the Fire Hall station in 2014/2015.

1.5 Ozone

Ozone (O_3) is a pale blue gas with a pungent smell. O_3 is a photochemical oxidant that is formed in the atmosphere from chemical reactions involving NO_x, ultraviolet radiation (sunlight), oxygen and hydrocarbons (HC). Ozone is a natural component of the atmosphere, with peak concentrations experienced in the lower stratosphere where it is beneficial as it absorbs harmful ultraviolet radiation. In the lower troposphere, ground level ozone is a secondary pollutant and can be formed at considerable distances from the origin(s) of the primary pollutants. Ground level ozone can irritate the respiratory system, impair lung function and cause chronic respiratory illnesses (Metro Vancouver, 2014). Most ground level ozone is produced through the chemical reaction of NO_x (nitrogen oxides), VOCs (volatile organic compounds) and sunlight, so it is considered a secondary pollutant. At night, atmospheric chemical reactions take place in the absence of sunlight, resulting in lower ozone concentrations and a distinctive diurnal pattern (Bates & Caton 2002; WHO, 2005; WHO, 2013). Some sources of NO_x and VOCs include vehicle exhaust, industrial facilities, open burning, petroleum products, and chemical solvents. High concentrations of ozone tend to be downwind of these precursor substances. Ambient O_3 concentrations were monitored at the BC Hydro station in 2001/2002 and at the Fire Hall station in 2014/2015.

2 Datasets

Meteorological and air quality datasets from industrial (Catalyst Pulp and Paper), provincial, and federal monitoring stations in and around Port Alberni were examined in this report.

The locations of the Canadian Climate Normals Stations that provided historical data on regional climate are provided in Table 1 and labelled on the map in Figure 2. Similarly, the locations of the BC Air Quality Monitoring Network stations that provided more recent data on meteorology and air quality in Port Alberni have been provided in Table 2 and also labelled on the maps in Figure 2 and Figure 3. Information on the spatial variability of fine particulate matter concentrations across Port Alberni was obtained using a mobile Nephelometer, which is discussed further in Section 3.3.2.3. The variables contained in these datasets are discussed below.

Table 1: Canadian Climate Normals Stations near Port Alberni (Environment Canada, 2015).

Station Name	Latitude (decimal degrees)	Longitude (decimal degrees)	Elevation (m)
Cox Lake	49.20	-124.75	100
Robertson Creek	49.34	-124.98	73.75
Port Alberni A (Somas)	49.25	-124.83	2.4

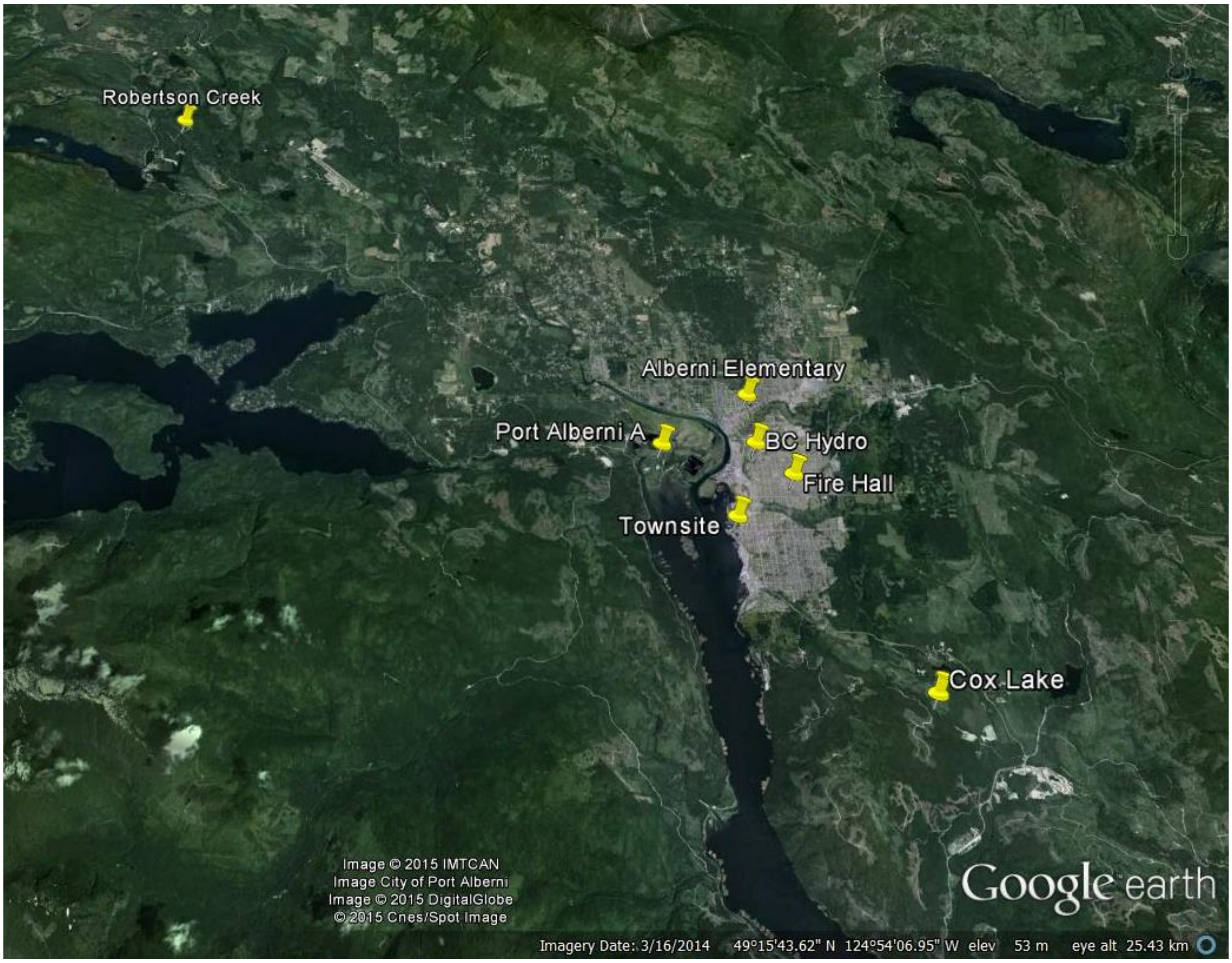

Figure 2: Monitoring stations in and around Port Alberni. Historical climate data was collected at Cox Lake, Port Alberni A and Robertson Creek stations.

Table 2: BC Air Quality Monitoring Network stations in Port Alberni (BC MOE, 2015).

Station Name	Latitude (decimal degrees)	Longitude (decimal degrees)	Elevation (m)	Period of Operation
Alberni Elementary	49.261	-124.806	17	04/2010 – Present
Fire Hall (MAML)	49.243	-124.797	45	29/01/2014-18/02/2015
Townsite (Boathouse)	49.234	-124.815	7	01/1998-12/2010
BC Hydro	49.250	-124.809	9	06/2001-01/2002
Mobile Nephelometer	Varied	Varied	Varied	12/2012-02/2013

Figure 3: A closer view showing the location of the four air quality monitoring stations in Port Alberni (Alberni Elementary, BC Hydro, Fire Hall and Townsite).

2.1 Climate and Short-Term Meteorological Data

Climate refers to long term trends in environmental conditions including variables such as temperature and precipitation. In contrast, weather refers to the short term condition of the same environmental variables. Climate data is summarized using climate normals – averages of at least 15 years of data over a 30 year period. Historical climate data for the Alberni Valley was summarized from three monitoring stations (Table 1) located in and around Port Alberni – Cox Lake, Robertson Creek and Port Alberni A (Figure 2).

Meteorological data was also collected at two air quality monitoring locations in Port Alberni (see Table 3 for parameters measured and period of record) in order to help determine the weather conditions that coincide with poor air quality, as well as providing directional information that could assist with source apportionment. The stations in operation in 2014 have been provided in Table 2, and can also be seen on the map in Figure 2. Precipitation data was not collected at any of the local air quality monitoring stations.

Table 3: Meteorological parameters measured at BC Air Quality Monitoring Network stations in Port Alberni.

Station Name	Meteorological Parameters Measured				
	Wind Speed	Wind Direction	Temperature	Relative Humidity	Precipitation
Alberni Elementary (Oct. 12, 2012- Jan. 31, 2015)	✓	✓	✓	✓	
Fire Hall (MAML) (Feb. 1, 2014- Jan. 31, 2015)	✓	✓	✓	✓	

2.2 Air Quality Data

Over the last 15 years, ambient air monitoring has been in place for a number of different air pollutants in Port Alberni. The parameters examined, the time period monitored and the location of the various monitoring sites are provided in Table 2, Table 4 and Figure 3. These monitoring programs and short-term monitoring projects were put in place for various purposes.

Table 4: Air quality parameters measured at air quality monitoring stations in Port Alberni.

Station Name	Air Quality Parameters Measured					
	$PM_{2.5}$	PM_{10}	NO_2	NO	SO_2	O_3
Alberni Elementary	✓ (BAM1020) 05/2010- Present				✓ (API T100) 01/2014- Present	
Fire Hall (MAML) 01/2014-02/2015	✓ (E-BAM)		✓ (TECO42i)	✓ (TECO42i)	✓ (TECO43i)	✓ (API400E)
Townsite (Boathouse) 01/1998-12/2010		✓ (TEOMAB)				
BC Hydro 06/2001-01/2002			✓ (API200A)	✓ (API200A)		✓ (API400A)
Mobile Nephelometer 12/2012-02/2013	✓ (Radiance M903)					

Historical ambient air monitoring for PM_{10} (fine particulate less than 10 micrometers in diameter) was carried out by Catalyst Paper at the Townsite monitoring location as a requirement under their air emissions permit (PA-01863). It was later determined that $PM_{2.5}$ (fine particulate less than 2.5 micrometers in diameter) was a more relevant parameter from a human health perspective and Catalyst was required to monitor for this parameter at the Alberni Elementary School location beginning in 2010 – the Townsite PM_{10} monitoring site was subsequently closed. The Alberni Elementary School monitoring site is the active core monitoring site in Port Alberni. The data from this site is reported out to the public on a near real-time basis through the Ministry of Environment bcairquality.ca website.

The BC Hydro monitoring site was established for 7-8 months in 2001/2002 to collect baseline information on Ozone (O_3) and Nitrogen Dioxide (NO_2) during an Environmental Assessment process. The purpose of a year-long MAML study at the Port Alberni Firehall in 2014 was to obtain a snap-shot of conditions to compare to ambient air quality objectives, and to historical baseline concentrations (O_3 and

NO_2) to assess if there has been any change in the past 13 years. The MAML study was also used to compare $PM_{2.5}$, Sulphur Dioxide (SO_2), and meteorology to the same data collected at the Alberni Elementary School over the same time period. A mobile Nephelometer study was conducted during the winter months of 2012/2013 to examine spatial differences in $PM_{2.5}$ concentrations across the community.

2.3 Data Validation Criteria

MoE requires at least 75% data availability in order for a data set to be considered valid. As such, valid daily averages (midnight to midnight) require at least 18 hourly measurements. Due to seasonal variability, annual data sets require at least 75% of calendar days in each quarter to be valid in order for that year's data to be considered valid. In addition, ozone data requires 75% completeness for the combined 2nd and 3rd quarters (April 1 to September 30). See the CCME site for further information on data completeness guidance (CCME, 2012).

Data sets that did not meet data completeness requirements have been flagged in this report.

3 Results

Meteorological and air quality results are presented below, accompanied by a discussion of patterns identified in the results.

3.1 Climate

Port Alberni is part of the South Coast region of BC, which has a modified version of the Mediterranean climate, featuring a well-defined dry season in summer and cool, wet conditions for much of the remainder of the year. The seasonal variation in precipitation is due to the seasonal shifts of the North Pacific High, which occupies its most northerly position in summer thus deflecting storm systems towards the northern Coast and Alaska. In fall, the North Pacific High shifts southward and the westerly jet stream strengthens ushering lows and fronts across Vancouver Island and into the southern BC mainland. The waters of the Pacific Ocean moderate the air temperatures of the South Coast, resulting in a much smaller temperature range than that of continental regions east of the Coast Mountains (Stantec, 2013).

3.1.1 Precipitation and Temperature

Climate Normals data were obtained from three monitoring stations near Port Alberni – Cox Lake, Robertson Creek, and Port Alberni A (Figure 2). Monthly mean precipitation was very similar between the three stations, though the station closest to the city (Port Alberni A) recorded the lowest values (Figure 4), particularly during the winter months. This could be due to its lower elevation (2.4m) relative to Cox Lake (100m) and Robertson Creek (74m). On average, the lowest precipitation rates occurred in July at all three sites with the highest levels occurring between November and January.

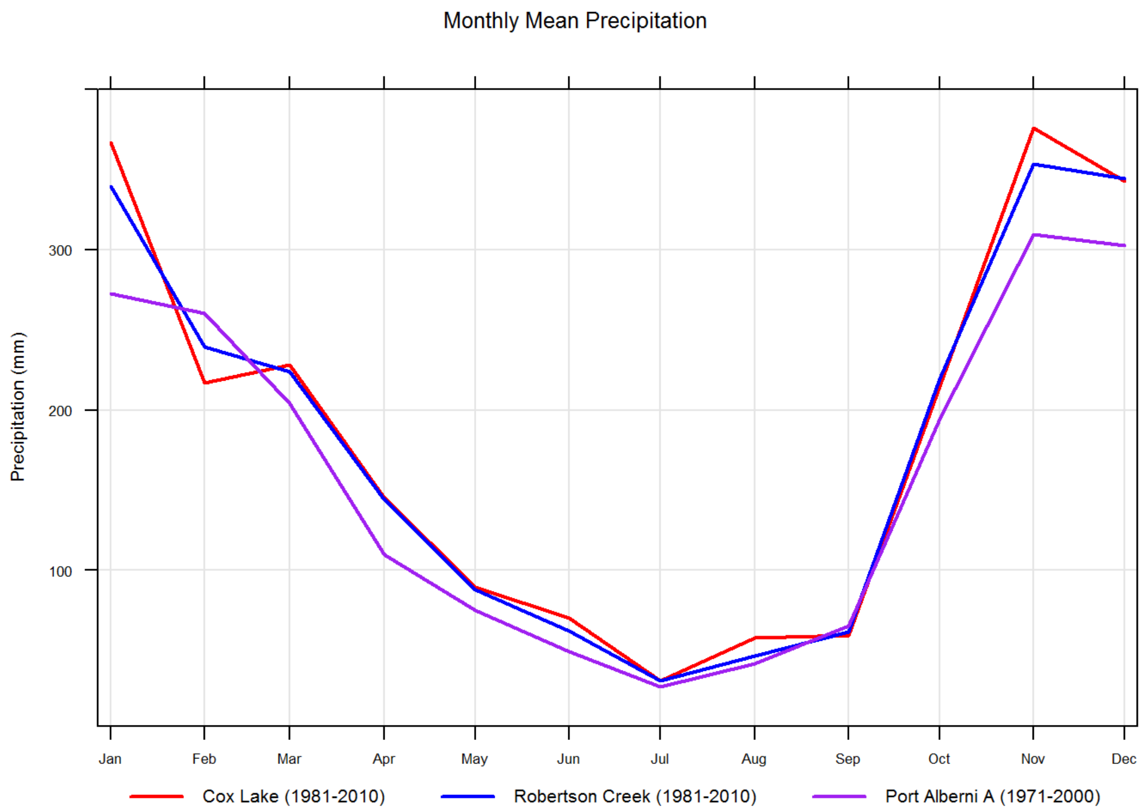

Figure 4: Monthly mean precipitation recorded at Canadian Climate Normals Stations near Port Alberni.

Monthly mean temperatures at the Cox Lake, Robertson Creek, and Port Alberni A stations were also very similar (Figure 5). Recent temperature information was also collected at the Alberni Elementary and Port Alberni Fire Hall ambient air monitoring stations. Relative to the 30-year mean climate normals stations referenced above, mean monthly temperatures recorded at Alberni Elementary and Fire Hall in 2014 were cooler in February and warmer through the summer and fall. Temperatures recorded at the Alberni Elementary station in 2013 were much more typical as they matched up much more closely to the climate normals data (Figure 6). Note that temperature data from the Fire Hall from Nov. 27th and 28th and all of December were removed due to invalid readings. A summary of mean monthly temperatures from all sites can also be seen in Table 5.

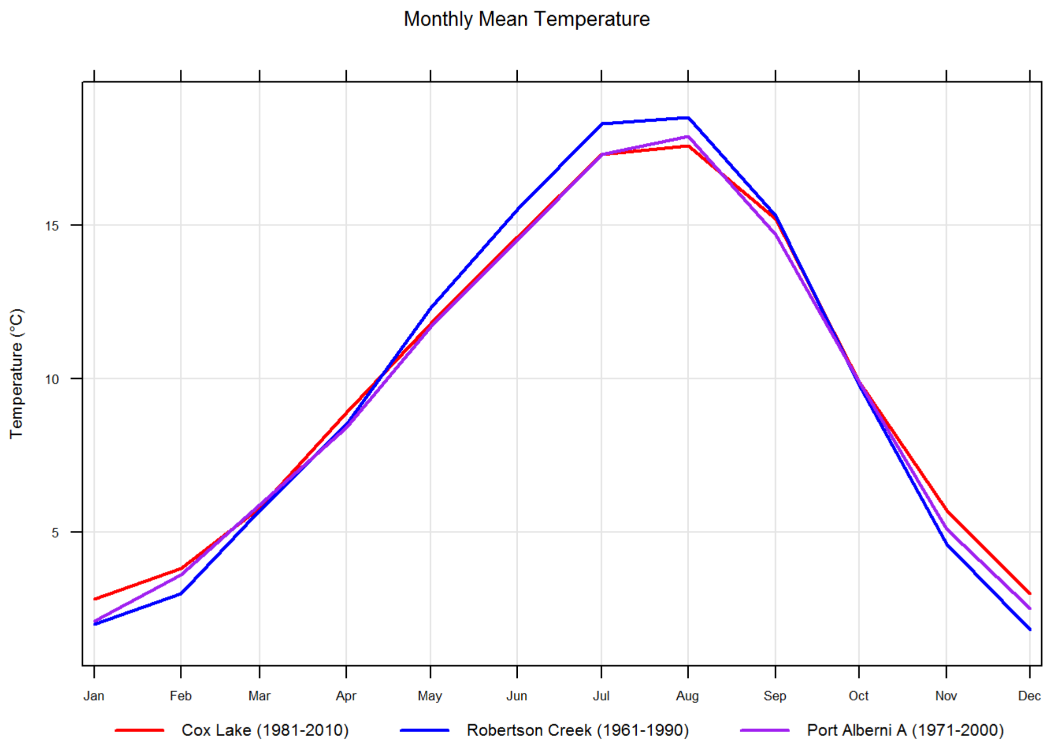

Figure 5: Monthly mean temperature recorded at Canadian Climate Normals Stations near Port Alberni.

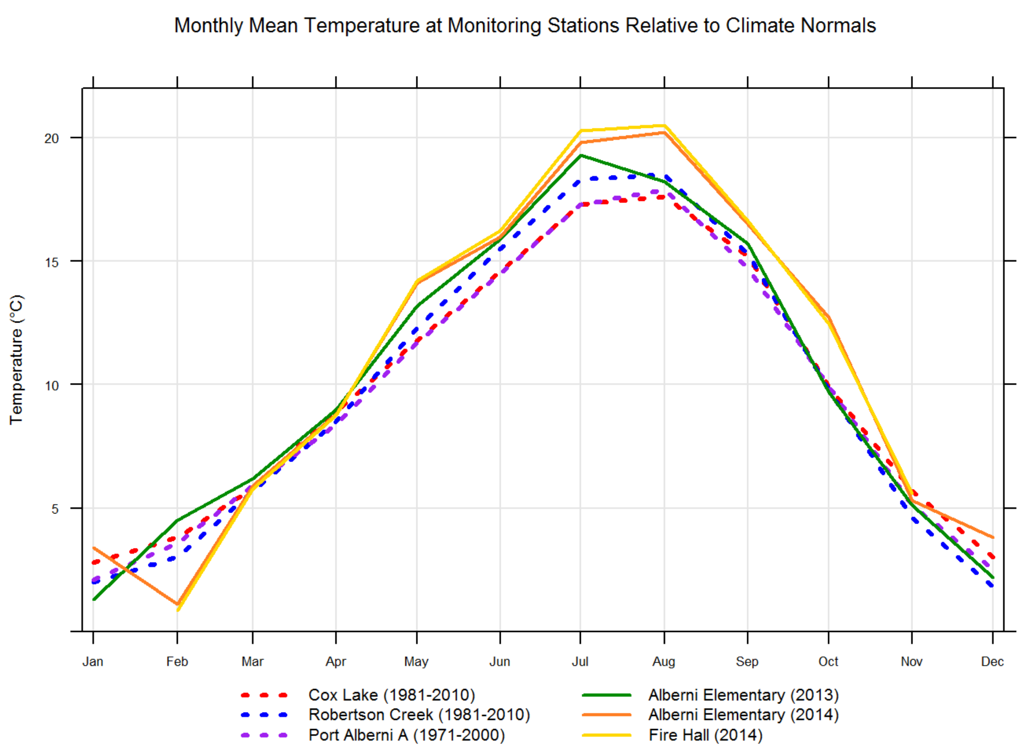

Figure 6: Mean monthly temperatures from the Alberni Elementary and Fire Hall stations compared with nearby Canadian Climate Normal Stations.

Table 5: Mean monthly temperatures (°C) measured at monitoring stations in and around Port Alberni.

	Cox Lake	Robertson Creek	Port Alberni A	Alberni Elementary	Alberni Elementary	Fire Hall
Year(s) monitored	**1981-2010**	**1981-2010**	**1971-2000**	**2013**	**2014**	**2014**
January	2.8	2.0	2.1	1.3	3.4	N/A
February	3.8	3.0	3.6	4.5	1.1	0.8
March	5.8	5.7	5.9	6.2	5.9	5.8
April	8.9	8.5	8.4	9.0	8.8	8.8
May	11.8	12.3	11.7	13.2	14.1	14.2
June	14.6	15.5	14.5	15.9	16.0	16.3
July	17.3	18.3	17.3	19.3	19.8	20.3
August	17.6	18.5	17.9	18.2	20.2	20.5
September	15.2	15.3	14.7	15.7	16.5	16.6
October	9.9	9.8	9.9	9.7	12.7	12.5
November	5.7	4.6	5.1	5.1	5.3	5.6
December	3.0	1.8	2.5	2.2	3.8	N/A

3.2 Meteorology

3.2.1 Influence of Meteorology on Air Quality

In order to understand air quality, an understanding of the state of the atmosphere is necessary. For example, elevated ambient particulate levels coincident with calm or very light wind speeds may be indicative of local pollutants accumulating near the point of origin (e.g. wood stove smoke, road dust and automobile exhaust). The same levels of particulate associated with a moderate wind may well indicate transport of pollutants from a source outside of the local area (e.g. forest fires, open burning, industrial emissions, etc.). The likely source of elevated particulate levels during a strong wind event may be wind-blown soil particles.

Calm (wind speeds less than 0.5 m/s) and light wind conditions are generally associated with a stable atmosphere and either elevated (e.g. frontal, etc.) or ground-based inversions. In Port Alberni, as in other communities located in river valleys, ground-based *nocturnal* or *radiation* inversions occur with the greatest frequency. These temperature inversions (when temperature increases with height above ground) are associated with a climatological process known as radiative cooling. At nighttime, the heat energy that the earth receives from the sun during the day is radiated back to space as long wave radiation. As the ground cools, the air in immediate contact with it also cools and mixing extends this cooling upward, creating the nocturnal inversion. The inversion deepens over the course of the night and may reach its maximum depth just after sunrise. Light winds, cloudless skies and long nights (e.g. winter months) favor the development of deep, strong radiation inversions (Angle and Sakiyama, 1991).

The topography in and around Port Alberni also influences the local meteorology and the pollution potential in the valley bottom. On clear nights the surface air cools on the surrounding hillside slopes in the same manner as described above, and becomes dense. This heavy air flows downhill to the valley floor (similar to the flow of water), displacing the warm air which is forced aloft. These light winds, termed drainage or katabatic winds, are a regular occurrence during clear nights in most mountainous regions of the world (Angle and Sakiyama, 1991). The nocturnal temperature inversion that would already be forming in the valley bottom due to radiative cooling at the surface is intensified by these cold drainage flows. Pollutants released at ground level would tend to travel with these katabatic flows and accumulate in the valley bottom within the inversion layer. These conditions may lead to degraded air quality in the valley bottom. Note that in some cases, stronger katabatic flows can also have a cleansing effect.

Although the term inversion has come to be synonymous with air pollution problems, this is a misleading generalization. In reality the base height, thickness and strength of the inversion relative to the source of pollutants must be considered. For example, a ground-based inversion a few hundred meters thick certainly creates a potential air pollution situation in an urban area where most sources of pollutants are at or near ground level. However, the plumes from even moderately tall stacks are likely to rise above the inversion and disperse in the less stable air above. The ground-based inversion will then effectively block this industrial pollution from reaching the ground. However, with thick ground-based inversions, the plumes from tall stacks may become embedded. Elevated inversions are responsible for reducing the dispersion of plumes from tall stacks. If the base of the inversion lies slightly above the level of the plume, then the volume of air available for dilution is severely limited. The elevated inversion acts as a lid restricting mixing in the vertical, reducing dilution and increasing ground level concentrations (Angle and Sakiyama, 1991).

High ground level concentrations (GLCs) of pollutants can also occur during inversion break up. This phenomenon is known as “fumigation”. Fumigation occurs when daytime solar heating is sufficient to produce a neutral or unstable layer that reaches the height of a pollutant plume that is trapped within the inversion layer. When this happens, the pollutants within this layer are brought to the ground more or less simultaneously along the full length of the plume. This condition produces high GLCs but generally only for a short period of time (up to 30 minutes) in flat terrain. It should be noted that in valley bottom locations like Port Alberni, fumigation can last for several hours depending on how fast the ground is being heated and how thick the polluted layer is.

3.3 Wind

Wind direction patterns in Port Alberni are influenced in large part by the topography in and around the city. Air flows into the valley via the river valley to the northwest of the city, along the Alberni Inlet to the south, and can drain down (Katabatic flows) from most directions off the surrounding hills and mountains (Figure 7). There is also a mountain pass to the northeast of the city that allows air movement to and from the Strait of Georgia between the Beaufort Range to the north and Mount Arrowsmith to the east.

Wind speed and direction was monitored at the Alberni Elementary School in 2013 and 2014 and at the Alberni Fire Hall station in 2014 only. The Fire Hall station measured these variables with meteorological sensors attached to an E-BAM (Environmental Beta Attenuation Monitor) situated at 5.5m above ground level. Meteorological variables at the Alberni Elementary Station were measured using a 10m meteorological tower located on the roof of the two-story school. As the wind sensor at Alberni Elementary was much higher above the ground, it would be expected to measure higher wind speeds less influenced by surface roughness, while measurements from the Fire Hall would be expected to be more reflective of local wind patterns influenced by nearby terrain and buildings.

Figure 7: Terrain features around Port Alberni. Note Alberni Inlet to the south, the river valley running northwest of the city, the mountain pass to the northeast, and the mountains and hills otherwise encircling Port Alberni and limiting air flow (Google Maps).

A wind rose shows the frequency at which wind blows at certain speed ranges from certain directions at a given location. The wind direction in a wind rose refers to where the winds are blowing from and the direction of the longest spoke on the wind rose indicates the direction wind blows from with the greatest frequency. Wind roses were produced for both sites for the same monitoring period (February 2014-January 2015) so that direct comparisons could be made.

3.3.1 Alberni Elementary

The 2014/15 annual wind rose for the Alberni Elementary School shows that winds were predominantly coming from the northeast and southwest (Figure 8). Winds flowing from the south up the Alberni inlet would tend to turn to the southwest as they follow the Somass River near this location. When broken down by season, most of the higher wind speeds that came from the southwest and northeast occurred during the spring (March, April and May) and summer (June, July and August) months. Autumn (September, October and November) is dominated by winds from the northeast, while much lighter winds came mainly from the north sector in the winter (December, January and February). Calm conditions (when wind speed is below 0.5 m/s) were most prevalent in the winter. The mean wind speeds were lowest in the winter and highest in the summer. Lighter wind speeds and a high frequency of calms (22.4% of the time) during the winter period would result is poor atmospheric dispersion and could lead to a build-up of pollutants in the area.

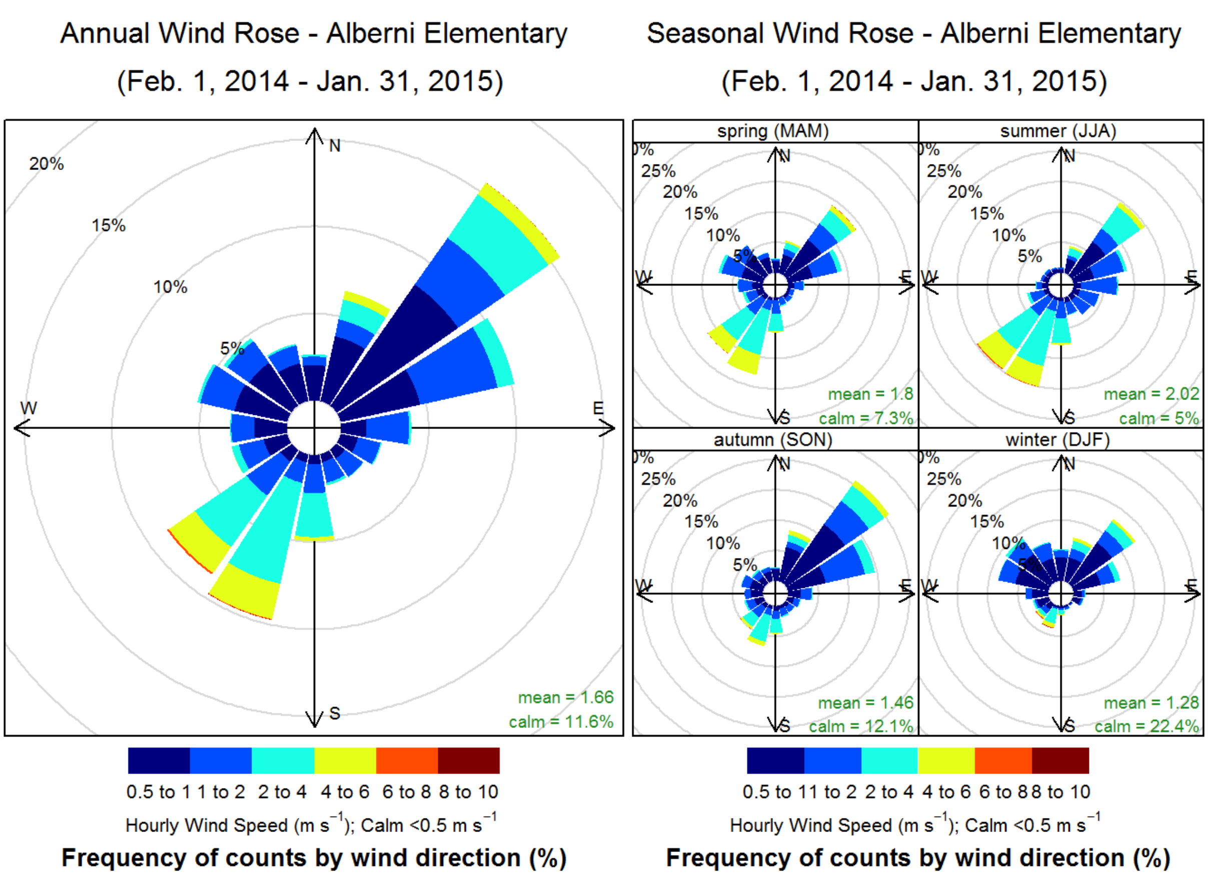

Figure 8: Annual and seasonal wind roses from the Port Alberni Elementary station. Spokes on the roses represent wind coming from those compass directions, with colours denoting wind speed class.

Annual and seasonal wind roses were produced for the daytime and nighttime hours to examine differences in diurnal wind patterns. Figure 9 presents the annual wind roses from Alberni Elementary broken down by day and nighttime hours. During the day, the prevailing winds were either up the Alberni Inlet from the southwest or through the mountain passes to the northeast of Alberni Elementary. The stronger winds associated with large weather systems would be channelled by the local terrain into these directions, while a daytime sea breeze (particularly during the summer months) would also contribute to higher frequencies of southwest winds at this site (although much lighter). A sea breeze occurs due to the different heat capacities of land and water. During the summer, when skies are clear and winds are light, land surfaces heat more rapidly than water. As this air warms, it expands and rises as its pressure decreases. Cooler, higher pressure air above water is drawn toward the lower pressure above the land and replaces the rising air, resulting in a sea breeze. At nighttime, the winds are generally much lighter as energy from the sun isn't driving the system. Winds measured at the Alberni Elementary School during the nighttime period (Figure 9) were lighter and predominantly from the northeast sector. This suggests that a large portion of the air flowing past Alberni Elementary at night was coming from the foothills and mountains to the northeast of the school (through the Cherry Creek area) in the form of light katabatic winds or drainage flows.

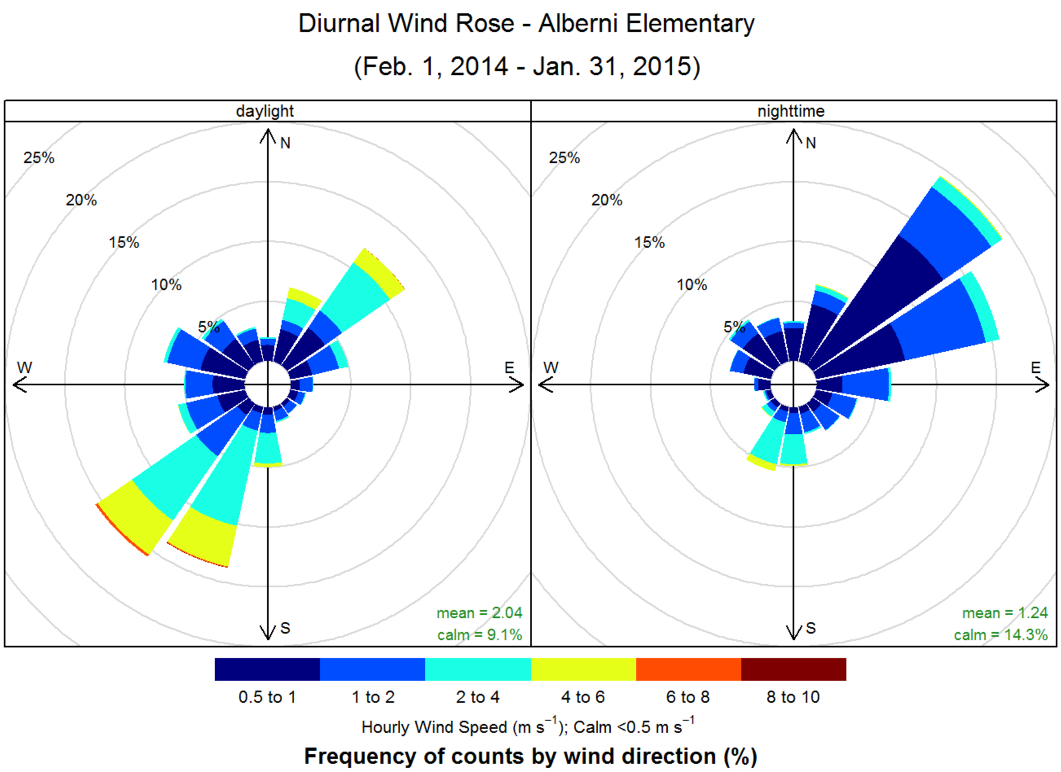

Figure 9: Annual day and nighttime wind roses showing diurnal patterns at the Alberni Elementary station.

Daytime versus nighttime wind patterns in the spring of 2014 were quite similar to annual average patterns, with stronger winds blowing mainly from the southwest, and to a lesser degree the northeast, during the day, and lighter winds being directed from the surrounding terrain features to the northeast and east at night (Figure 10). Spring is a transitional period that can feature synoptic scale storms as well as more thermally driven patterns such as land and sea breezes, which are more typical of summer. It is notable that northwest winds were largely absent during the summer months (Figure 11).

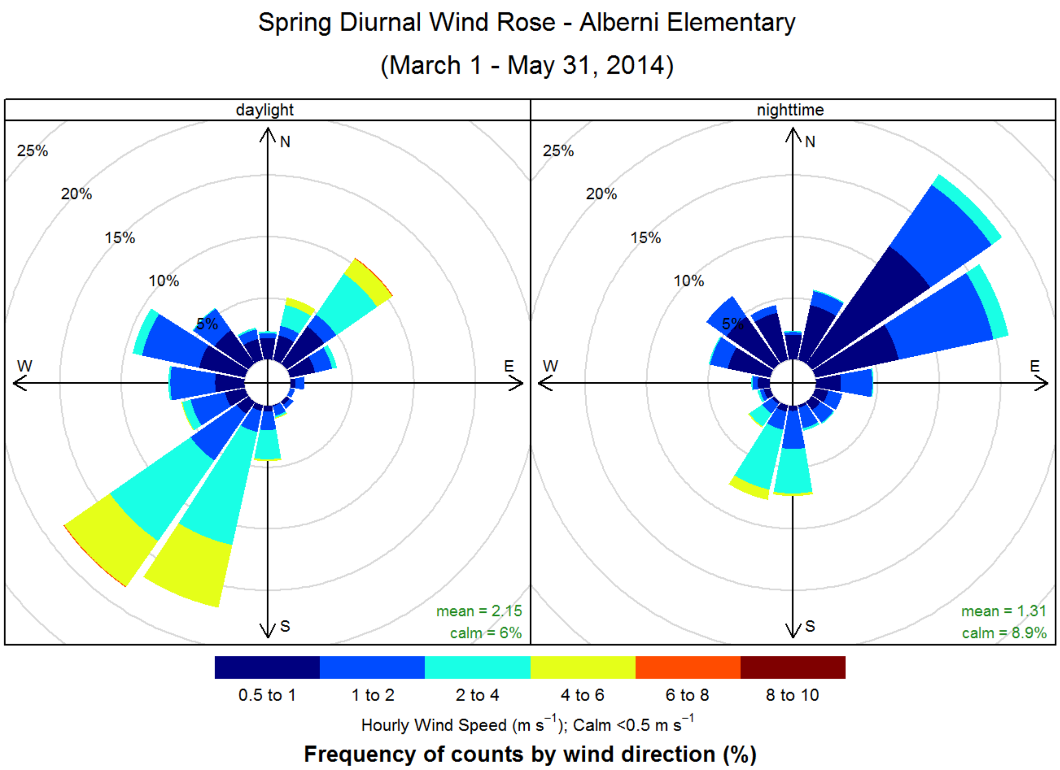

Figure 10: Day and nighttime wind roses showing diurnal patterns over the spring at the Alberni Elementary station.

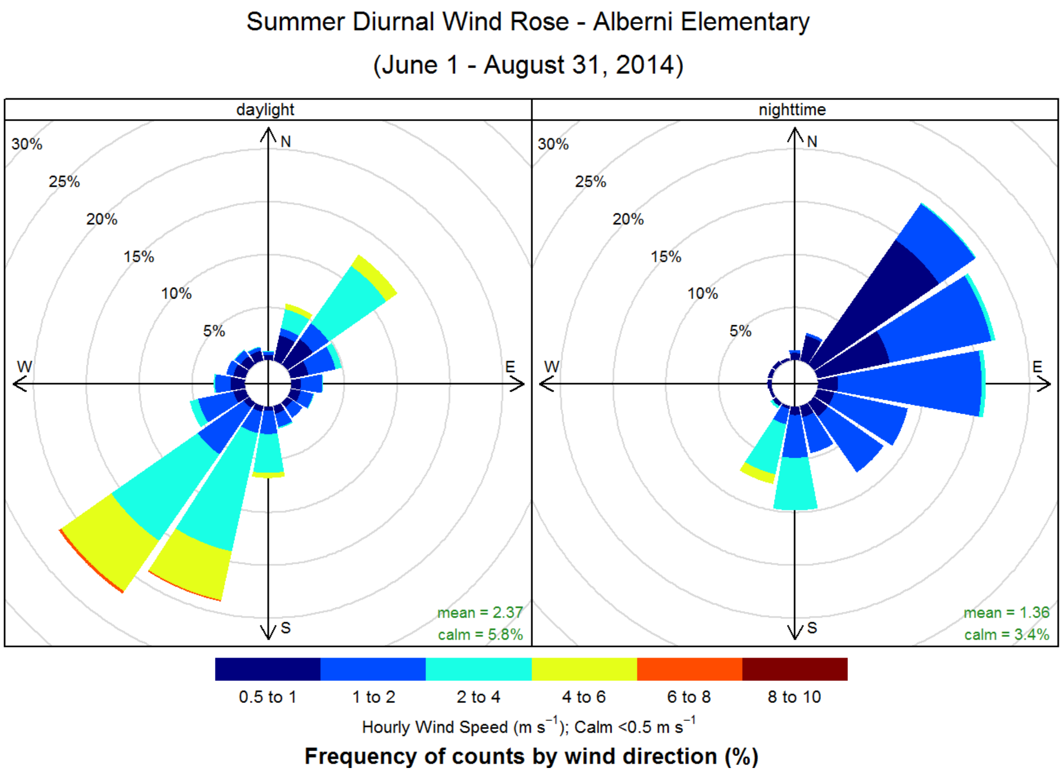

Figure 11: Day and nighttime wind roses showing diurnal patterns over the summer at the Alberni Elementary station

In the fall, winds were lighter, with a higher frequency of calms. During the daytime, winds from the southwest were less prevalent than in warmer months, and tended to be equally split between southwest and northeast. At night, fall winds were dominated by light drainage flows from the mountain pass to the northeast (Figure 12).

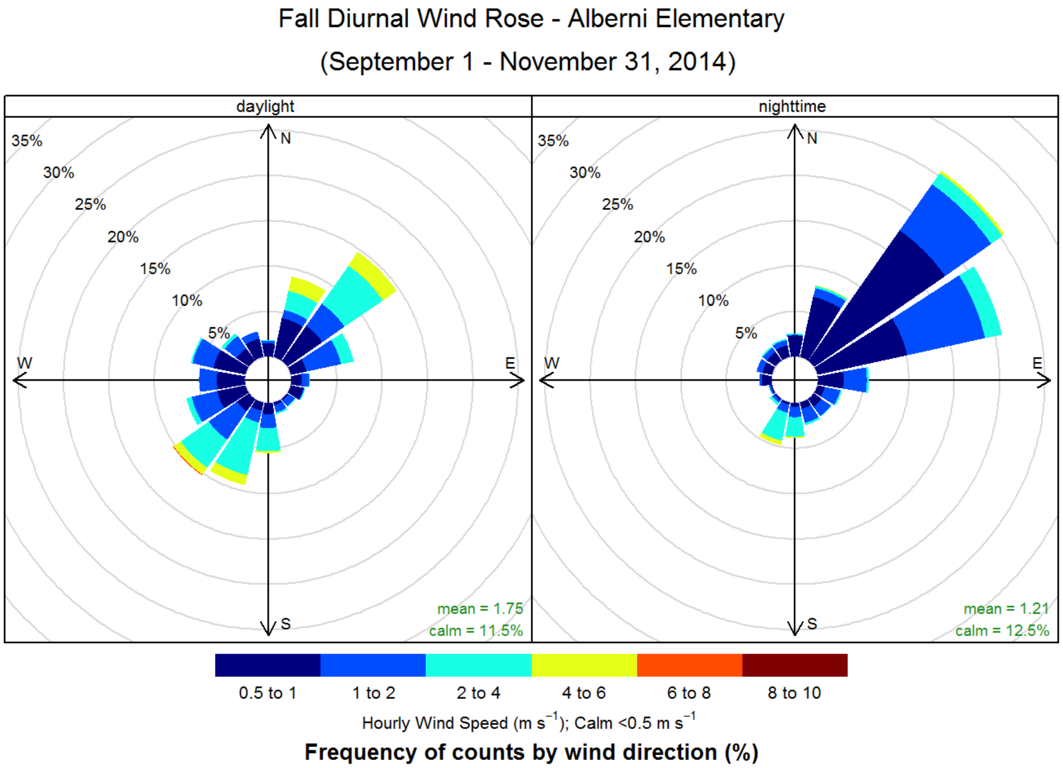

Figure 12: Day and nighttime wind roses showing diurnal patterns over the fall at the Alberni Elementary station.

Calms and light winds were the most frequent during the winter, during both the day and night (Figure 13). This is indicative of stable conditions during the coldest months of the year. During the day, lighter winds primarily flowed down the valley from the northwest, with stronger winds associated with weather events occasionally coming up from Alberni Inlet to the south, and over the mountain pass to the northeast. At night, light winds dominated from the northwest and northeast.

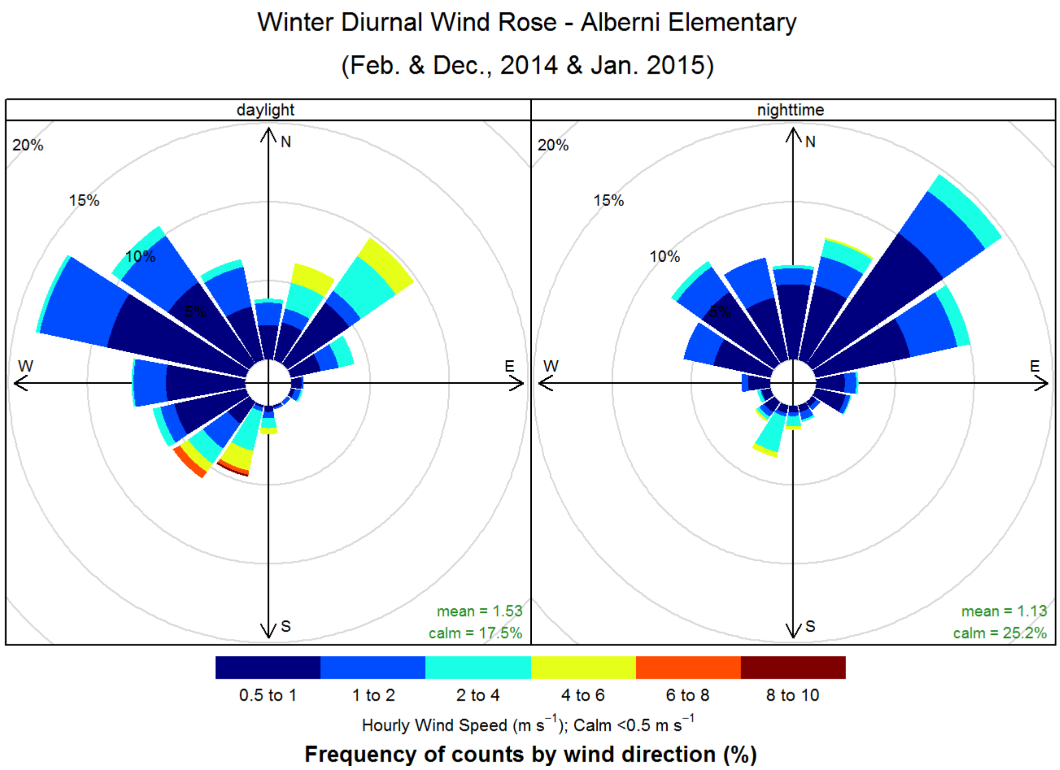

Figure 13: Day and nighttime wind roses showing diurnal patterns over the winter at the Alberni Elementary station.

3.3.2 Port Alberni Fire Hall (MAML)

Wind speeds and directions at the Fire Hall station were quite different to those measured at the Alberni Elementary station in 2014/15. At the Fire Hall, the prevailing wind on an annual basis was from the south and southeast, mainly due to the channeling effect of the Alberni Inlet which is oriented in a north/south fashion (Figure 14) at this location. Seasonal patterns in spring and summer were similar to the annual patterns, with higher wind speeds coming from the south sector. The autumn wind rose shifted to lighter winds from all wind directions, with the highest frequency of stronger winds coming from the south and southeast. During the winter, patterns were more similar to those found at the Alberni Elementary School with lighter winds generally coming from the north sector although there was a southeast component here as well. Overall, wind speeds were generally lower at the Fire Hall. The Fire Hall site exhibited a higher frequency of light winds from all directions and had a higher incidence of calm winds than Alberni Elementary (32.3% of the time vs. 11.6%). This is likely in part because the sensor at the Fire Hall was located much closer to the ground (5.5m) than the sensor at Alberni Elementary (~25m) and would be more easily influenced by local surface roughness features like terrain and buildings.

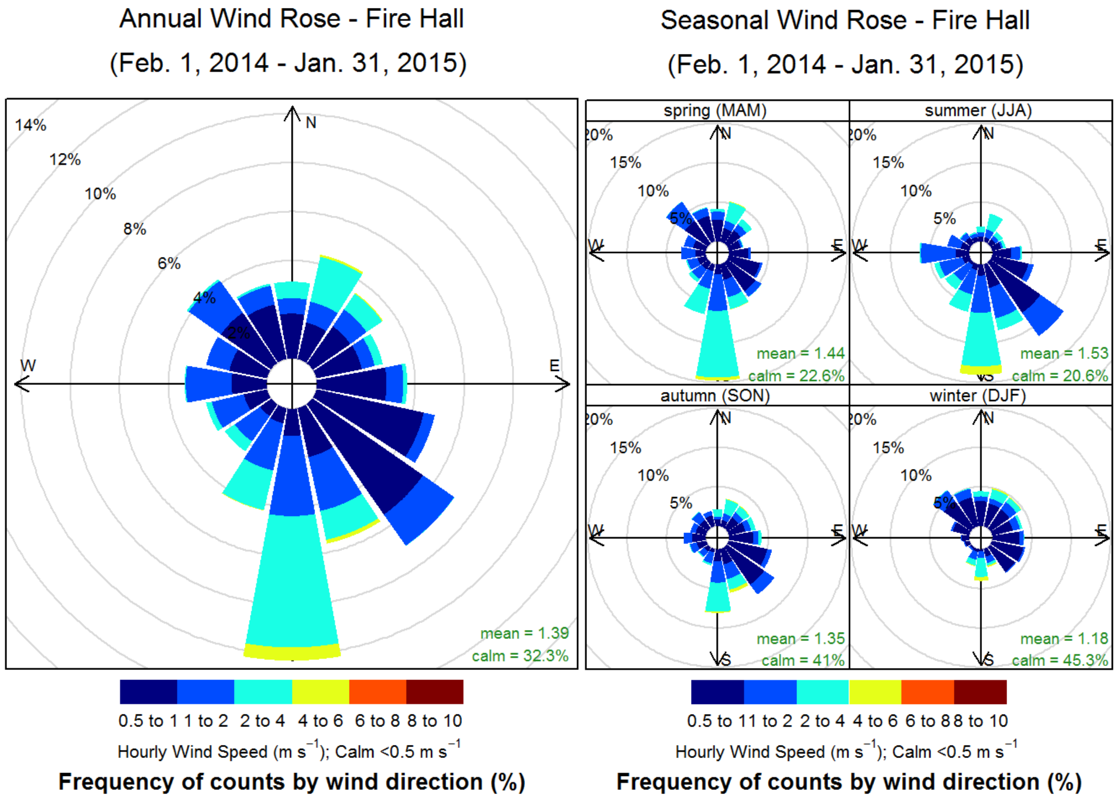

Figure 14: Annual and seasonal wind roses from the Port Alberni Fire Hall station (MAML). Spokes on the roses represent wind coming from those compass directions, with colours denoting wind speeds.

Figure 15 presents the annual diurnal wind roses for the Fire Hall. Light nighttime drainage winds at the Fire Hall site had a similar northeastern component to the Alberni Elementary site, but there were additional stronger easterly and southeasterly components as well. This suggests that drainage winds from the surrounding terrain will have different effects depending on the location in the City and the dominant terrain features in these directions (e.g. mountains, hills, secondary valleys, etc.). There were also some higher wind speeds at night from a more southerly direction that are likely associated with larger scale weather systems being channelled along the inlet. These same patterns existed at the Alberni Elementary site but more of the stronger winds were channelled in a southwestern direction due to local terrain effects.

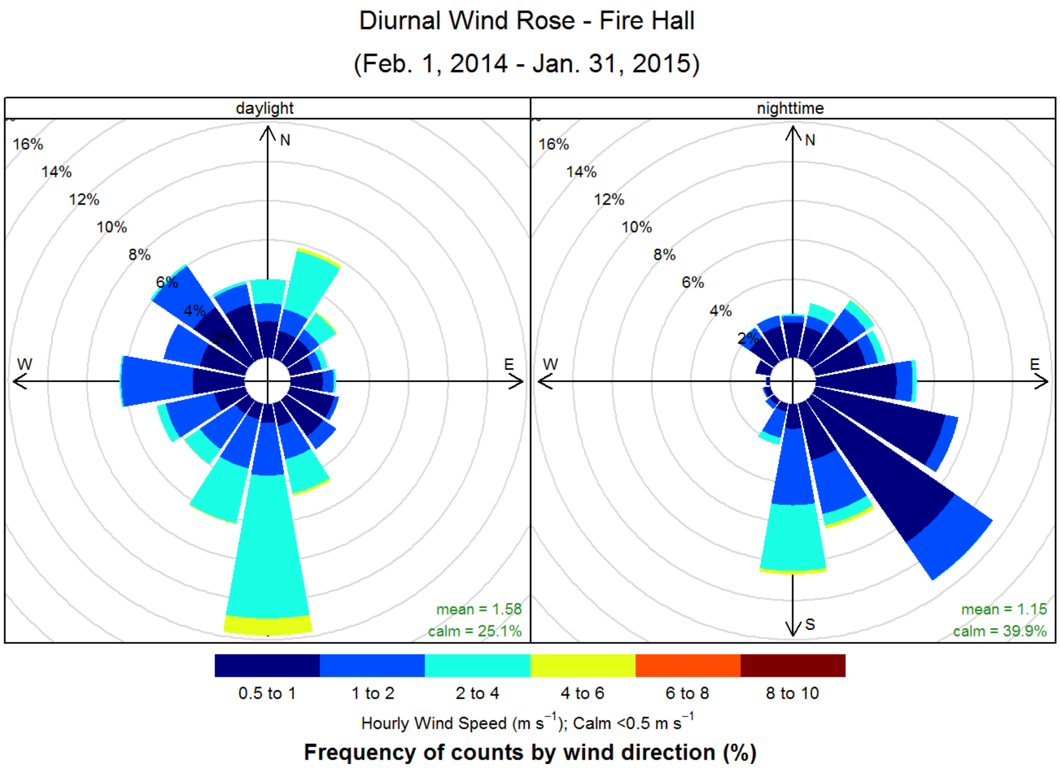

Figure 15: Annual day and nighttime wind roses showing diurnal patterns at the Fire Hall station (MAML).

Seasonally at the Fire Hall site, stronger winds came from the Alberni Inlet out of the south, and occurred both during the day and at night during the spring and summer months (Figure 16 and Figure 17). Stronger winds also blew from the north and northeast, especially during daylight hours in the fall and winter (Figure 18 and Figure 19). Lighter drainage flows from the southeast (from the Arrowview Heights area) were common at night throughout the year at the Fire Hall site. Light winds from the west and northwest were also observed during daylight hours in all seasons, and were most common in the summer and winter.

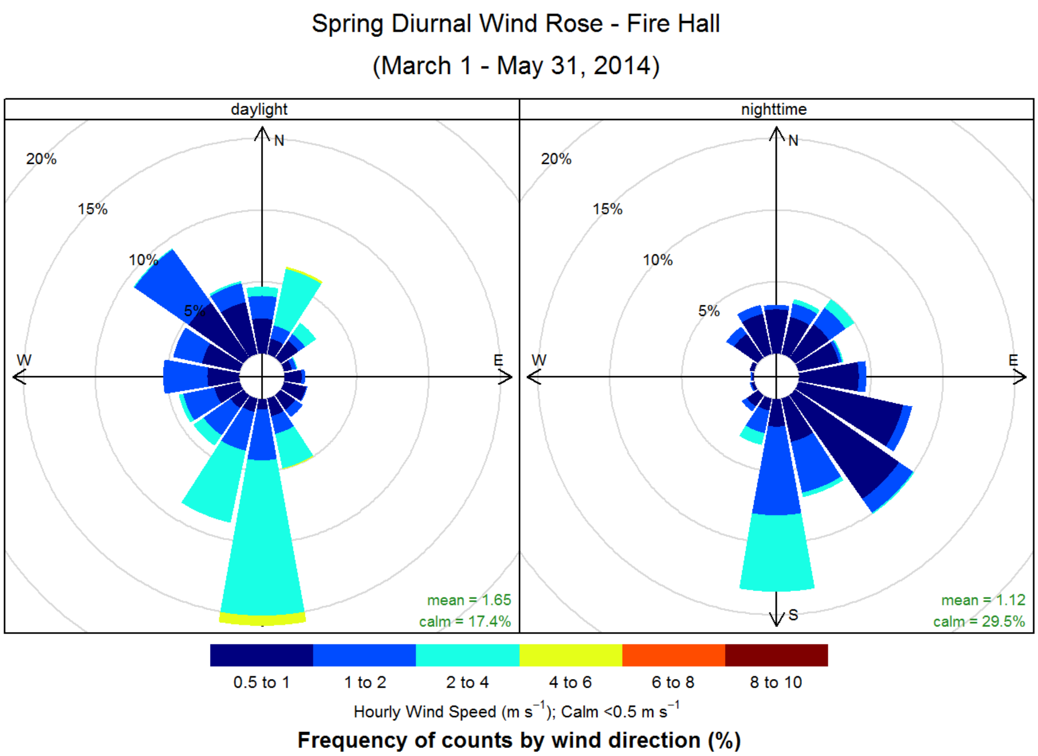

Figure 16: Day and nighttime wind roses showing diurnal patterns over the spring at the Fire Hall station (MAML).

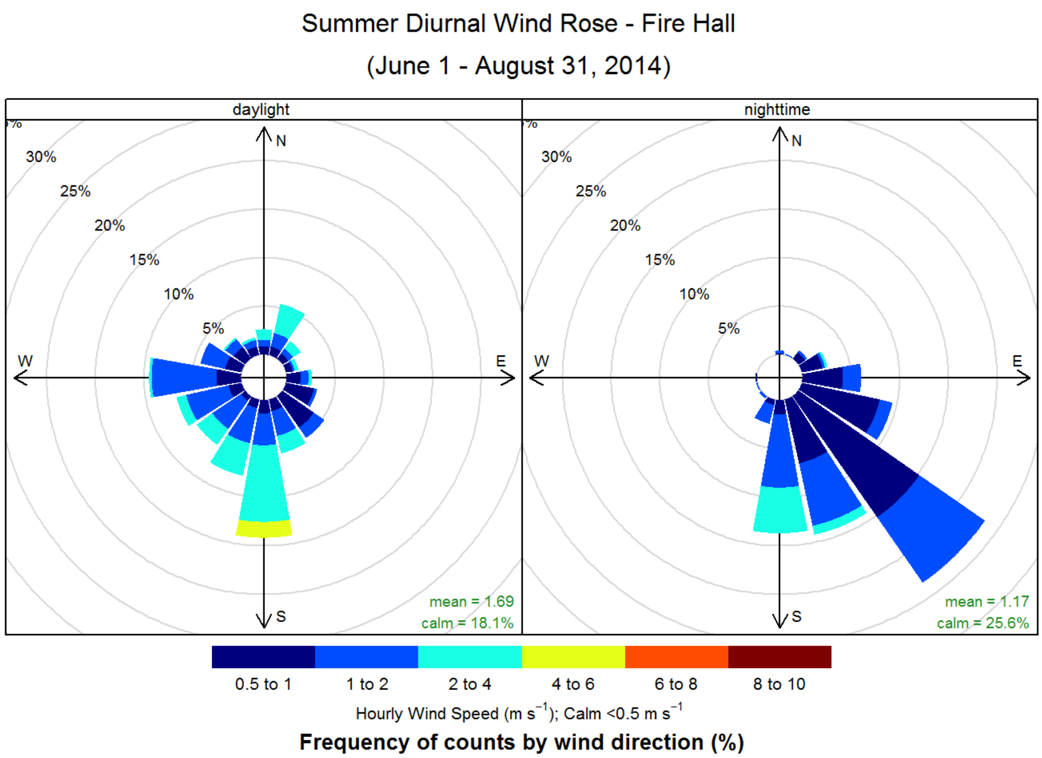

Figure 17: Day and nighttime wind roses showing diurnal patterns over the summer at the Fire Hall station (MAML).

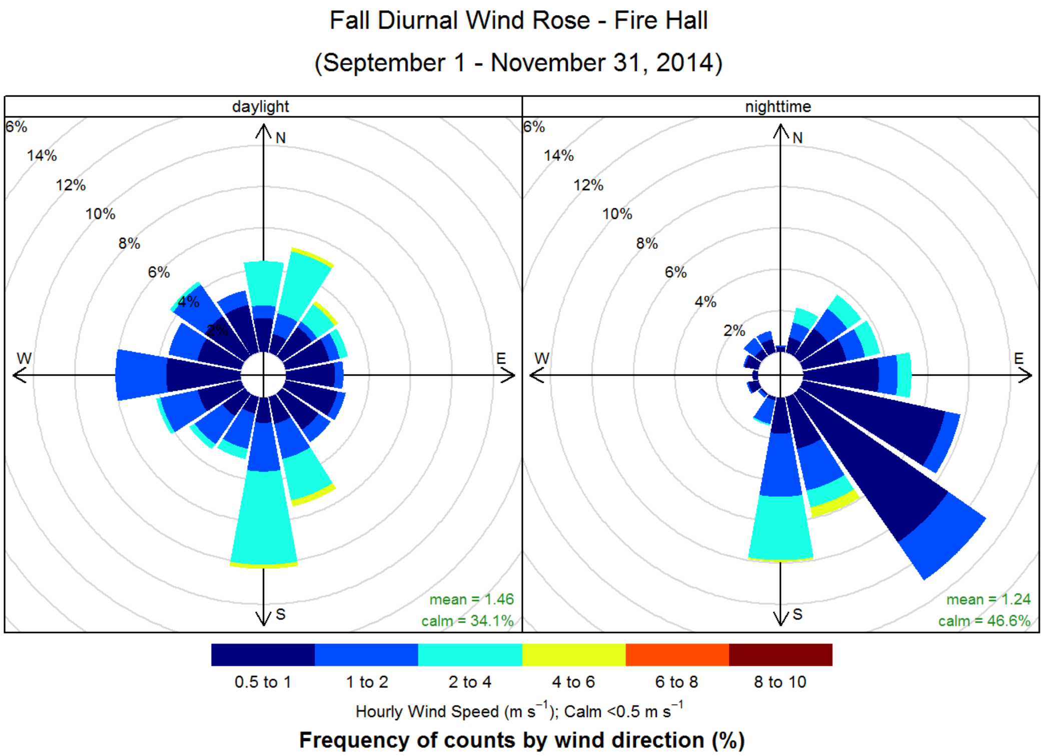

Figure 18: Day and nighttime wind roses showing diurnal patterns over the fall at the Fire Hall station (MAML).

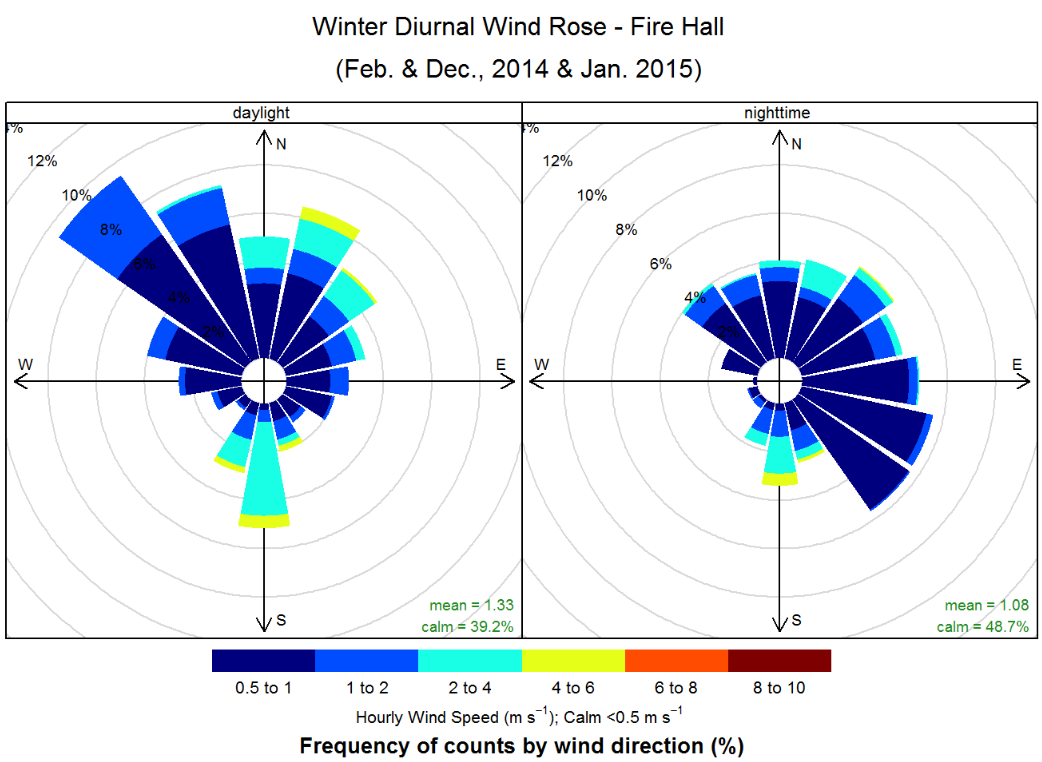

Figure 19: Day and nighttime wind roses showing diurnal patterns over the winter at the Fire Hall station (MAML).

3.4 Air Quality

3.4.1 BC Ambient Air Quality Objectives

The province of BC has developed Ambient Air Quality Objectives (AAQOs) to help inform decisions on air quality management in BC communities and air sheds. While there are also federal air quality targets (Canadian Ambient Air Quality Standards – CAAQS), this report will only refer to the BC AAQOs for $PM_{2.5}$, because they are either equal to, or more stringent than the CAAQS. The BC AAQOs and CAAQS for air contaminants considered in this report are provided in Table 6.

Table 6: Provincial and Federal Ambient Air Quality Objectives for CACs monitored in Port Alberni.

Pollutant	Averaging period	BC Objective
$PM_{2.5}$	24-hour[1]	25 $\mu g/m^3$
	Annual	8 $\mu g/m^3$
PM_{10}	24-hour	50 $\mu g/m^3$
SO_2	1-hour[2]	75 ppb
NO_2	1-hour[3]	100 ppb
	Annual	32 ppb
O_3	1-hour[4]	82 ppb
	8-hour[5]	63 ppb

[1] Daily average, annual 98th percentile, over one year
[2] Daily 1-hour maximum, annual 99th percentile value, over one year
[3] Daily 1-hour maximum, annual 98th percentile value, over one year
[4] For advisory purposes – no percentile for annual reporting
[5] 4th highest annual measurement, averaged over three consecutive years. Adopted by BC from CAAQS.

3.4.2 $PM_{2.5}$

Fine particulate matter ($PM_{2.5}$) has been measured at the Alberni Elementary School station since 2010 with a Model 1020 BAM (Beta-Attenuation Monitor). The BAM 1020 is an USEPA approved FEM (Federal Equivalent Method) for continuous $PM_{2.5}$ measurements. The MAML (Mobile Air Monitoring Laboratory) was stationed in the southeast corner of the Port Alberni Fire Hall parking lot from Jan. 28th, 2014 – Feb. 17th, 2015, and was equipped with an E-BAM to monitor air quality, including $PM_{2.5}$ and meteorology. This data was collected in order to examine spatial differences in $PM_{2.5}$ concentrations in Port Alberni and to determine if the Alberni Elementary School site was representative of conditions elsewhere in the City. Note that the E-BAM uses the same monitoring technology as the BAM but it is meant for surveillance purposes (not suitable for long-term monitoring). Hourly data from the E-BAM is typically noisier that what is measured from the BAM, especially at lower concentrations, while the 24-hour concentrations compare well between the units.

3.4.2.1 Alberni Elementary School

A summary of $PM_{2.5}$ concentrations measured at Alberni Elementary and compared to Provincial Air Quality Objectives (AQOs) is provided in Table 7 and Table 8. Annual average concentrations ranged from a low of 6.2 $\mu g/m^3$ in 2012 to a high of 8.2 $\mu g/m^3$ in 2013 and 2014. Annual average concentrations in 2013 and 2014 did not meet the Provincial AQO of 8 $\mu g/m^3$. Daily 98th percentile $PM_{2.5}$ concentrations ranged from a low of 17.9 $\mu g/m^3$ in 2012 to a high of 35.5 $\mu g/m^3$ in 2014. The provincial AQO for daily

$PM_{2.5}$ of 25 µg/m^3 was exceeded in 2013 and 2014 and there were more daily exceedances of the provincial AQO in 2013 and 2014 than in 2011 and 2012 (up to 5.4% of the time in 2013) - note that this metric is directly compared to daily levels of $PM_{2.5}$ for air quality advisory purposes.

Table 7: $PM_{2.5}$ measurements relative to provincial objectives at the Alberni Elementary and Fire Hall (MAML) monitoring stations.

$PM_{2.5}$ (µg/m^3)	Port Alberni Elementary School					
Year	Mean Hourly	24 Hr 98th Percentile	# Days > 25 µg/m^3	Percent of days > 25 µg/m^3	Valid hours	Valid days
2011	8.0	24.8	6	1.7%	8446	354
2012	6.2	17.9	1	0.3%	8405	355
2013	8.1	30.6	19	5.4%	8437	353
2014	8.1	35.5	13	3.6%	8692	364
Feb 1/2014- Jan 31/2015	8.2	38.5	15	4.1%	8692	365
	Fire Hall					
Feb 1/2014- Jan 31/2015	8.2	20.3	3	1.0%	7279	303

Table 8: Air quality results for criteria air contaminants in Port Alberni (provincial objectives in brackets, exceedances in red).

Objective		Alberni Elementary (Feb. 1, 2014 – Jan. 31, 2015)	BC Hydro (June 6, 2001 – Jan. 10, 2002)	Fire Hall (Feb. 1, 2014 – Jan. 31, 2015)	Town Site (Jan. 1, 2010 – Jan. 31, 2010)
$PM_{2.5}$ (µg/m^3)	24-hour [a]	38.5 (25)		20.3[1] (25)	
	Annual	8.2 (8)		8.2[1] (8)	
PM_{10} (µg/m^3)	24-hour [a]				19.4 (50)
SO_2 (ppb)	1-hour [b]	7.9 (75)		3.9[1] (75)	
NO_2 (ppb)	1-hour [c]		28.0[1] (100)	20.5[1] (100)	
	Annual		5.1[1] (32)	4.1[1] (32)	
O_3 (ppb)	1-hour [d]		49[1] (82)	54.6[1] (82)	
	8-hour [e]		36[1] (63)	41.5[1] (63)	

[a] Daily average, annual 98th percentile, over one year
[b] Daily 1-hour maximum, annual 99th percentile value, over one year
[c] Daily 1-hour maximum, annual 98th percentile value, over one year
[d] For advisory purposes – no percentile for annual reporting
[e] 4th highest annual measurement, averaged over three consecutive years
[1] Does not meet data requirements – provided only for comparative purposes

An examination of the time series of daily $PM_{2.5}$ values measured from June of 2010 to December 31st 2014 (Figure 20) indicated that $PM_{2.5}$ concentrations were relatively low (good air quality) during the spring and summer months but increased during the fall and winter months. All of the exceedances of the daily AQO in all years occurred during the colder months. Dispersion meteorology is much poorer at this time of the year and there are additional sources of $PM_{2.5}$ in the airshed – e.g. residential/commercial/ industrial heating, open burning, increased idling, etc.

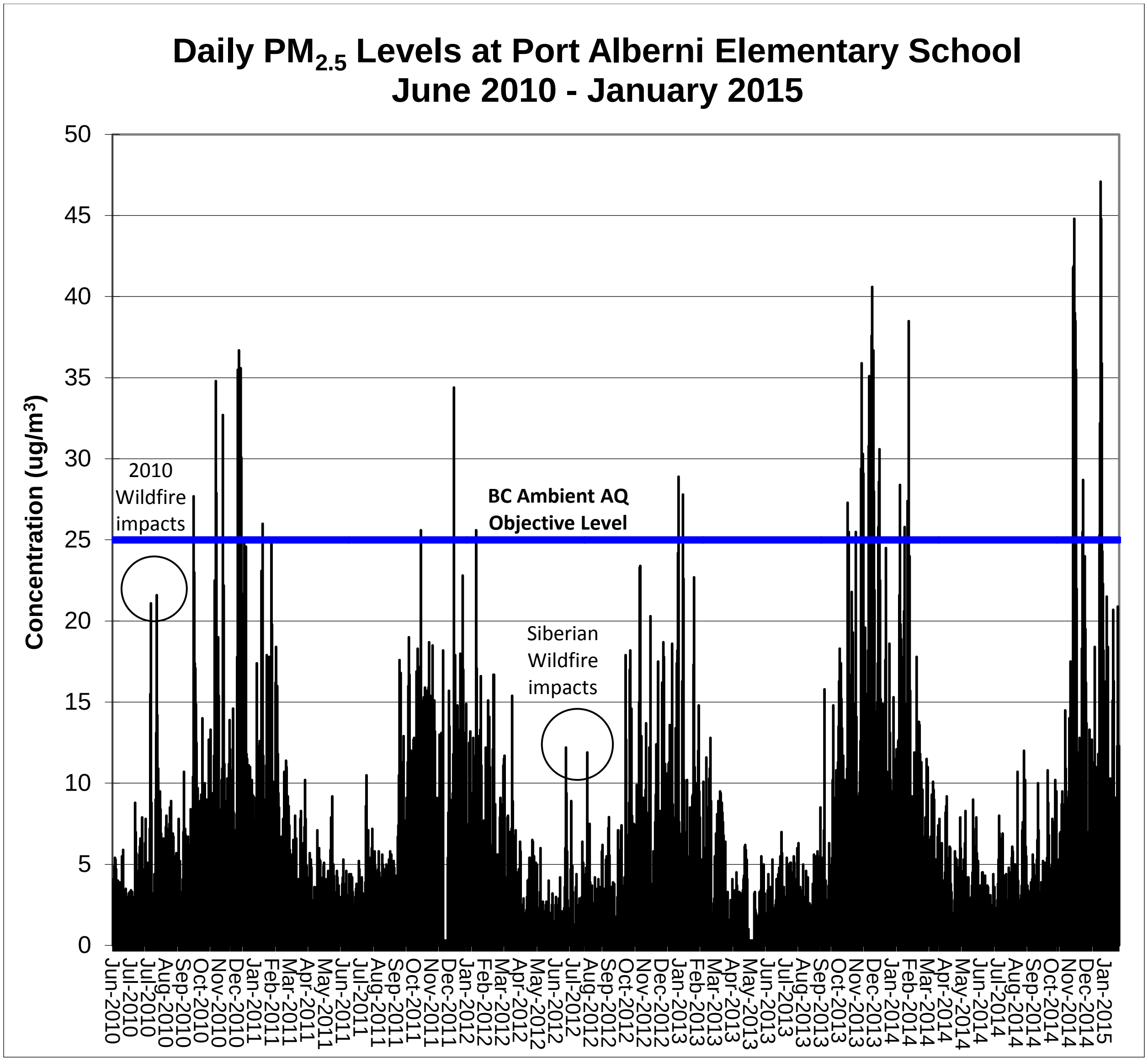

Figure 20: Daily $PM_{2.5}$ measurements at the Port Alberni Elementary School station from June 1, 2010 to January 31, 2015, relative to the 24-hour provincial objective.

Figure 21 shows $PM_{2.5}$ levels from a number of air quality monitoring stations across the province (BC Lung, 2015) in 2014. The Port Alberni Elementary School site ranked 9th highest out of 43 communities reporting $PM_{2.5}$ concentrations across the province.

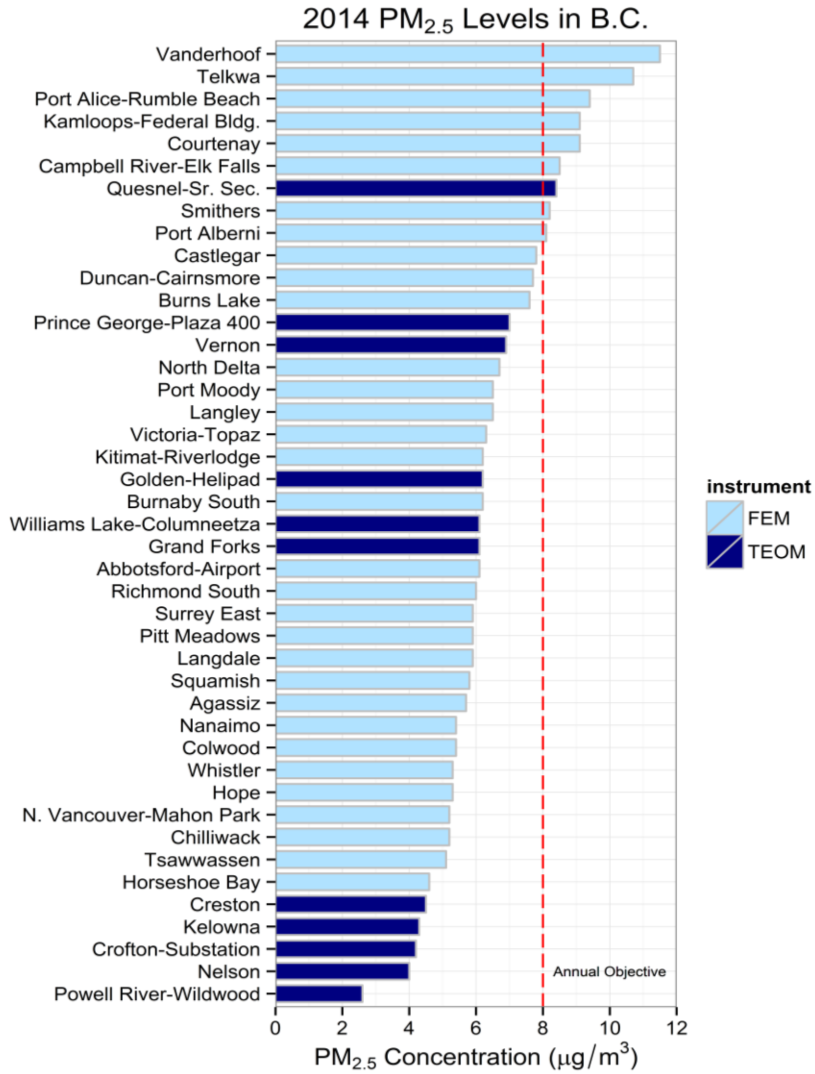

Figure 21. Annual average $PM_{2.5}$ levels across British Columbia in 2014 (BC Lung, 2015).

Temporal patterns in $PM_{2.5}$ concentrations at the Alberni Elementary station over the entire monitoring period (June 1, 2010 – Sept. 30, 2015) can be seen in Figure 22. Monthly average $PM_{2.5}$ concentrations were highest from November to February and lowest in June. The day of the week (Hebdomadal) analysis indicates that concentrations tended to increase over the weekend with a maximum average concentration on Sundays, and decrease during the week with the lowest concentrations occurring on Friday. The maximum concentrations on the weekend suggest that additional $PM_{2.5}$ sources came into play over and above what is experienced during the week. These additional sources may have included residential backyard burning and/or increased wood stove usage, which are both more prevalent while people are at home. Hour of the day (diurnal) concentrations showed an afternoon minimum concentration consistent with surface heating (and associated good ventilation) and evening maximums, with the highest concentrations occurring near midnight. A secondary maximum during mid-morning also occurred. Secondary morning peaks typically occur once surface heating is sufficient to break down the nocturnal inversion and short-term fumigation events occur (see section 3.2.1). It can also reflect additional sources at this time of day such as rush hour traffic and morning wood heat emissions.

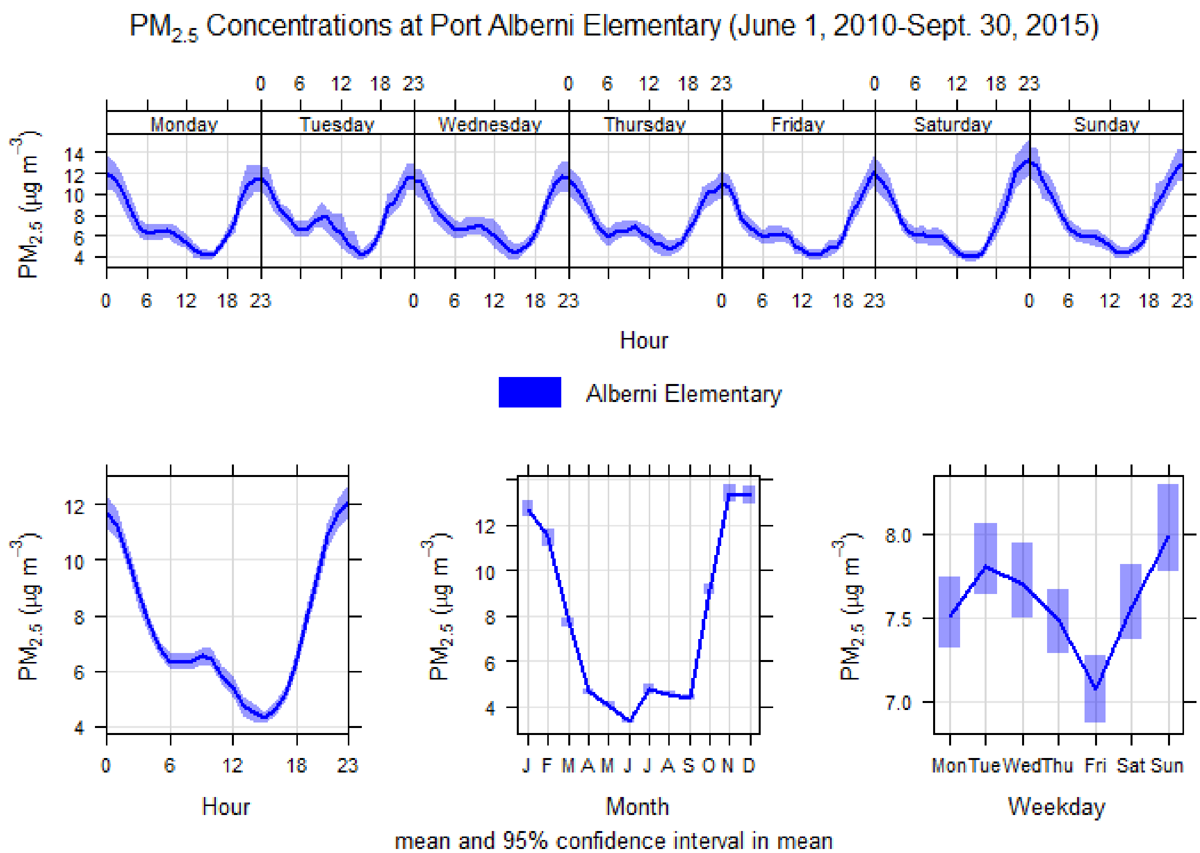

Figure 22: Temporal patterns for $PM_{2.5}$ concentrations at the Alberni Elementary station (June 1, 2010 – Sept. 30, 2015).

A pollution rose is produced by pairing hourly air quality concentration data with hourly wind direction information to produce a chart similar to a wind rose. Pollution transport is generally determined based on wind direction, so wind and pollution roses generally have the same shape. A pollution rose shows the relative contribution from different directions to the total pollution recorded at a specific location, and the relative frequency at which different concentrations of pollution were recorded as coming from those directions. This information can be useful for source apportionment and mitigation purposes.

The 2014/15 annual pollution rose for Alberni Elementary indicated that higher concentrations of $PM_{2.5}$ were recorded when wind was blowing from the north, and in particular from the northeast quadrant (Figure 23). When broken down by season, almost all of the highest concentrations were recorded during the autumn and winter, with winds blowing from the northeast tending to have the highest frequencies of elevated concentrations. Higher frequencies of low $PM_{2.5}$ concentrations tended to come from the southwest during the spring and summer months (the direction of the Port and Catalyst pulp mill). There is a dense residential area in the northeast direction and the community of Cherry Creek (Regional District Electoral Area E) is also in this direction.

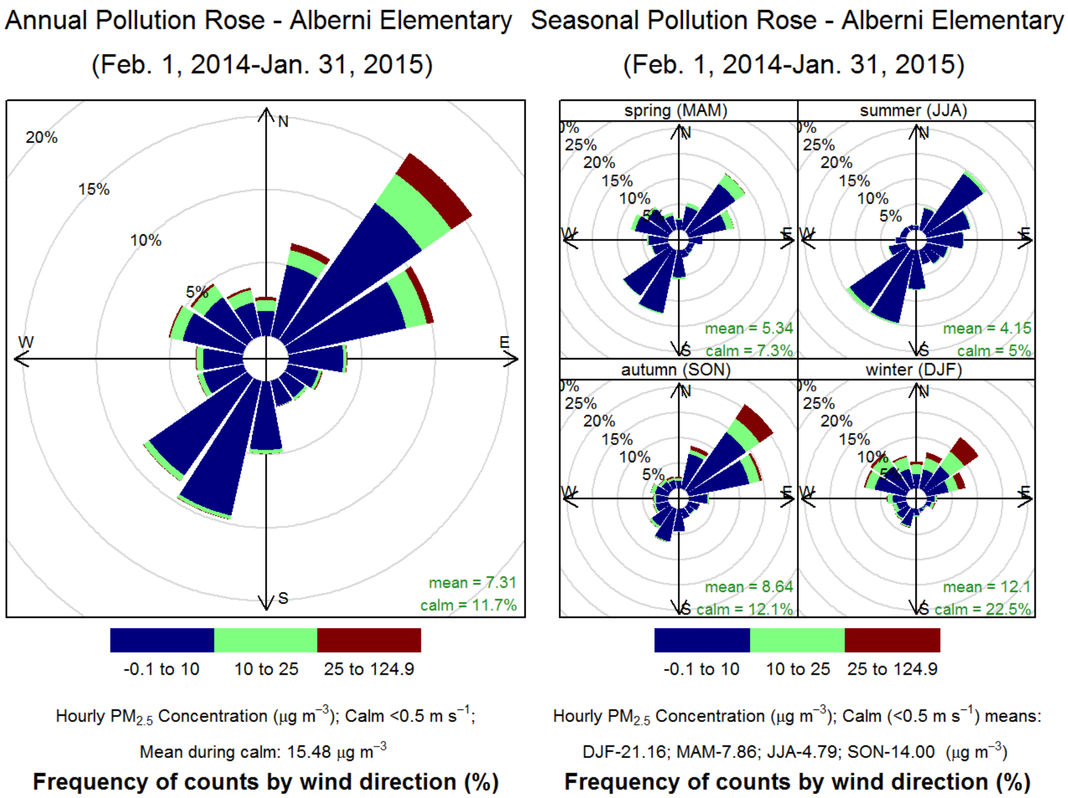

Figure 23: Annual and seasonal pollution roses of $PM_{2.5}$ from the Port Alberni Elementary station. Spokes on the roses represent pollution coming from those compass directions, with colours denoting $PM_{2.5}$ concentrations.

Given the seasonal nature of the highest values, likely sources include emissions from residential wood heating, emissions from residential back yard burning, and emissions from open burning (agricultural/developer land clearing, and forestry operations). Forest harvesting and wildfire hazard abatement (slash burning) activities occur throughout the region during the fall. October is generally the first month in which local forest companies and land developers are able to open burn woody debris, as the moisture in the surrounding fuels is sufficient to prevent escape which might result in a wildfire. Most forestry hazard abatement burning is complete by mid-November while development/agricultural land clearing burning can occur all winter if venting conditions are suitable. The City of Port Alberni prohibits residential backyard burning until October 15th and land-clearing burning is prohibited all year-round. However, there are no open burning restrictions in the ACRD (e.g. Cherry Creek). This activity is the dominant source of wood smoke during the fall. Once colder temperatures settle in, people also begin to heat their residences using woodstoves. A provincial wood stove survey conducted in 2012 found that about 24% of households (or about 1 in 4) in Port Alberni use wood for heating (Envirochem, 2012). Emissions from the Catalyst pulp mill and the local sawmills occur all year long and also contribute to $PM_{2.5}$ emissions in the airshed. However, the pulp mill is situated to the SW of the monitoring station and does not appear to contribute significantly to the $PM_{2.5}$ concentrations measured at this location during the fall and winter months.

The annual diurnal (daytime vs. night time) pollution roses for Alberni Elementary (Figure 24) shows that the majority of the higher $PM_{2.5}$ concentrations occurred at night, which strongly suggests wood smoke from sources like wood stoves and open burning in the evening to be the primary cause of $PM_{2.5}$ exceedances at Alberni Elementary. However, any source of emissions emitted into the stable layer during the evening hours would also contribute to these patterns (e.g. industrial, commercial, and mobile emissions). During the day, air coming from the Alberni Inlet up through the port area to the school had relatively low $PM_{2.5}$ concentrations.

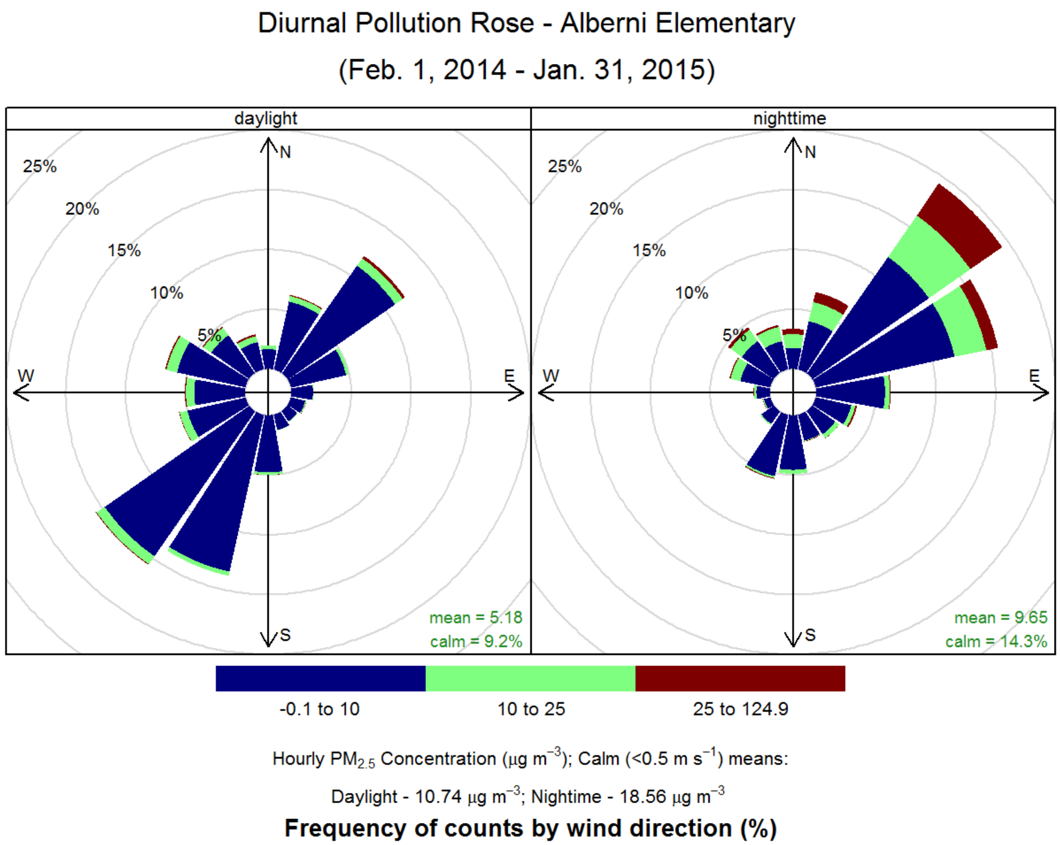

Figure 24: Annual pollution rose showing diurnal patterns in $PM_{2.5}$ concentrations at the Alberni Elementary station in 2014.

Seasonal diurnal pollution roses (Figures 25-28) showed that hourly $PM_{2.5}$ concentrations rarely reached medium (10-25 $\mu g/m^3$) or high (> 25 $\mu g/m^3$) values during daylight hours in the spring and summer. Medium and high $PM_{2.5}$ concentrations occurred most frequently at night in the fall and winter when drainage flows were coming from sources to the northeast of Alberni Elementary. In the winter, medium and high concentrations of $PM_{2.5}$ also came from the north and northwest during both the day and nighttime hours. This points to open burning and residential heating sources in that sector (the Beaver Creek area).

Mean $PM_{2.5}$ concentrations for all wind conditions other than calms (wind speed < 0.5 m/s) were highest in the winter (14.3 $\mu g/m^3$ at night and 8.6 $\mu g/m^3$ during the day) followed by fall (10.8 $\mu g/m^3$ at night and 5.9 $\mu g/m^3$ during the day). Calm winds occurred most frequently in the winter (25.3% at night and 17.4% during the day), followed by the fall (12.5% at night and 11.6% during the day). Mean $PM_{2.5}$ concentrations during calm wind conditions were highest in the winter (23.1 $\mu g/m^3$ at night and 16.0 $\mu g/m^3$ during the day), followed by fall (15.8 $\mu g/m^3$ at night and 11.6 $\mu g/m^3$ during the day).

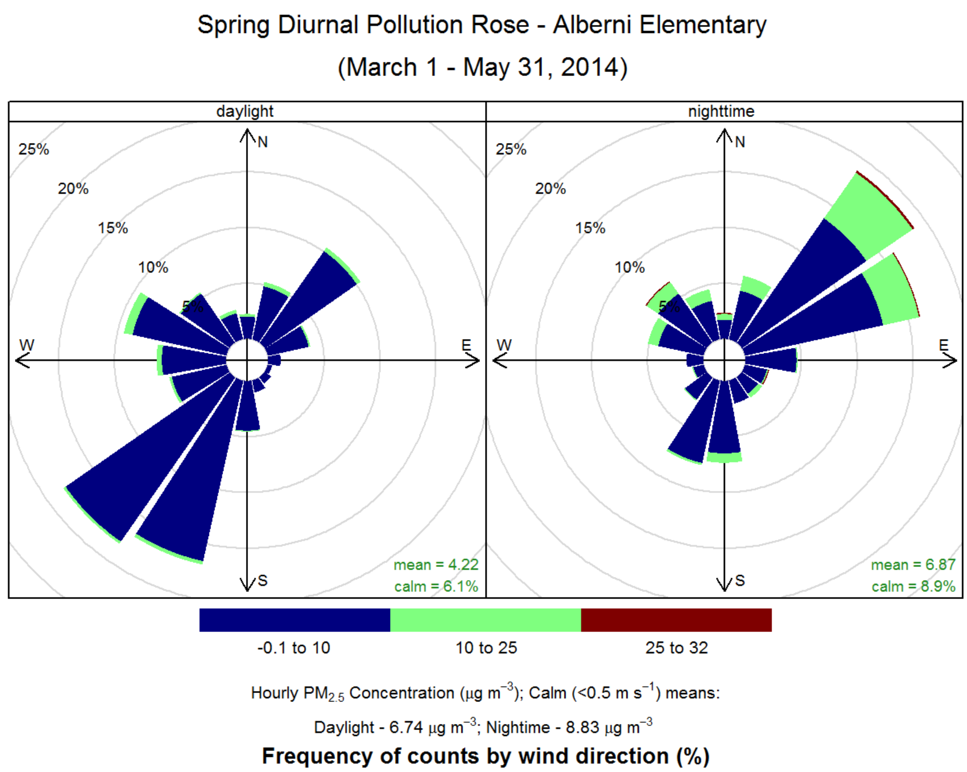

Figure 25: $PM_{2.5}$ pollution roses showing day and nighttime patterns during the spring at the Alberni Elementary station.

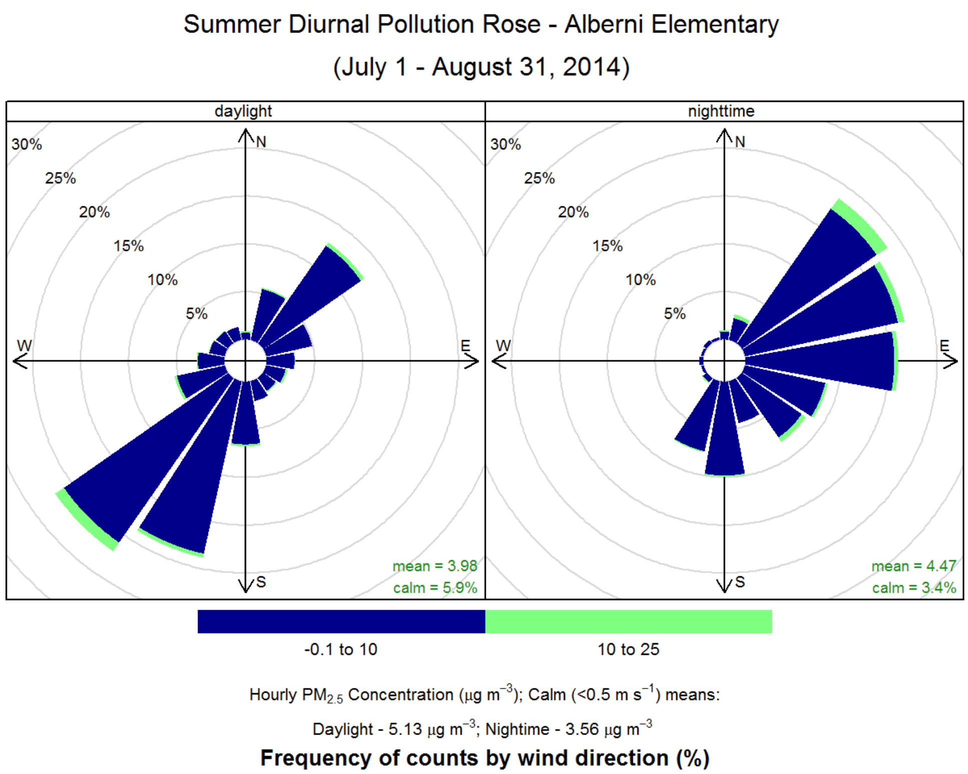

Figure 26: $PM_{2.5}$ pollution roses showing day and nighttime patterns during the summer at the Alberni Elementary station.

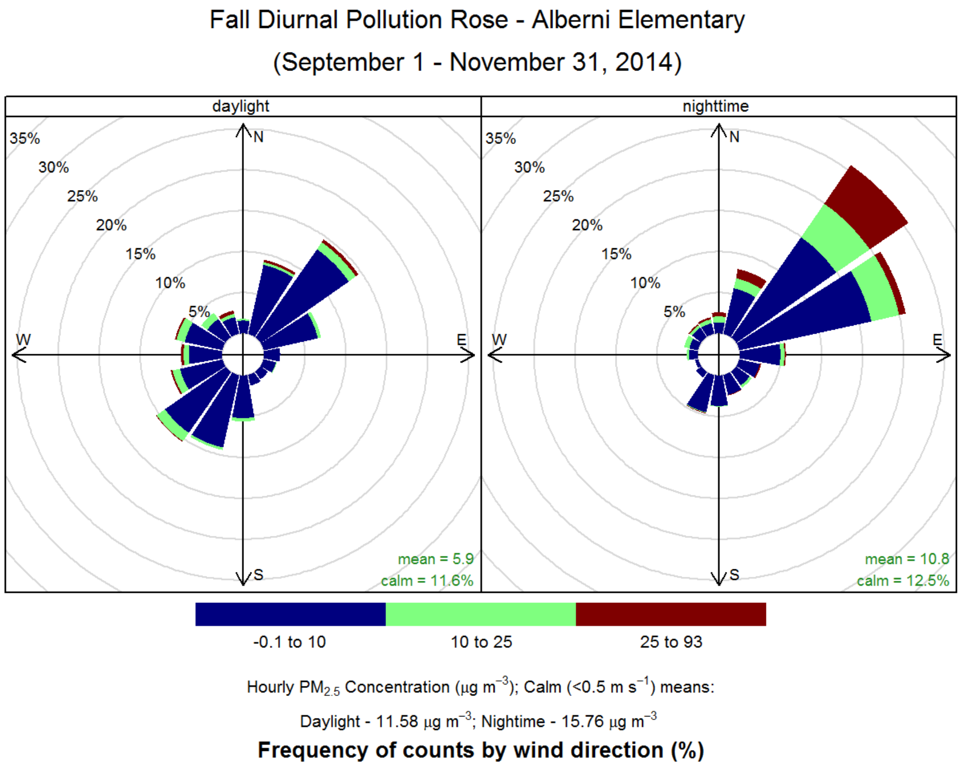

Figure 27: $PM_{2.5}$ pollution roses showing day and nighttime patterns during the fall at the Alberni Elementary station.

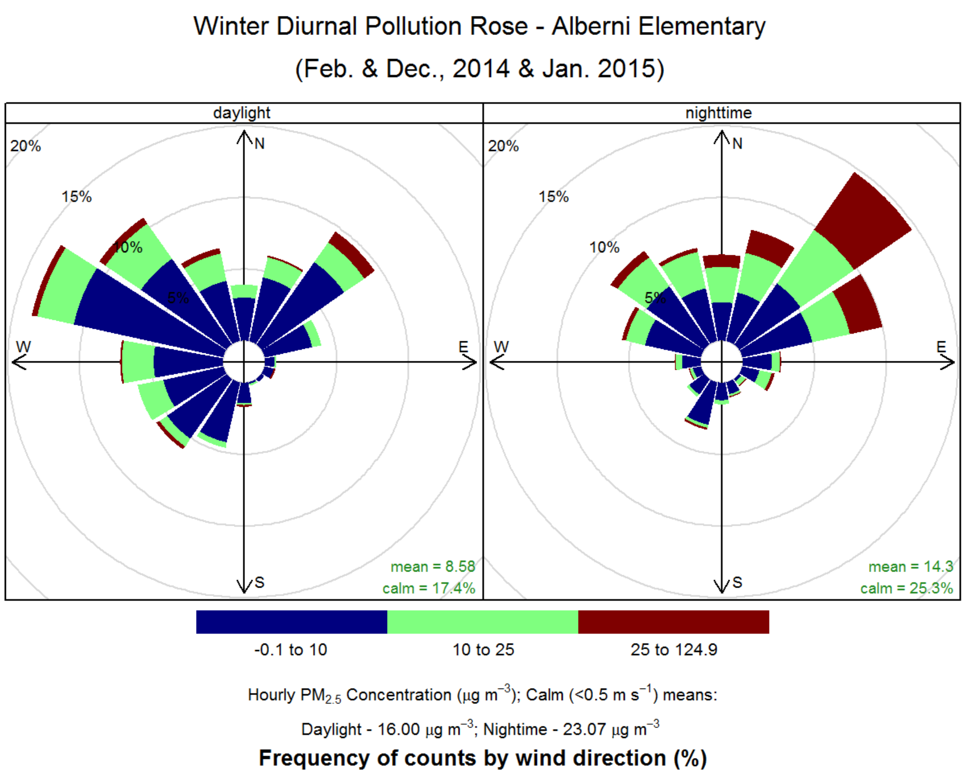

Figure 28: $PM_{2.5}$ pollution roses showing day and nighttime patterns during the winter at the Alberni Elementary station.

Elevated $PM_{2.5}$ concentrations when winds are calm suggest that local sources (wood stoves) are important near the measurement site. It is also notable that peak $PM_{2.5}$ concentrations occurred in the winter, when widespread wood stove use and open burning (residential backyard burning and non-forestry related open burning) were most common.

3.4.2.2 Site Comparisons Fire Hall (MAML) vs. Alberni Elementary

Data collected over the same period (Feb. 1, 2014 – Jan. 31, 2015) from both the Alberni Elementary and Fire Hall stations were analyzed in this section in order to compare patterns between the two sites. The Fire Hall was not operating long enough in 2014 to meet data completeness criteria. However, for comparative purposes, a full year of data was used from both sites (January 31, 2014 to February 1, 2015) and this year is considered complete.

A summary of $PM_{2.5}$ concentrations measured at the Alberni Fire Hall and compared to Provincial Air Quality Objectives (AQOs) is provided in Table 7 and Table 8. The annual average calculated from January 31, 2014 to February 1st 2015 exceeded the Provincial AQO at 8.2 $\mu g/m^3$ (the same as at Alberni Elementary) while the 98th percentile daily concentration met the AQO at 20.3 $\mu g/m^3$. The daily AQO of 25 $\mu g/m^3$ was exceeded 3 times during the period of monitoring vs. the 15 exceedances experienced at the Alberni Elementary site over the same time period. Data collected suggests that air quality was slightly better at the Fire Hall site from January 2014-February 2015 than at Alberni Elementary. It also suggests that the Alberni Elementary station is well located in terms of being able to measure worst case $PM_{2.5}$ impacts for residents of Port Alberni.

A graph of the paired daily mean $PM_{2.5}$ data collected over the same period at the Alberni Elementary and Fire Hall stations (Figure 29) shows that while $PM_{2.5}$ concentrations were generally quite similar, extreme values during the winter months tended to be much higher at the Alberni Elementary station. This can also be seen statistically in the higher 98th percentile of daily averages and the higher number of exceedances of the provincial objective at the Alberni Elementary station over the same time period (Table 7 and Table 8).

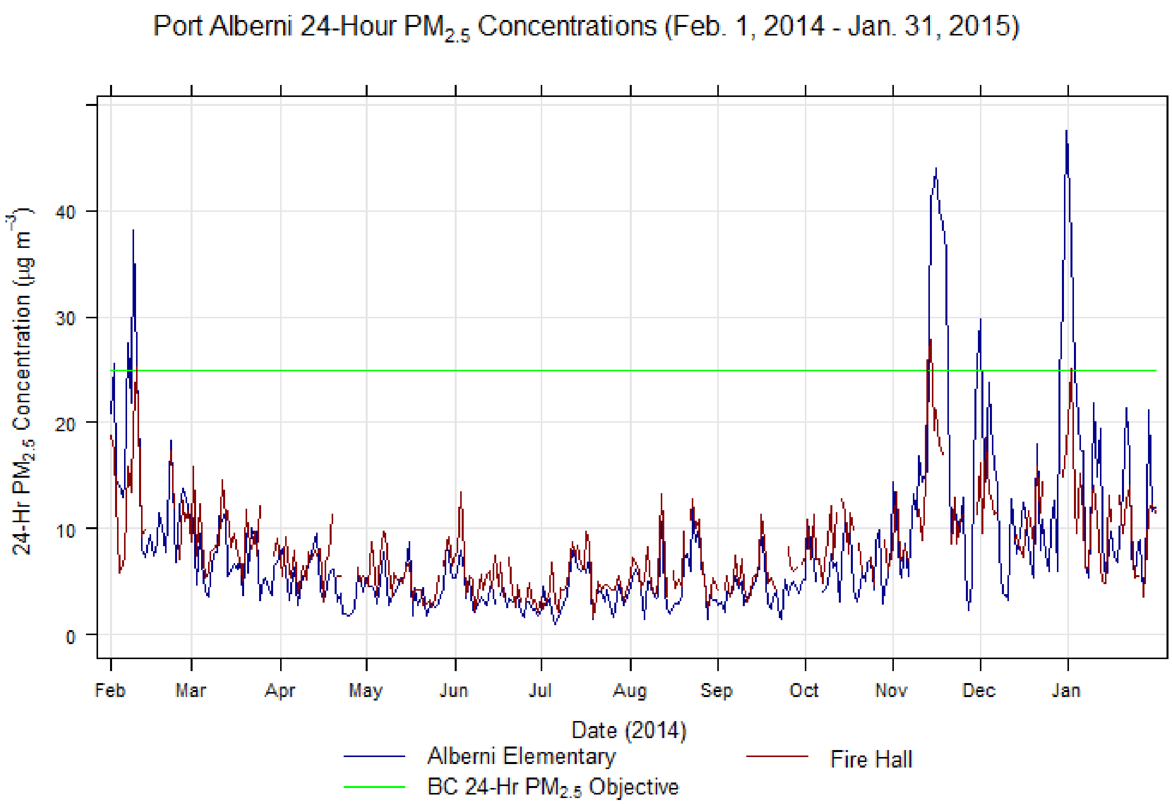

Figure 29: Daily average $PM_{2.5}$ results from Alberni Elementary (BAM) and Fire Hall (E-BAM) stations (Feb. 1, 2014 – Jan. 31, 2015). Provincial 24-hour objective is 25 µg/m^3.

Monthly, weekly, and daily $PM_{2.5}$ patterns at the Alberni Elementary and Fire Hall stations are shown in Figure 30. Monthly mean concentrations at both sites showed relatively low $PM_{2.5}$ concentrations from May until September, and then degraded air quality through the fall and winter months. It is interesting to note that warm month $PM_{2.5}$ concentrations were slightly higher at the Fire Hall site (although still very low) while cold month concentrations were higher at Alberni Elementary. As described in section 3.3.2.1 above, $PM_{2.5}$ concentrations tended to be highest over the weekend at the Alberni Elementary. Weekend values were elevated at the Fire Hall site as well (but not as high as Alberni Elementary), but the maximum value occurred on Friday. The late weekday values were higher than those experienced at Alberni Elementary, suggesting that different source types may be having an influence in this location.

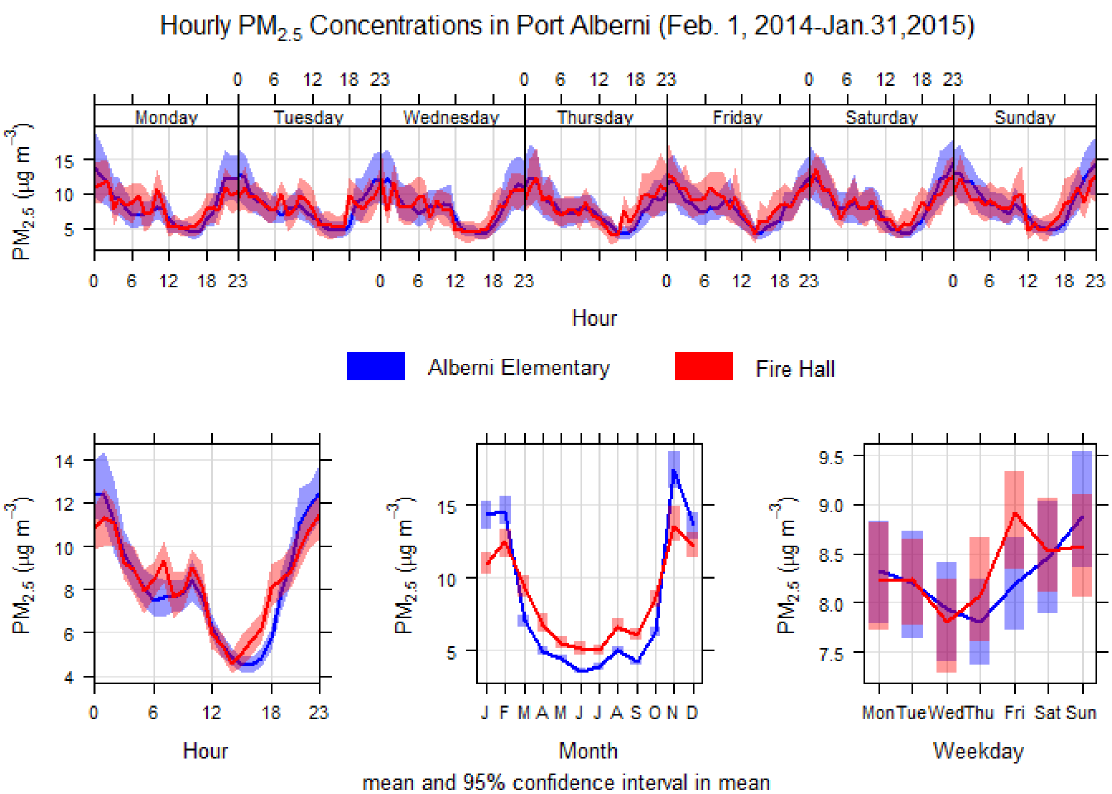

Figure 30: A comparison of temporal patterns for $PM_{2.5}$ measured at the Alberni Elementary and Fire Hall (MAML) stations over 12 months (Feb. 1, 2014 – Jan. 31, 2015).

Temporal patterns for the fall and winter months were further examined in Figure 31 and Figure 32 as these were the months that experienced degraded air quality at both locations. During the fall, average $PM_{2.5}$ concentrations were smilar at both sites on Monday, Tuesday and Wednesday. However, concentrations were higher later in the week at the Fire Hall than at the Alberni Elementary site; average concentrations became higher at the Alberni Elementary site on Weekends. During the winter months, $PM_{2.5}$ concentrations were higher at the Alberni Elementary site on every day of the week. As described in 3.3.2.1 above, air quality at the Alberni Elementary School site during the winter is affected by activities from the NE sector, much of which is outside of city limits. Emissions from activities such as residential backyard burning and open burning (weekend effects) in this area appear to have a more localized impact on the northern part of the community. Hourly concentration patterns suggest woodstove impacts at both locations with maximum $PM_{2.5}$ values occurring between 11:00PM and 1:00AM.

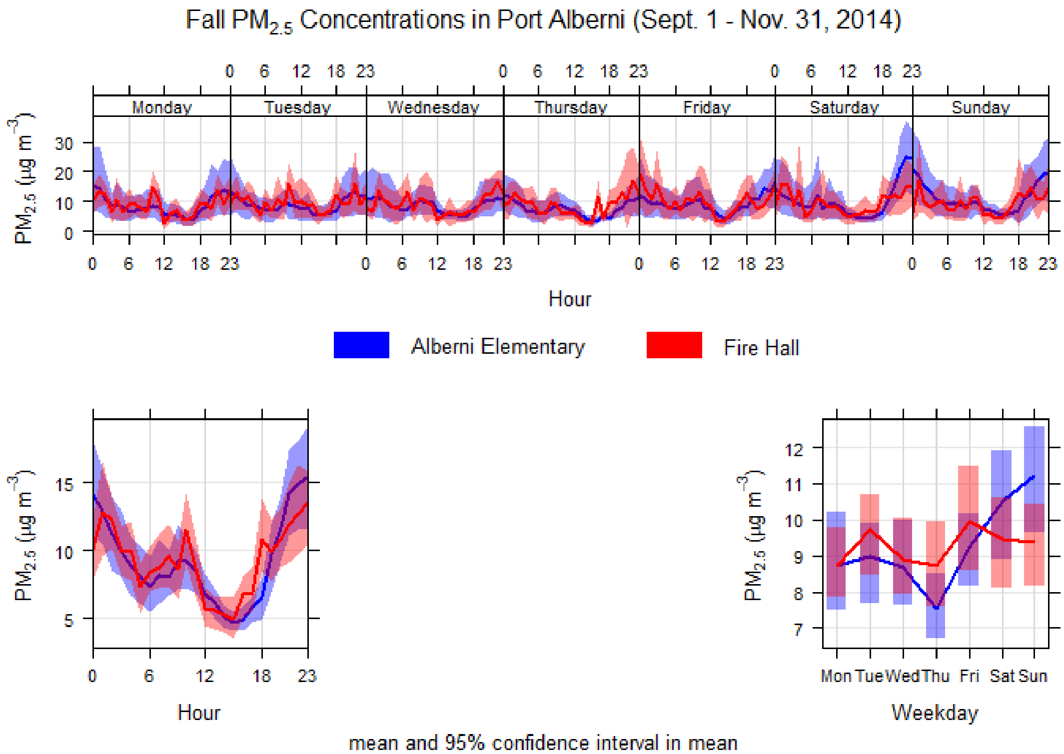

Figure 31: A comparison of temporal patterns for $PM_{2.5}$ measured at the Alberni Elementary and Fire Hall (MAML) stations during the fall months (Sept. 1 – Nov. 31, 2014).

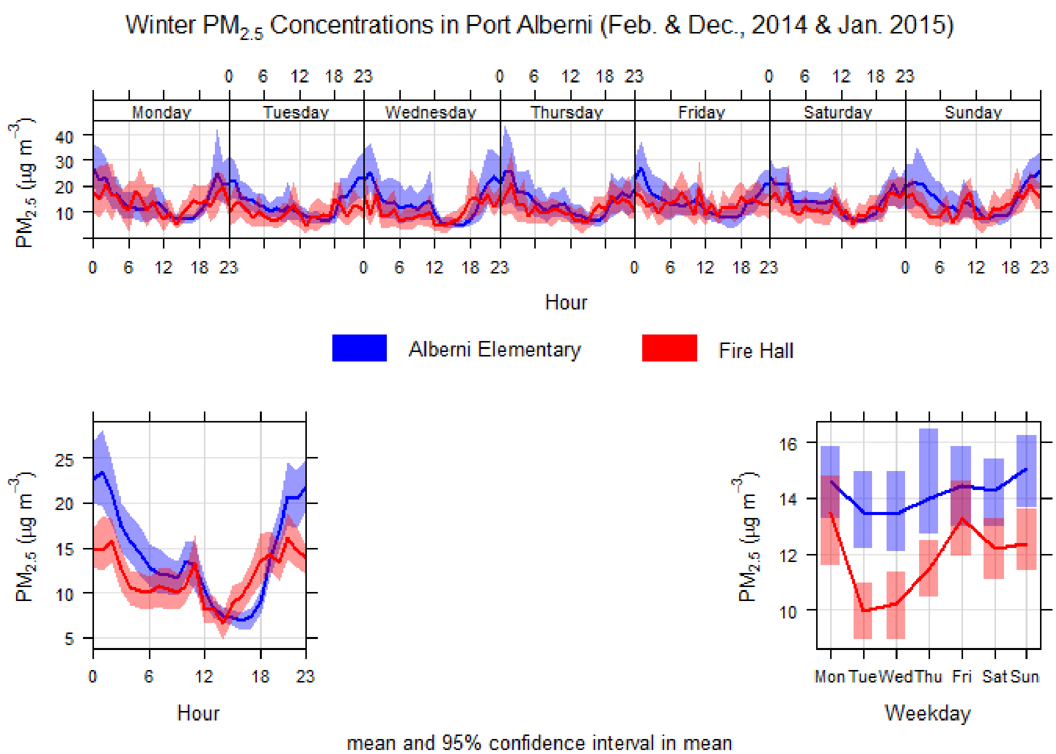

Figure 32: A comparison of temporal patterns for $PM_{2.5}$ measured at the Alberni Elementary and Fire Hall (MAML) stations during the winter months (Feb. & Dec. of 2014 and Jan. of 2015).

The 2014/15 annual pollution rose for the Fire Hall showed that although the most common wind directions associated with high frequencies of $PM_{2.5}$ were from the south and southeast, higher hourly concentrations were recorded when winds were from all directions (Figure 33). The highest frequency of elevated concentrations again tended to be measured in autumn and winter. The seasonal pollution rose breakdown also showed that $PM_{2.5}$ came from more dispersed directions at the Fire Hall than at Alberni Elementary, with contributions in the winter coming from almost all directions, though still with the highest frequencies out of the Southeast. The multi-directional nature of pollutant contributions at this location indicates that local sources play a significant role. However, it also suggests that other sources may be important. For example, the area pulp mill to the northwest of the Fire Hall site is closer to this monitoring site than to the Alberni Elementary station. The Fire Hall site is also higher in elevation (39 m ASL vs. 18 m ASL) and may be more easily impacted by point source stack emissions that are trapped under a low ceiling during the winter months.

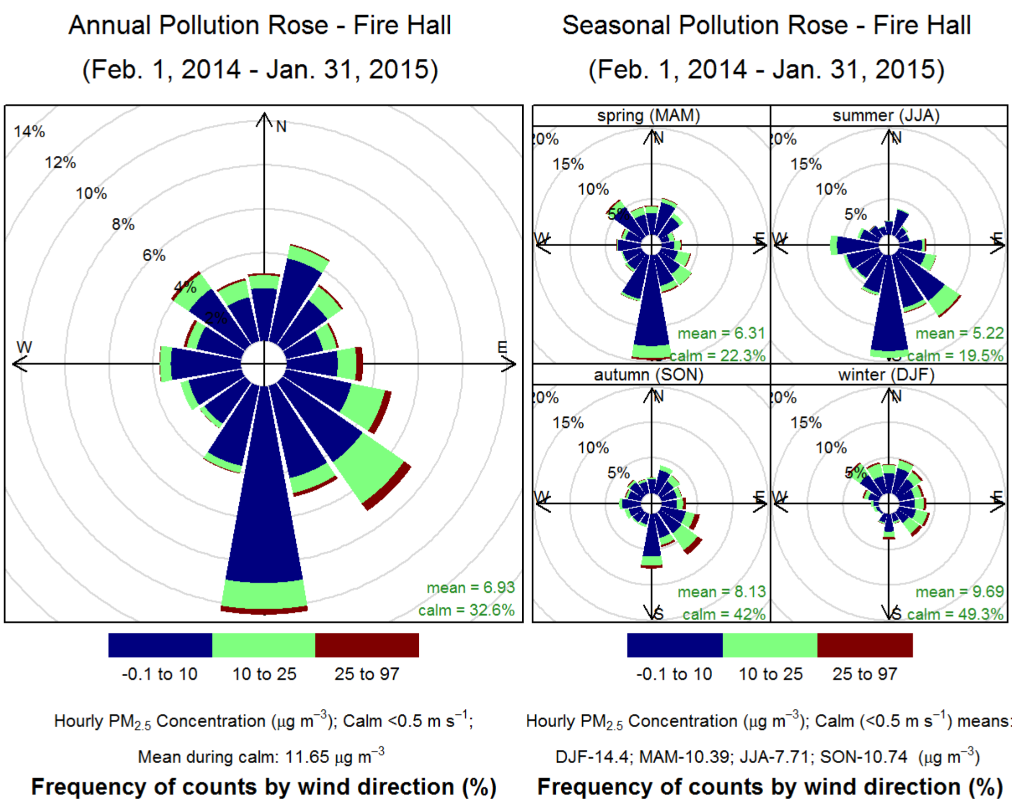

Figure 33: Annual and seasonal pollution roses of $PM_{2.5}$ from the Fire Hall station (MAML). Spokes on the roses represent pollution coming from those compass directions, with colours denoting $PM_{2.5}$ concentrations.

The Fire Hall annual diurnal pollution roses (Figure 34) are similar to those of Alberni Elementary in that they both show that higher $PM_{2.5}$ concentrations were recorded more often at night (average concentration 12.9 µg/m^3) than during the day (9.6 µg/m^3). That said, higher concentrations were observed more often during daylight hours at the Fire Hall station than at the Alberni Elementary station. The largest source of $PM_{2.5}$ at night came from the same direction as the prevailing wind – from the southeast sector. This repeated pattern of highest $PM_{2.5}$ concentrations occurring at night again suggests residential wood stove smoke and residential backyard burning (fall, winter and spring). One other possible source, however, could be smouldering overnight fires from resource management burning or residential burning on elevated terrain to the east of the city (Arrowview Heights). Based on the wind patterns, smoke generated on elevated terrain to the east could be brought down into the City with night time drainage winds, and would be less likely to impact the city during the day when dispersion is better and upslope flows are being generated.

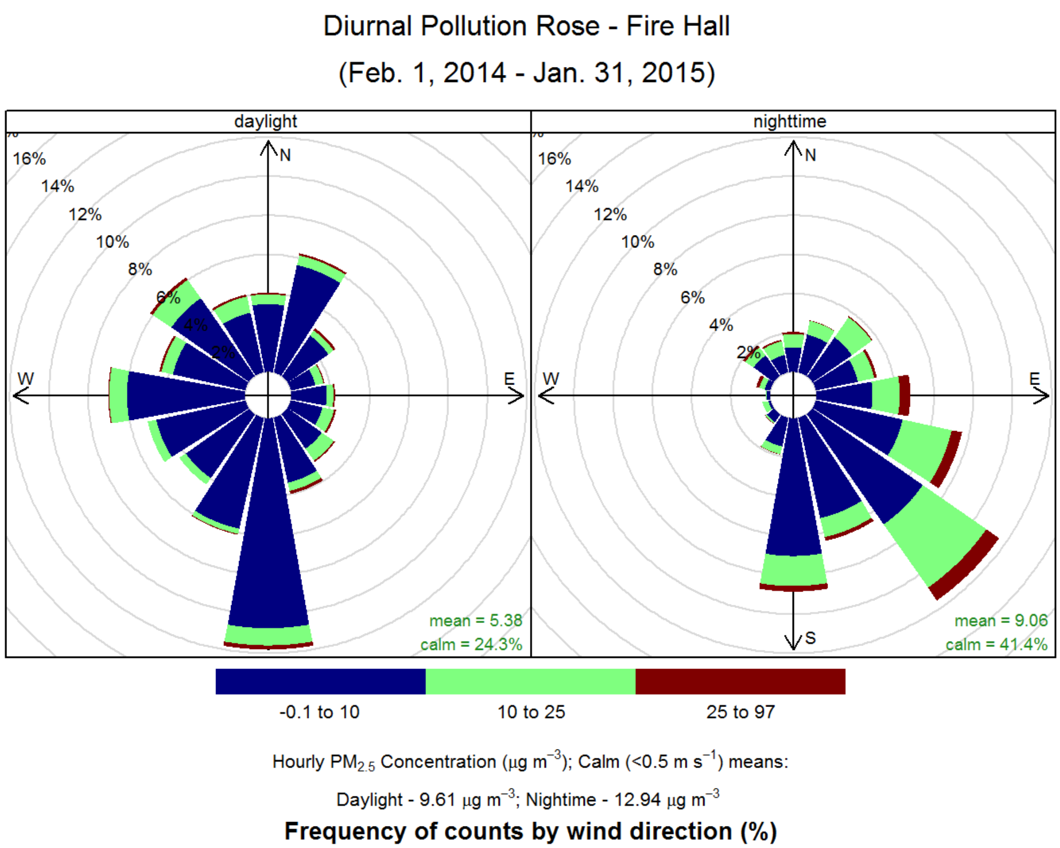

Figure 34: Annual pollution rose showing diurnal patterns in $PM_{2.5}$ concentrations at the Fire Hall station (MAML) in 2014.

Moderate $PM_{2.5}$ concentrations (between 10 and 25 µg/m^3) occurred more regularly throughout the year at the Fire Hall station than they did at the Alberni Elementary station, both during the day and at night. In the spring, summer and fall, the majority of moderate and some high concentrations of $PM_{2.5}$ occurred at night with light drainage winds from the southeast sector (Figures 35-37). A higher proportion of winds at night from the southeast had moderate and high (hourly concentrations < 25 µg/m^3) concentrations of $PM_{2.5}$ in the fall and winter (Figures 37 and 38); however there is also a secondary northeast component. Again, this suggests that activities to the southeast of the Fire Hall site may be having an impact on air quality. An examination of the daylight wintertime pollution rose at the Fire Hall indicates that high to moderate $PM_{2.5}$ concentrations are recorded when winds are out of the northwest sector. This suggests that industrial sources located in this sector may have more of an impact at this location during the winter months than at the Alberni Elementary site where southwest winds (from the industrial sector at this site) did not result in the same magnitude of $PM_{2.5}$ concentrations.

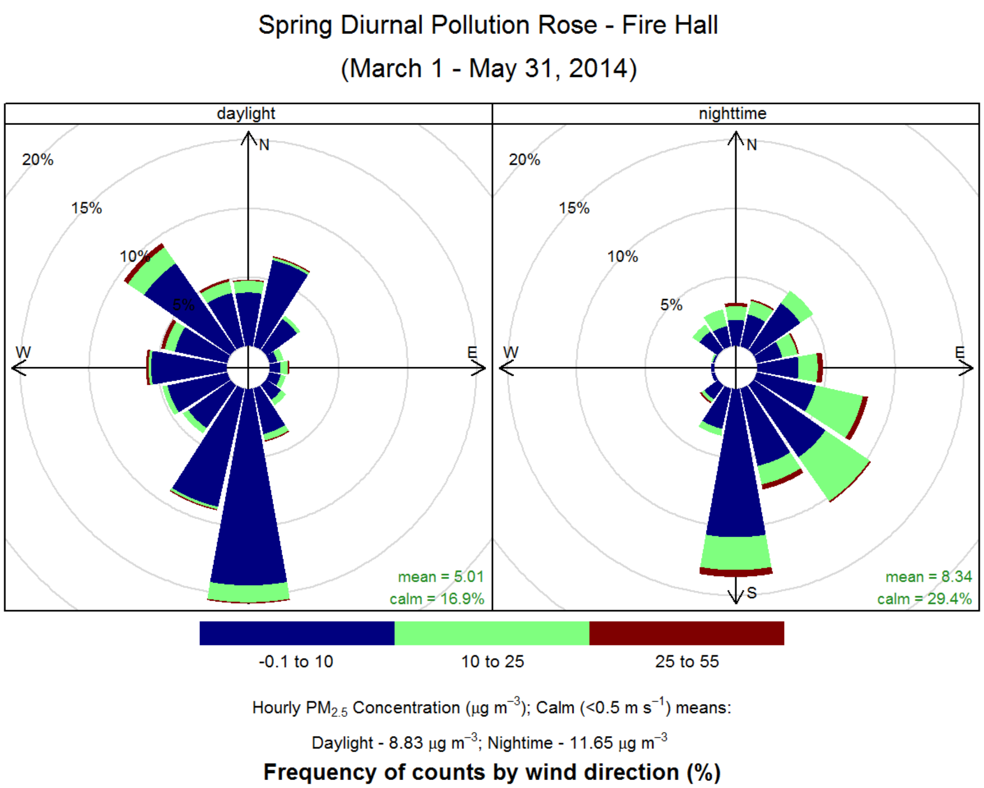

Figure 35: Day and nighttime pollution roses over the spring at the Fire Hall station (MAML).

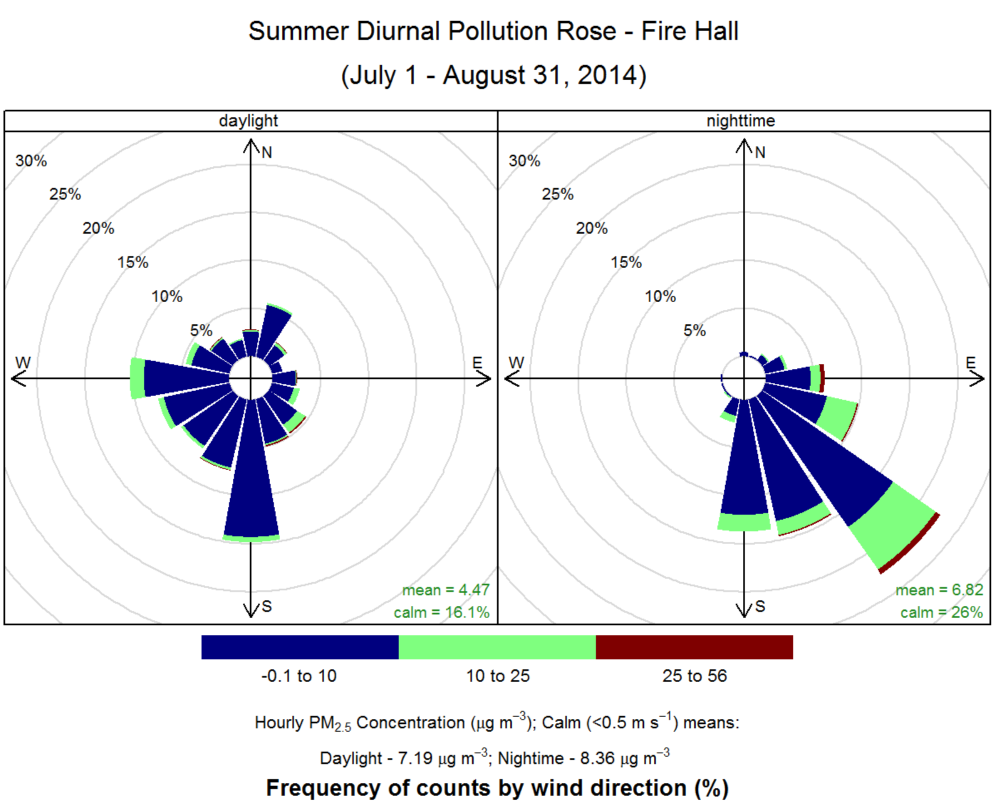

Figure 36: Day and nighttime pollution roses over the summer at the Fire Hall station (MAML).

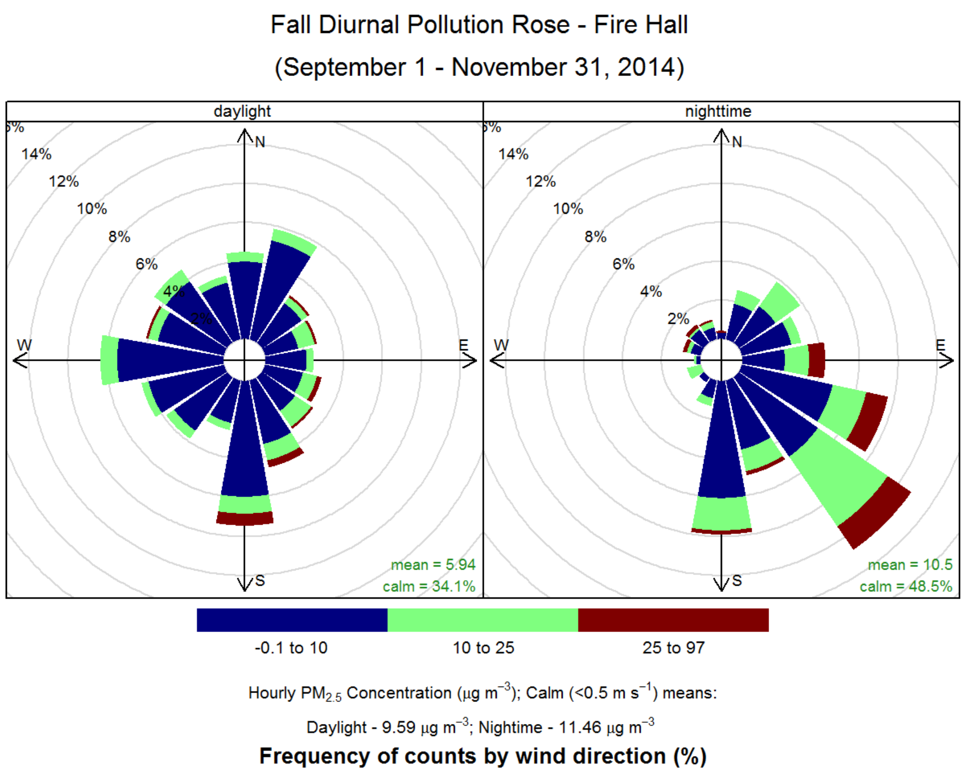

Figure 37: Day and nighttime pollution roses over the fall at the Fire Hall station (MAML).

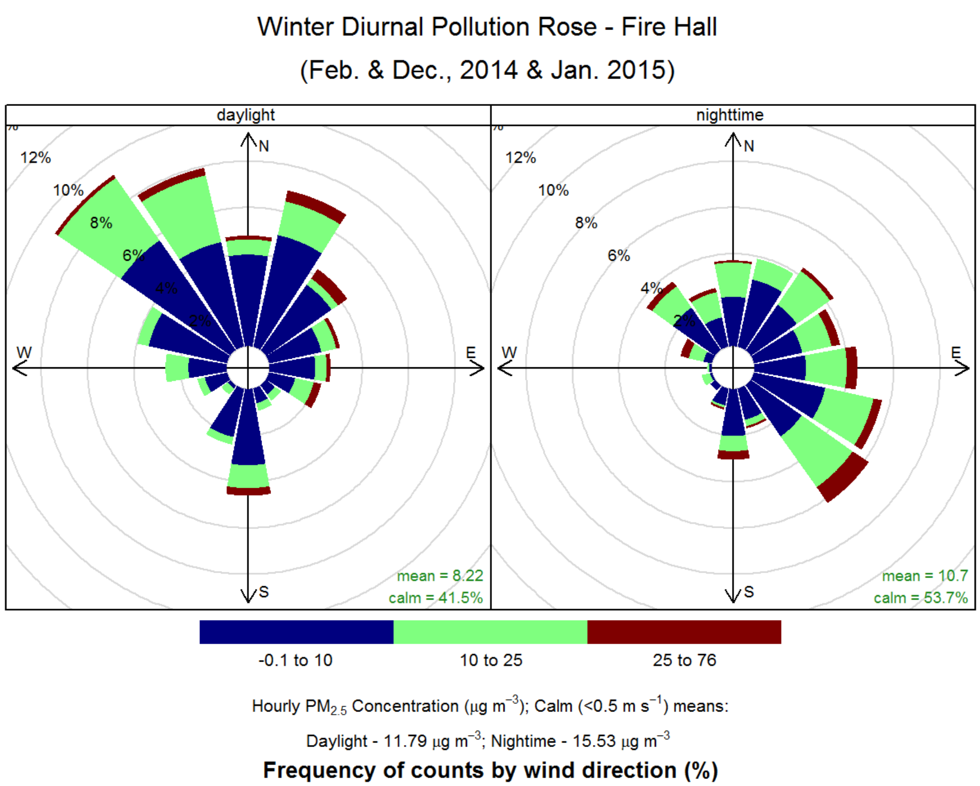

Figure 38: Day and nighttime pollution roses over the winter at the Fire Hall station (MAML).

Mean $PM_{2.5}$ concentrations at the Fire Hall site for all wind conditions other than during calms (wind speed < 0.5 m/s) were highest in the winter (10.7 µg/m^3 at night and 8.2 µg/m^3 during the day) followed by fall (10.5 µg/m^3 at night and 5.9 µg/m^3 during the day). Calm winds occurred most frequently in the winter (53.7% at night and 41.5% during the day), followed by the fall (48.5% at night and 34.1% during the day). Mean $PM_{2.5}$ concentrations during calm wind conditions were highest in the winter (15.5 µg/m^3 at night and 11.8 µg/m^3 during the day), followed by fall (11.5 µg/m^3 at night and 9.6 µg/m^3 during the day). These numbers demonstrate that $PM_{2.5}$ concentrations were highest during the winter months when wind conditions were calm; indicating that local source impacts such as woodstove emissions can be significant.

3.4.2.3 Spatial $PM_{2.5}$ Monitoring using a Mobile Nephelometer

Based on prior analysis of air quality results, there was an identified need to more closely examine the spatial impacts of $PM_{2.5}$ emissions from sources like wood stoves and residential back yard burning in Port Alberni. Monitoring the impacts of this type of pollution can be difficult because it is dispersed among the community (comes from individual households and properties), and can potentially cause 'hotspots' that might not be detected by a single stationary monitoring station. A technique known as mobile nephelometer monitoring was used to examine the spatial differences in $PM_{2.5}$ concentrations throughout the community and to identify the location of potential hotspots. A nephelometer is an instrument that measures light scatter; with higher $PM_{2.5}$ concentrations resulting in higher light scatter readings (see Appendix A for further details). The mobile nephelometer technique involves operating the unit out of the back-seat of a vehicle, paired with a GPS device so that the results can be plotted spatially over a map of the study area after each sampling run. The results can be used to evaluate the effectiveness of stationary monitoring, and can potentially be used for other actions, such as assisting with a targeted woodstove exchange program, bylaw development, or developing a targeted education program on best practices for wood stove use and open burning techniques.

The mobile nephelometer was operated on eight separate nights from December 18th, 2012 to February 25th, 2013. The methods used in this study, a map of the driving route, and associated figures can be found in Appendix A. Results from this study (Figures 52-59) show that there are areas of the city that, at times, experience more degraded air quality than the surrounding areas in terms of $PM_{2.5}$ concentrations. On three out of the eight evenings sampled (December 18th, February 5th and February 18th – Figures 52, 56 and 58), $PM_{2.5}$ concentrations were low uniformly across the city, and wind speeds were above 1 m/s (3.6 km/hr) on two of those evenings. On the evenings when air quality was most degraded, such as January 14th and 21st and February 11th of 2013 (Figures 54, 55 and 57), wind speeds tended to be quite light (less than 1.0 m/s). $PM_{2.5}$ concentrations were varied across the city on these evenings, with relatively low concentrations of $PM_{2.5}$ in Central Port and higher concentrations in South and North Port, in Cherry Creek, along Beaver Creek Road, and on the Tseshaht and Hupacasath reserve lands. South Port refers to the area south of Dry Creek (down to Scott Street), North Port refers to areas north of Rogers Creek and east of the Hupacasath reserve, and Central Port is the area between South and North Port (see Figure 51). The monitoring results also indicate that during some periods when air quality was good across much of the City, there are areas in Cherry Creek and in the neighbouring residential areas in North Port that experience relatively higher levels of fine particulate (see Figure 53).

The fact that higher $PM_{2.5}$ concentrations occurred in certain areas during low wind conditions strongly suggests buildup due to local sources such as wood stoves and open burning activities. Over the eight nights examined, the highest concentrations consistently occurred to the west of the city along Beaver Creek Rd. and in North Port.

It should be noted that the nephelometer driving route included the Port Alberni Elementary School monitoring site. Hourly $PM_{2.5}$ results from the Alberni Elementary monitoring station corresponded quite well to results from the mobile Nephelometer when the instrument was near the school, suggesting that the device was fairly well correlated with the BAM instrument. Results from the study also suggest that the Alberni Elementary station is located appropriately as it is located in an area of North Port that consistently records higher $PM_{2.5}$ concentrations.

3.4.3 PM_{10}

PM_{10} was measured at the Townsite monitoring station from Jan. 1st, 1998 to Dec. 31st, 2010. There was little change in annual PM_{10} concentrations in the 12 years of data examined, (Table 9) ranging from a low of 8.9 µg/m^3 in 1999 to a high of 10.4 µg/m^3 in 2009. Annual distributions of daily PM_{10} measurements over the entire monitoring period are provided in the boxplot in Figure 39 (see Appendix B for how to read a box-plot). There were no daily averages that exceeded the provincial AQO of 50 µg/m^3 from 1998-2010. PM_{10} is no longer monitored in Port Alberni, in part because of heightened interest in $PM_{2.5}$, and in part because concentrations of PM_{10} were found to be stable and consistently below provincial objectives at this monitoring location.

Table 9: PM_{10} measurements relative to provincial objectives at the Townsite monitoring station from 1998-2010.

PM_{10}			(µg/m^3)	Port Alberni Townsite		
Year	**Valid Hours**	**Valid Days**	**Mean Hourly**	**Maximum Daily Mean**	**98% Daily**	**Number of exceedances of AQO (50 µg/m^3)**
1998	8577	357	9.2	42.9	22.7	0
1999	8716	364	8.9	26.2	19.2	0
2000	8529	354	10.3	30.0	23.6	0
2001	8689	362	9.8	24.3	20.3	0
2002	8732	365	10.3	31.0	23.3	0
2003	8731	365	9.8	42.1	23.4	0
2004	8565	357	10.0	31.4	20.5	0
2005	8712	364	9.6	26.7	18.0	0
2006	8692	362	10.0	26.8	21.7	0
2007	8734	365	9.1	25.8	20.1	0
2008	8756	366	9.6	21.6	18.4	0
2009	8706	364	10.4	31.5	25.3	0
2010	8719	365	9.0	28.3	19.4	0

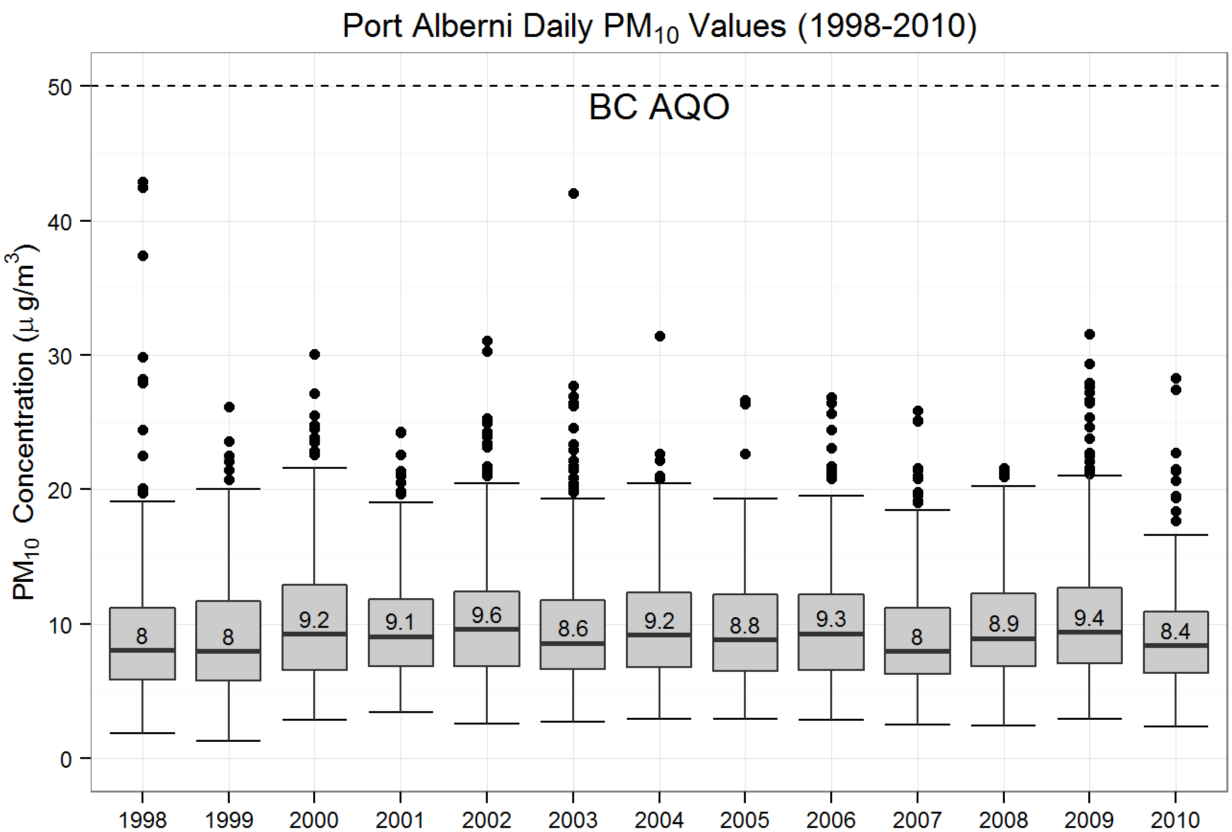

Figure 39: Distribution of daily PM_{10} values at the Town Site monitoring station over the period 1998-2010. The 24-hour provincial objective is 50 µg/m^3.

Temporal patterns in PM_{10} concentrations at the Townsite station from1998-2010 can be seen in Figure 40. It should be noted that PM_{10} mass tends to be dominated by larger particles between 2.5 and 10 microns in diameter (PM_{coarse}). As described in section 2.2.1, PM_{coarse} particles are generally produced from grinding processes and natural sources. The coarse fraction can include things like road dust, pollen, industrial emissions (e.g. sander dust and cyclone emissions), and dust from construction, mining, and demolition activities. These larger particles are much more easily removed from the atmosphere through gravitational settling and precipitation than finer particles.

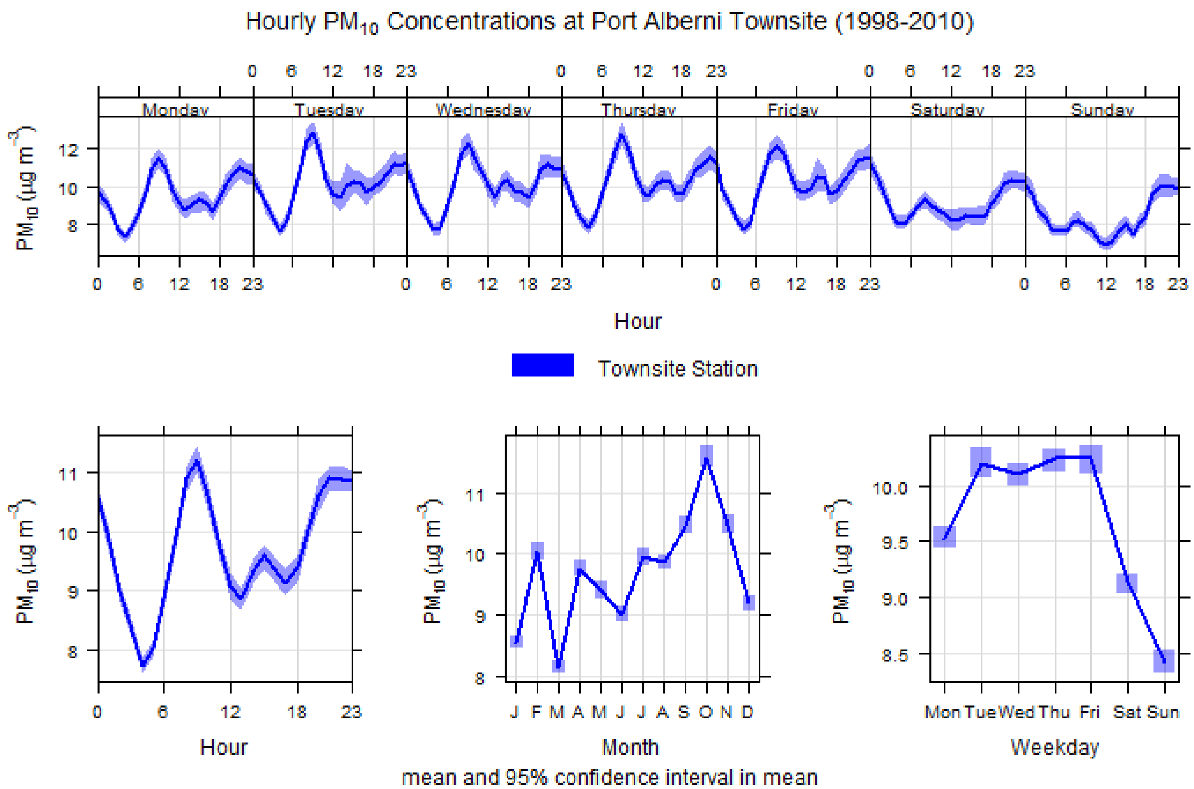

Figure 40: Temporal patterns for PM_{10} concentrations at the Townsite station from January 1st, 1998 – December 31st, 2010.

Hebdomadal (day of the week) patterns suggest that anthropogenic sources can be significant in terms of PM_{10} contributions. Given a large enough data set, geophysical conditions such as mixed layer depth, wind speed and humidity levels should be randomly distributed by day of the week (i.e. no geophysical variable "takes the weekend off"), but emissions patterns may be strongly dependent upon the day of the week (Pryor and Steyn, 1995). At the Townsite location, average PM_{10} values rose during the week days reaching peak values on Friday and then quickly dropped off to corresponding minimum values on Sunday. The average concentration on Sunday was 20% lower than the peak concentration on Friday (average of 8.4 µg/m^3 vs. 10.3 µg/m^3). This high mid-week vs. low weekend pattern suggests sources tied to work week activities such as fugitive dust from industrial/commercial activities and road dust generated by commuter traffic.

Average monthly PM_{10} values were highest in the fall, and lowest in the winter due to increased precipitation. The highest levels in September, October, and November appear to be correlated with fall open burning activities combined with local fugitive dust sources. This is the time of the year when the Ministry of Forests typically lifts burn bans and allows large scale open burning to occur; this is also the time of year when area residents are able to begin land clearing burning and residential back yard burning activities. PM_{10} was likely highest in October due to this sudden increase in open burning activity combined with road dust sources which were still present until the winter rains/snow begins. Sources of PM_{coarse} like road dust are suppressed during the winter months as the roadways are either wet or covered in snow. Rain events remove mobile source dust from the air and inhibit re-suspension of dust for hours to days after precipitation has occurred (Amato et al. 2012). Local residents also begin to heat with wood at this time of the year and these emissions will contribute to ambient PM_{10} concentrations.

Hourly average patterns in PM_{10} (Figure 40) showed a spike in the morning at around 8-10 AM from Monday-Friday. This same morning peak was not evident during the weekends suggesting that the weekday source was mainly dust that was mobilized by traffic as people commuted to work. A secondary spike which was evident during the overnight hours was much more muted on the weekends and almost disappeared by Sunday night when activity near the monitoring site was at a minimum.

3.4.4 Sulphur Dioxide

Sulphur dioxide (SO_2) was monitored at the Fire Hall station from Jan. 28th, 2014 – Feb. 17th, 2015 (MAML) and at the Alberni Elementary station from December 19th, 2013 through to the present. For comparative purposes, paired data from the two sites are examined from February 1, 2014 to January 31, 2015. Concentrations have consistently been very low at both stations relative to provincial objectives (Table 10). There were no exceedances of the one hour guideline of 75 ppb at either monitoring station – the 99th percentile of daily maximum 1-hour averages were 3.9 and 7.9 ppb at the Fire Hall and Alberni Elementary stations, respectively. The annual means recorded at the Fire Hall and Alberni Elementary stations were 0.4 ppb and 0.5 ppb, respectively. While still well below provincial objectives, ambient SO_2 concentrations at the Alberni Elementary station from February 1, 2014 to January 31, 2015 were generally higher than those measured at the Fire Hall station for all metrics examined (Table 10).

Table 10: SO_2 concentrations measured at the Port Alberni Elementary and the Fire Hall stations (Feb. 1, 2014 – Jan 31, 2015).

Performance Indicator	Alberni Elementary	Fire Hall (MAML)
Annual Mean (ppb) [1]	0.5	0.4
Mean 24-hour maximum (ppb) [1]	2.2	1.5
1-hour maximum (ppb) [1]	10.4	8.1
99th Percentile of daily 1 hour max[a] (ppb) (provincial objective is 75 ppb)	7.9	3.9

[a] Daily 1-hour maximum, annual 99th percentile value, over one year
[1] Not a provincial objective

Daily SO_2 concentrations are presented for both sites in Figure 41 and for other temporal scales in Figure 42. Monthly SO_2 concentrations were higher at the Alberni Elementary School site from late spring to early fall. At the Alberni Elementary station, wind comes more often from the Southwest during the spring and summer (especially during the daytime), where industrial and marine vessel SO_2 sources are located (Figure 8). Other more minor sources of SO_2 include mobile sources such as heavy duty diesel truck traffic. There is more truck traffic near the Alberni Elementary School site along Highway 4 than there is near the Fire Hall site along 10th Avenue.

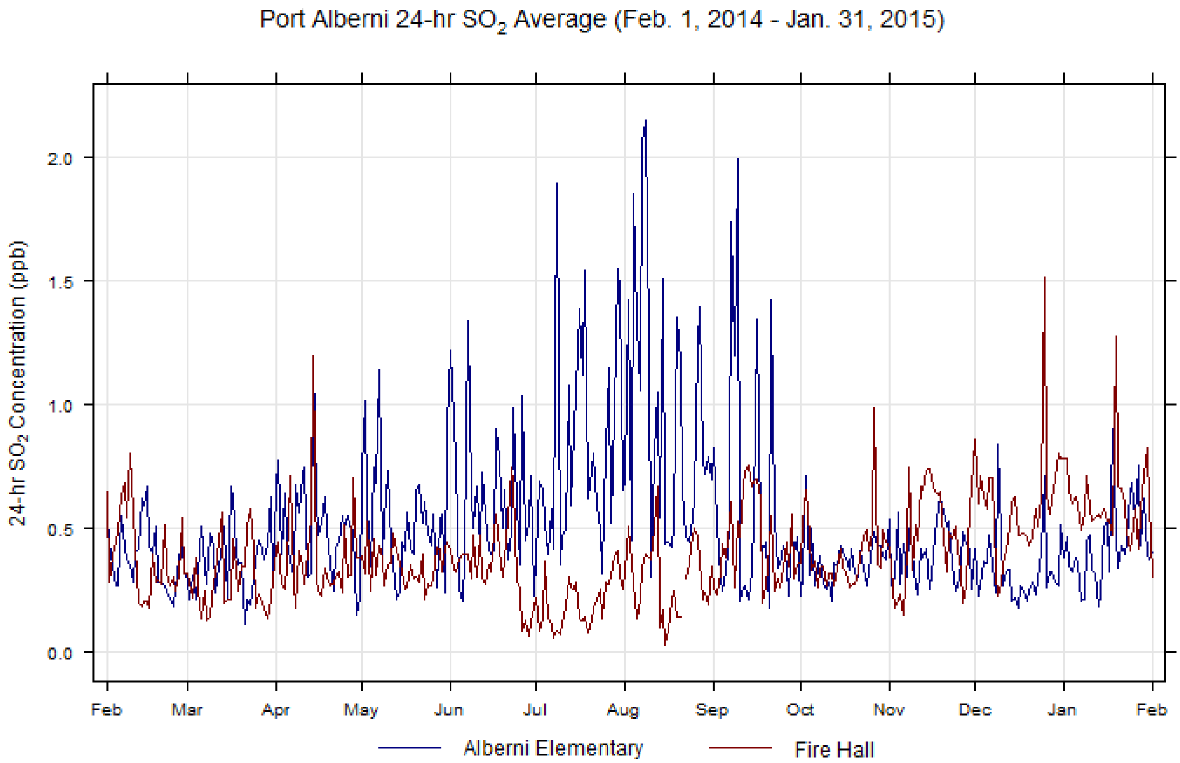

Figure 41: SO_2 concentrations at the Alberni Elementary and Fire Hall (MAML) stations from Feb. 1, 2014 – Jan. 31, 2015.

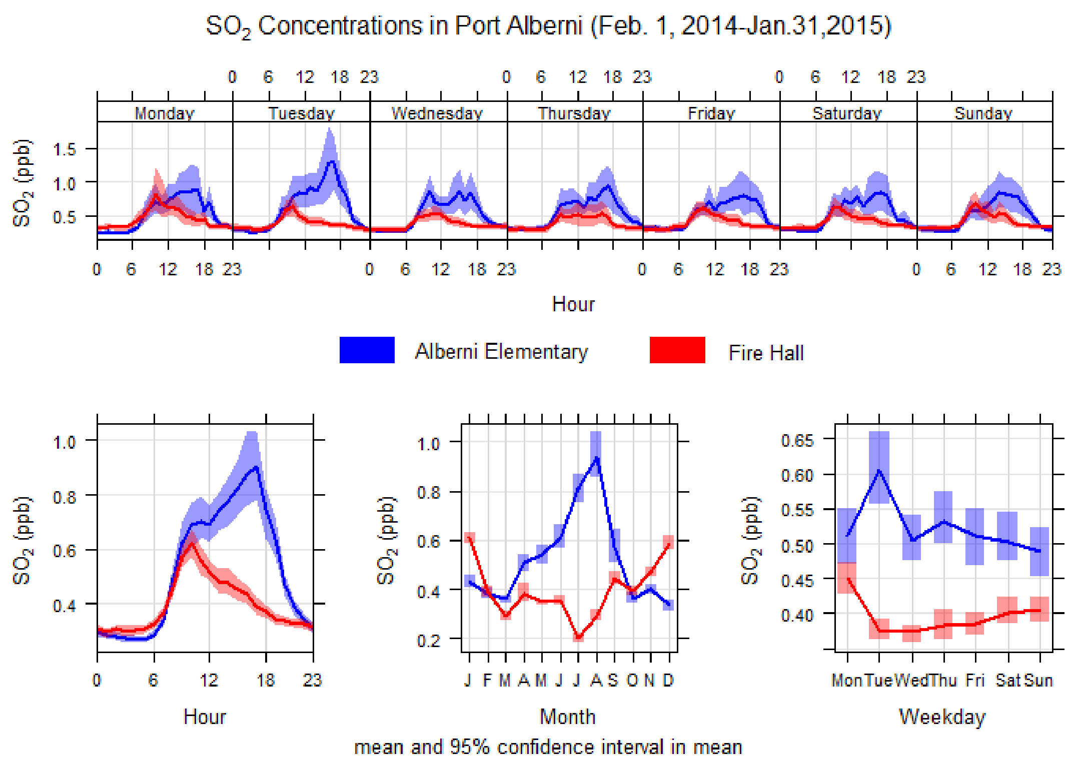

Figure 42: Temporal patterns for SO_2 concentrations at the Alberni Elementary and Fire Hall (MAML) monitoring stations in 2014/2015.

During the late fall and winter months, daily and monthly average concentrations were generally higher at the Fire Hall site than at the Alberni Elementary station. At this of the time of year, there is a higher frequency of northwesterly winds that would tend to direct SO_2 emissions from industrial (e.g. pulp mill emissions) and marine vessel sources toward the Fire Hall site rather than toward the Alberni Elementary station. Hourly concentrations tended to decrease to similar levels at both stations at night, when production and transportation sources would be at a minimum, and increased at the same time in the morning at both stations (Figure 42). However, SO_2 concentrations continued to increase for much longer in the day at the Alberni Elementary station, until almost 6 PM, whereas concentrations at the Fire Hall peak and began dropping around 9-10 AM.

Figure 43 shows SO_2 levels from a number of air quality monitoring stations across the province (BC Lung, 2015) in 2014. The Port Alberni Elementary School site ranked 13th cleanest out of 28 stations reporting SO_2 concentrations across the province.

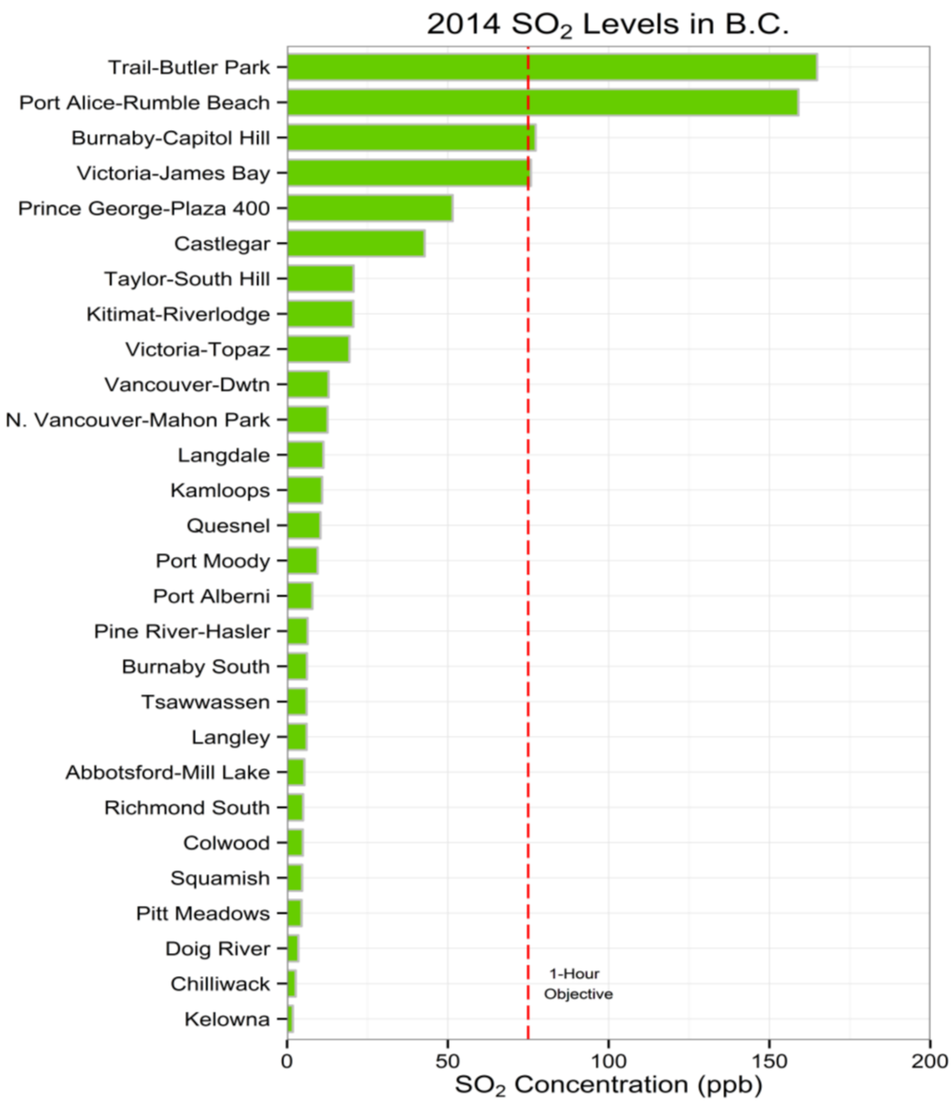

Figure 43. 99th percentile of daily 1-hour maximum SO_2 concentrations across BC (BC Lung, 2015).

The highest SO_2 concentrations (although still very low) appeared to be tied to periods when wind directions were coming from the Catalyst pulp mill. As the Catalyst mill is the largest source of continuous SO_2 emissions in the Airshed (marine vessel emissions are quite varied), this makes intuitive sense.

3.4.5 Nitrogen Dioxide

Nitrogen dioxide (NO_2) was monitored at the BC Hydro station from June 21, 2001 – January 10, 2002 and at the Fire Hall station (MAML) from February 1, 2014 – January 31, 2015. There was not sufficient data collected at the BC Hydro site to meet annual data completeness requirements, but the NO_2 data that was gathered suggested that concentrations were low and would most likely have been well below provincial objectives (Table 11). The annual average for the entire year of data collected at the Fire Hall site from February 1, 2014 to January 31, 2015 was 4.0 ppb, which is well below the Provincial AQO of 32 ppb. There were also no exceedances of the one hour guideline of 100 ppb at either monitoring station. The maximum hourly values recorded at the BC Hydro and Fire Hall stations were 38.0 ppb and 35.9 ppb, respectively. For comparative purposes, the hourly mean values recorded at the BC Hydro and Fire Hall stations in 2001/2002 and 2014/2015 over the same 8 month periods (June to January) were 5.1 ppb and 4.1 ppb, respectively. This represents a drop of 1 ppb or a 20% decrease over the 13 years between measurements in Port Alberni.

Table 11: NO_2 concentrations measured at the Port Alberni BC Hydro (June 16, 2001 – Jan. 11, 2002) and the Fire Hall stations (Feb. 1, 2014 – Jan 31, 2015).

Performance Indicator	BC Hydro[1] (June 21, 2001 – Jan. 10, 2002)	Fire Hall[1] (June 21, 2014 – Jan. 10, 2015)	Fire Hall[1] (Feb. 1, 2014 – Jan. 31, 2015)
Annual mean (ppb) (provincial objective is 32 ppb)	5.1	4.0	4.1
24-hour maximum[2] (ppb)	16.3	10.3	12.3
1-hour maximum[2] (ppb)	38.0	25.0	35.9
Annual 98th percentile of daily 1 hour max (ppb - provincial objective is 100 ppb)	28.0	20.5	20.5

[1] Does not meet data requirements – provided only for reference
[2] Not a provincial objective

As described in Section 2.2, one purpose of the 2014/15 monitoring campaign at the Fire Hall site was to obtain a snapshot of specific pollutants to compare to historical levels measured at the BC Hydro site. Temporal patterns in NO_2 concentrations from the two sites are examined in Figure 44. The highest levels of NO_2 occurred from Monday to Friday in the morning at both stations with a secondary peak in the late afternoon. NO_2 concentrations then drop to overnight minimums due to surface deposition and atmospheric transformation. These week day peaks point mainly to vehicle emissions as people commute to and from work, and also to commercial/industrial source emissions that operate throughout the week, although these emission sources would be relatively constant.

The lowest NO_2 concentrations were measured on weekends at both sites. This highlights the contribution of traffic emissions during the work-week to overall levels. Over the year, concentrations were highest over the winter at both stations; likely in part due to increased combustion sources (heating, increased idling, etc.) at that time of year, poor dispersion meteorology, and less solar energy being available, which is required to convert NO_x into O_3. Between the two stations, NO_2 concentrations measured at the Fire Hall site were generally lower than historical measurements at the BC Hydro station at all time-scales examined. A number of factors may have contributed to the reduction in ambient concentrations. The decrease in NO_x emissions over time in the airshed is likely due to a decrease in emissions from motor vehicles (mainly due to more stringent federal emissions standards), but the higher historical levels measured could also be influenced by the station's proximity to both a busier traffic corridor (Stamp Avenue) and the industrial/mobile activities located near the port.

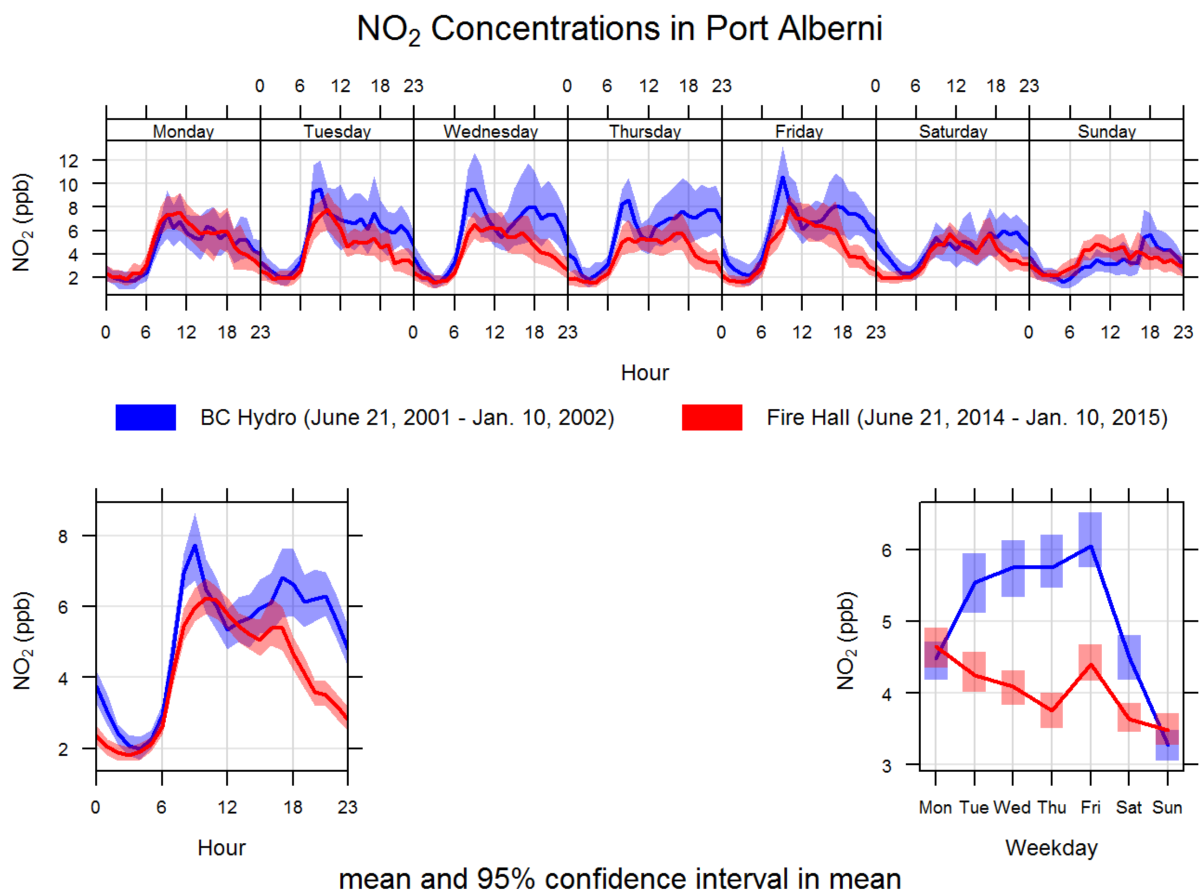

Figure 44: Comparison of temporal patterns for nitrogen dioxide concentration at the BC Hydro (2001/2002) and Port Alberni Fire Hall (2014/2015) monitoring stations (1-hour provincial objective is 100 ppb).

The temporal patterns for NO_2 concentrations at the Fire Hall site for the entire data record (February 1 2014-January 31, 2015) are also presented in Figure 45. Generally, the temporal patterns are the same as in Figure 44 (which shows data from both stations, but only from June 21–January 10). NO_2 concentrations were lowest during the summer and highest during the winter months, likely due to changes in emissions and meteorological conditions.

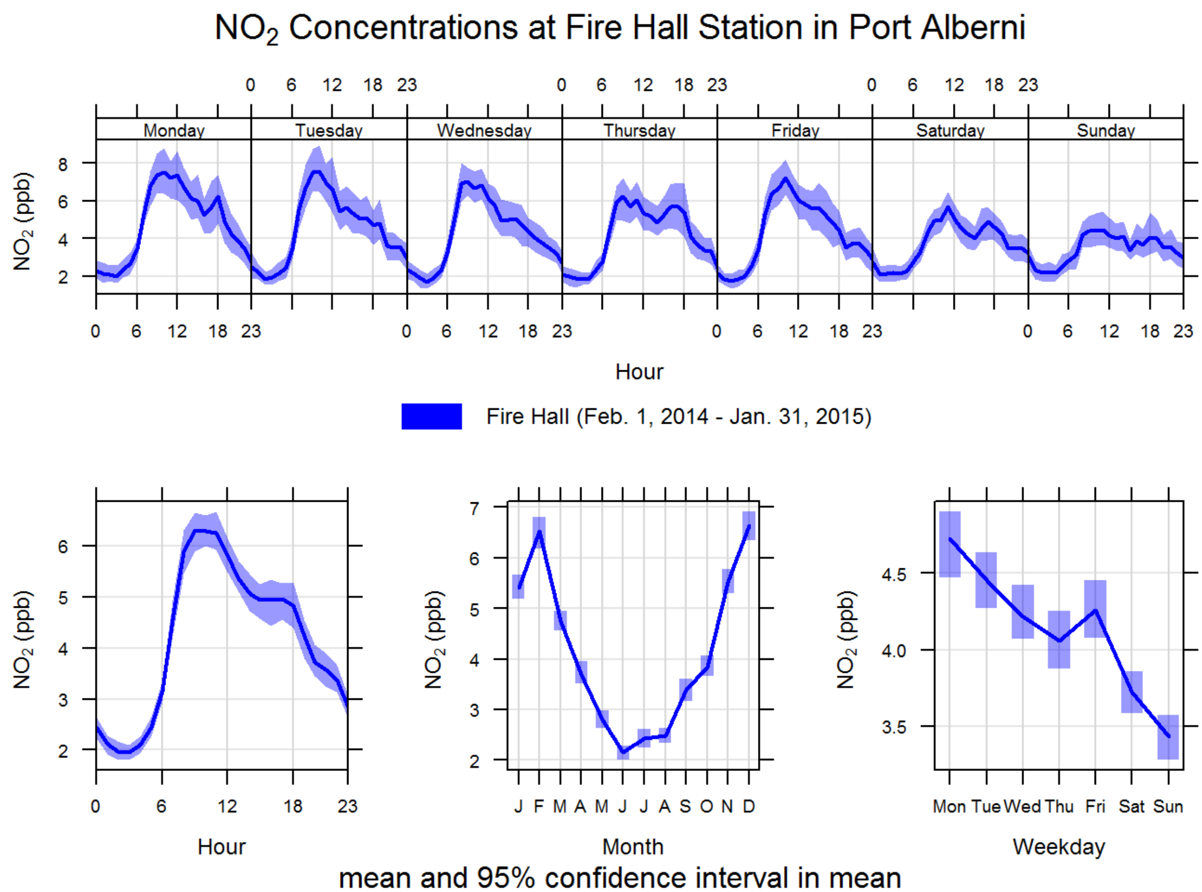

Figure 45. Temporal patterns in nitrogen dioxide concentrations at the Fire Hall (MAML) Site - Feb 1, 2014-Jan 31, 2015.

Overall, the NO_2 concentrations measured at the Fire Hall site in 2014/15 were lower than those measured in 2001/02 at the BC Hydro site. The decrease in hourly average concentrations from 2001/02 to 2014/15 is consistent with what has been measured across the Canadian National Air Pollution Surveillance Program (NAPS) network. NAPS reported a decreasing trend of 0.3 ppb per year in British Columbia from 1999 to 2013 for NO_2 and stated that this is consistent with the reduction in NO_x emissions from cars and trucks resulting from more stringent emissions standards (Environment and Climate Change Canada, 2016).

3.4.6 Ozone

Ozone (O_3) was monitored at the BC Hydro station from June 16, 2001 – January 10, 2002 and at the Fire Hall station February 1, 2014 – January 31, 2015. There was not sufficient data collected at the BC Hydro site to meet annual data completeness requirements, but the ozone data that was gathered suggests that concentrations were low and would have been well below provincial objectives (Table 12). There were no exceedances of the one hour AQO of 82 ppb or of the 8-hour mean AQO of 63 ppb at either monitoring station. For comparative purposes, the hourly mean values recorded at the BC Hydro and Fire Hall stations in 2001/2002 and 2014/2015 over the same 8 month periods (June to January) were 13.8 ppb and 14.3 ppb and the maximum hourly values recorded were 49.0 ppb and 45.6 ppb, respectively. These values are quite similar and within the range of what might be expected due to differences in meteorology between the periods examined.

Table 12: O_3 concentrations measured at the Port Alberni BC Hydro (June 16, 2001 – Jan. 11, 2002) and Fire Hall stations (Feb. 1, 2014 – Jan 31, 2015).

Performance Indicator	BC Hydro[1] (June 16, 2001 – Jan. 10, 2002)	Fire Hall[1] (Feb. 1, 2014 – Jan. 31, 2015)	Fire Hall[1] (June 16, 2014 – Jan. 10, 2015)
Annual mean (ppb) [2]	13.8	17.0	14.3
Maximum 24-hour mean (ppb) [2]	31.9	41.5	35.6
Maximum 1-hour mean[a] (ppb) (provincial objective is 82 ppb)	49.0	54.6	45.6
4th highest 8-hour mean[b] (ppb) (provincial objective is 63 ppb)	36.0	41.5	40.3

[a] For advisory purposes – no percentile for annual reporting
[b] Annual 4th highest value of 8 hour average, calculated every hour, averaged over three consecutive years
[1] Does not meet data requirements – provided only for comparative purposes
[2] Not a provincial objective

Temporal patterns in O_3 concentrations from the two sites are examined in Figure 46. At both sites, the diurnal cycle of ozone concentration reached a peak during the middle of the day and had lower nighttime concentrations. The O_3 concentration slowly increased after sunrise, reaching maximum concentrations in the late afternoon when solar irradiance was at its peak, and then slowly decreased to a minimum in the early morning hours. There were slight differences in peak timing and magnitude measured at the two sites that could be attributable to differences in meteorology during the two periods of measurement, but could also be influenced by local sources of NOx. There were also differences between the sites in terms of hebdomadal and monthly average patterns, but generally the concentrations were similar.

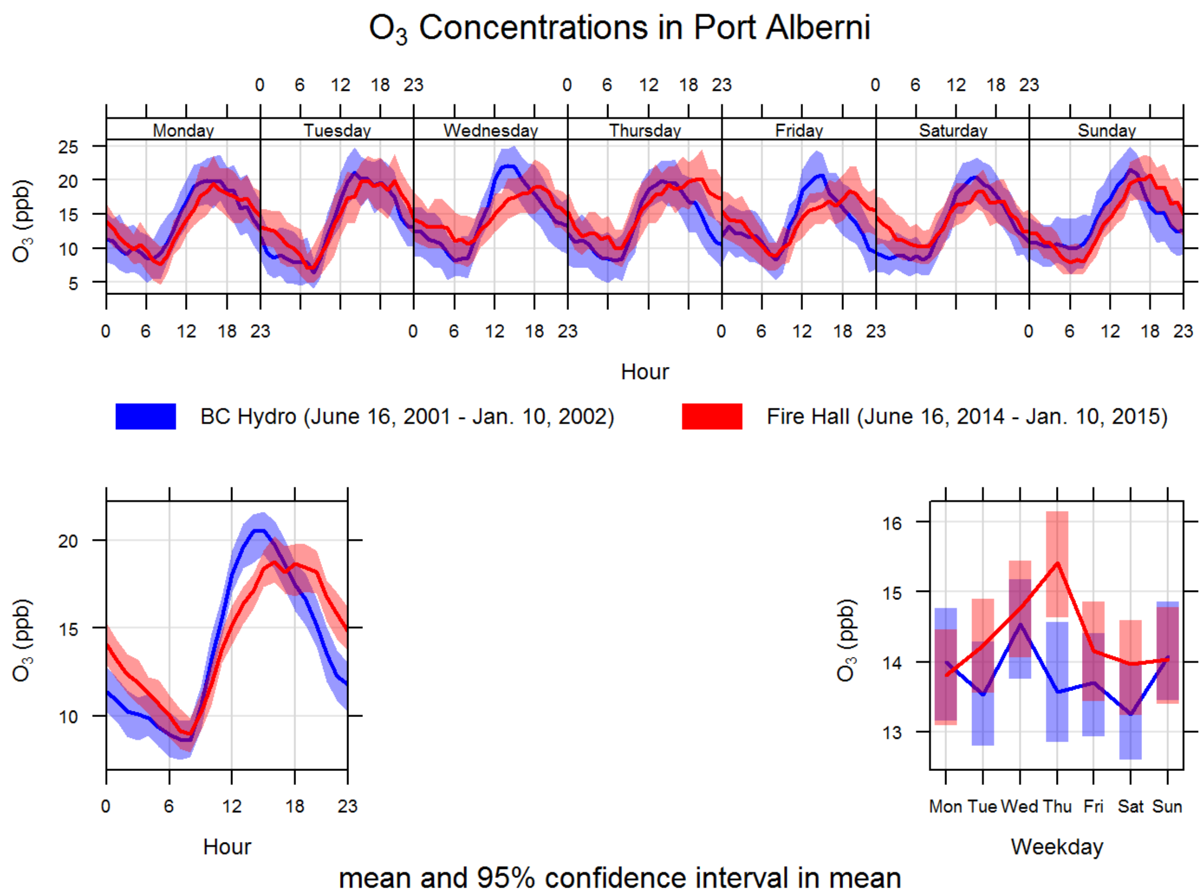

Figure 46: Temporal ozone concentration comparisons at the Fire Hall (2014/2015) and BC Hydro (2001/2002) monitoring stations.

The temporal patterns for O_3 concentrations measured at the Fire Hall site for the entire monitoring period (February 1 2014-January 31, 2015) are presented in Figure 47. Generally, the diurnal and hebdomadal patterns are the same as in Figure 46 even though a complete annual record is shown. Seasonally, O_3 is highest in the spring and lowest in the winter, with a secondary peak in the fall. Ozone levels peaking in the spring is typical for the Northern Hemisphere (Vingarzan, 2004) and is generally indicative of background conditions rather than local emissions, although the origin of the spring maximum remains under continued debate. One popular theory supports a buildup of precursor pollutants over the winter months, which is caused by increased anthropogenic pollution as well as biogenic Volatile Organic Compounds (VOCs) in the spring as a result of vegetative growth. Enhanced photochemical activity results from the reaction of this pollutant pool with increased solar radiation in the spring (Gibson et al., 2009).

Annual distributions of hourly O_3 measurements over the entire monitoring period at the Fire Hall site are provided in the boxplot in Figure 48. It is interesting to note that there is not a significant mid-summer peak (July and August) in monthly or hourly O_3 concentrations which are generally attributed to local photochemical production.

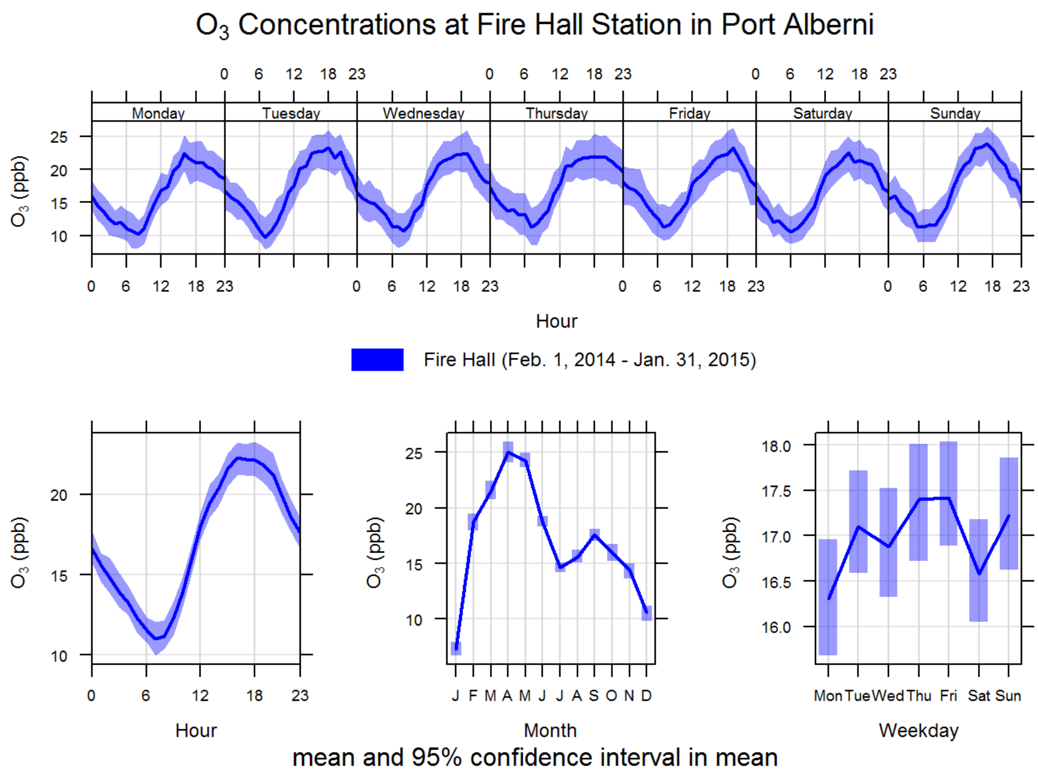

Figure 47. Temporal patterns in ozone concentrations at the Fire Hall Site (Feb 1, 2014-Jan 31, 2015).

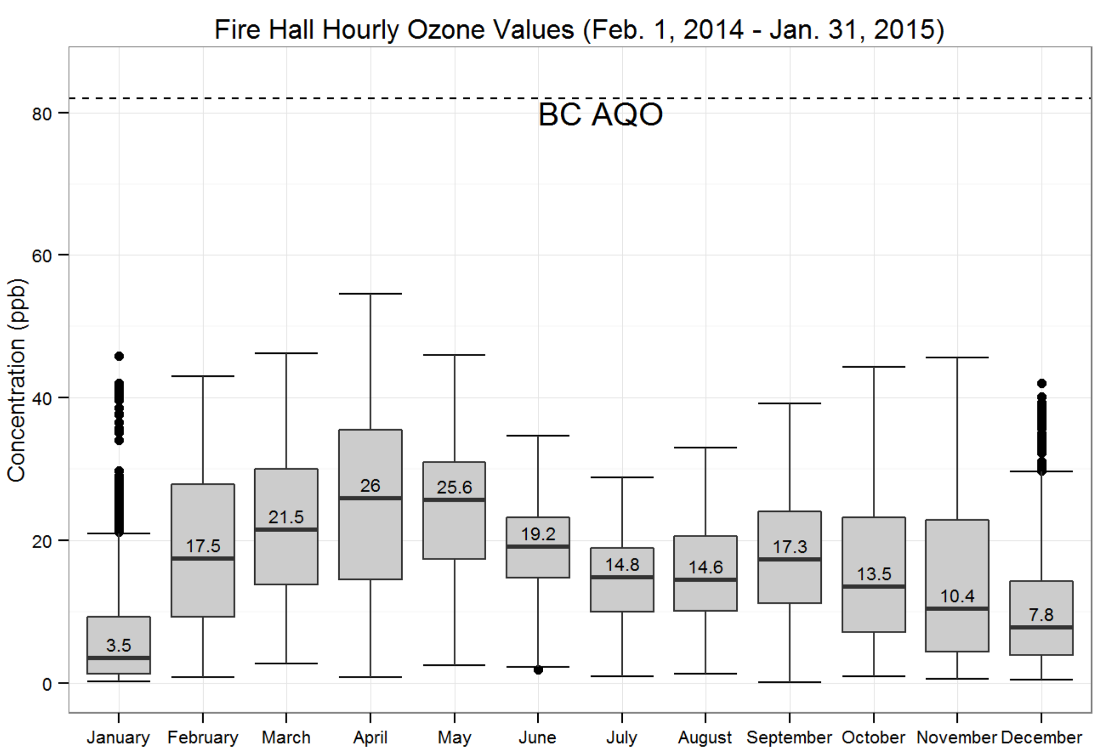

Figure 48: Annual distribution of 1-hour average ozone concentrations at the Port Alberni Fire Hall (MAML) - February 1, 2014 to January 31, 2015.

Ground-level ozone concentrations were well below provincial AQOs and were low relative to concentrations found in other BC communities. Figure 49 shows ozone levels from a number of air quality monitoring stations across the province (BC Lung, 2015) for 2014. The Port Alberni Fire Hall site (MAML) recorded the 3rd lowest ozone concentration out of 31 reporting sites across the province.

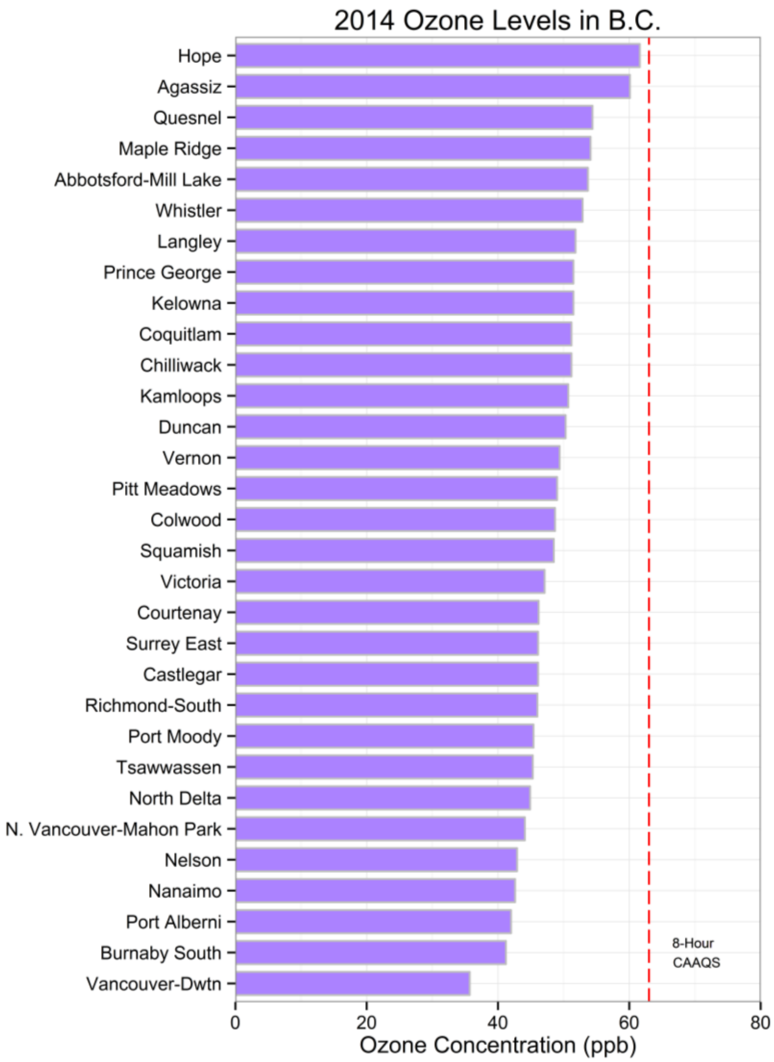

Figure 49. Maximum 8-hour average ozone levels across British Columbia 2014 (BC Lung, 2015).

Generally, the O_3 measurements obtained from the Fire Hall site are similar to those collected at the BC Hydro site 13 years ago and the differences are within the range of what might be expected due to differences in meteorology between the periods examined, and differences in influence from local NOx sources.

4 Conclusions

The mountainous terrain around Port Alberni inhibits air circulation which can reduce the ability of the atmosphere to disperse pollutants. The valley location of Port Alberni also makes it susceptible to the frequent formation of temperature inversions, particularly during the colder months. An analysis of meteorological data for Port Alberni from October 2012 to January 2015 indicated that mean wind speeds were lowest in the winter and highest in the summer, and that calm wind conditions (when wind speed is below 0.5 m/s) were most frequent during the fall and winter months. Lighter wind speeds and a high frequency of calms (up to 45% of the time) during the winter period results in poor atmospheric dispersion that can lead to a build-up of pollutants in the area.

$PM_{2.5}$ is the main pollutant of concern in Port Alberni. It is the only parameter for which both annual and daily exceedances of BC's AAQOs were observed. The 2014 annual average for the Port Alberni Elementary School monitoring location ranked the site 9th highest out of 43 communities reporting $PM_{2.5}$ concentrations across the province. Daily average AAQO exceedances occurred up to a maximum of 5.4% of the time in 2013 and occurred in every year since $PM_{2.5}$ monitoring began. $PM_{2.5}$ concentrations measured at two sites in Port Alberni showed a clear seasonal pattern with lower concentrations being measured in the spring/summer and higher concentrations measured in the fall/winter due to changes in emissions and meteorology. All of the exceedances of the daily AAQO in all years occurred during the colder months; however, wildfire smoke impacts were evident during the summer months in some years. Smoke from wildfire hazard abatement burning from numerous forestry operations in the area can be a significant source of $PM_{2.5}$ during the fall as is commercial (land clearing) and residential (backyard burning) open burning.

There was a bimodal pattern in peak diurnal $PM_{2.5}$ concentrations with maxima occurring in the evening and morning hours. These patterns are mainly attributable to the influence of space heating, especially woodstoves. Hebdomadal $PM_{2.5}$ concentration patterns show that average weekend levels are higher than average mid week levels at the Port Alberni Elementary station. This suggests that residential open burning on weekends is a significant source of $PM_{2.5}$ as this is when people are the most active around their homes. An increase in woodstove use on weekends may also be a contributing factor.

Annual mean $PM_{2.5}$ concentrations were the same at the two monitoring locations in 2014/15. However, there were a higher number of daily AAQO exceedances and extreme values experienced during the winter months at the Alberni Elementary station than at the Fire Hall station (MAML). Analysis of seasonal and diurnal pollution roses suggests that $PM_{2.5}$ emission sources impacting this area during the winter months were located to the Northeast of the Alberni Elementary School, much of which is outside of city limits (e.g. the Cherry Creek area). High concentrations of $PM_{2.5}$ also occurred with winds from the North and Northwest during both the day and nighttime hours, pointing to open burning and home heating sources in that sector (the Beaver Creek area). Analysis also indicates that industrial source emissions might play a more important role at the Fire Hall site during the winter than at the Alberni Elementary site. The weekend effect is not as strong at the Fire Hall site suggesting that emissions from activities such as residential backyard burning and open burning have a more localized impact on the northern part of the community. Drainage flows also appear to be an important feature in Port Alberni and can bring emissions from sources located at higher elevations to residential areas located in the valley bottom.

The mobile Nephelometer study found that $PM_{2.5}$ concentrations were quite varied over the City on any given night. It also found that elevated $PM_{2.5}$ concentrations were recorded more often in some areas of the city, like Beaver Creek Road to the west of the city and in North Port even when levels were low across much of the rest of the City. Higher $PM_{2.5}$ concentrations occurred in certain areas during low wind conditions, strongly suggesting buildup due to local sources such as wood stoves and open burning activities. Over the eight nights examined, the highest concentrations consistently occurred to the west of the city along Beaver Creek Rd. and in North Port. Results from the study also suggest that the Alberni Elementary station is located appropriately as it is in an area of North Port that consistently recorded higher $PM_{2.5}$ concentrations during the study.

Over the 1998-2010 monitoring period, PM_{10} concentrations remained stable and were below the 24-hour BC AAQO, with no exceedances observed. Hebdomadal patterns in 24-hour PM_{10} concentrations show a late weekday maximum and a weekend minimum. The high mid-week vs. low weekend pattern suggests sources tied to work week activities such as fugitive dust from industrial/commercial activities and road dust generated by commuter traffic. Diurnal patterns in PM_{10} suggest that concentrations are largely driven by road dust from people commuting to and from work. Average monthly PM_{10} values were highest in the fall due to additional PM_{10} emissions from open burning combined with local dust sources, and were lowest in the winter due to the scavenging/binding effect of increased precipitation on PM_{coarse} particles.

SO_2 levels measured in Port Alberni were very low and were well below the BC Ambient Air Quality Objective (BC AAQO). In 2014, the Port Alberni Elementary School site ranked 13th cleanest out of 28 stations reporting SO_2 concentrations across the province. Analysis of the data sets from Alberni Elementary School and the Fire Hall site in 2014/15 showed that there were slightly higher concentrations measured at the Alberni Elementary site. Seasonally, SO_2 concentrations were similar at both sites during the spring and fall, higher at the Alberni Elementary site during the summer and higher at the Fire Hall site in the winter. The data collected at two locations in Port Alberni suggest that the Alberni Elementary School site is well located to capture SO_2 impacts from industrial and mobile sources in the valley.

An analysis of NO_2 concentrations measured at two sites in Port Alberni showed a clear seasonal pattern with lower NO_2 concentrations in the summer and higher concentrations in the winter, likely due to changes in emissions and meteorology. The diurnal pattern showed two peaks, one in the morning and one in the late afternoon, corresponding with commuter traffic patterns. Hebdomadal patterns showed higher concentrations during the week and lower concentrations on weekends when commuter traffic was at a minimum. NO_2 concentrations measured at the BC Hydro and Fire Hall stations were well below the BC AAQOs. A comparison of the hourly mean values recorded at the BC Hydro and Fire Hall stations over the same 8 month periods (June to January) indicated a 20% decrease in average concentrations over the 13 years between measurements in Port Alberni. This is consistent with declines in NO_2 concentrations across Canada and can likely be attributed to reductions in vehicle emissions over this time.

Mean monthly O_3 concentrations at the Fire Hall site exhibited a springtime peak consistent with other communities in the northern hemisphere. The lack of a significant summertime peak in 1-hour averages indicates that locally generated O_3 is not an important consideration and that local emissions are not sufficient to create an ozone problem in the valley. O_3 levels measured at the BC Hydro and Fire Hall stations were well below provincial objectives and concentrations from the Fire Hall site ranked Port Alberni 3rd lowest out of 31 reporting sites in the province in 2014. The O_3 measurements obtained from the Fire Hall site in 2014/15 were similar to those collected at the BC Hydro site 13 years ago and the differences are within the range of what might be expected due to differences in meteorology, and NOx concentration/source influences, between the periods examined.

In summary, an examination of ambient air quality data from four monitoring stations in the City of Port Alberni found that there were no exceedances of the BC AAQO for PM_{10}, NO_2, O_3, or SO_2 during the study period while there were exceedances of the BC AAQO for $PM_{2.5}$ in every year since monitoring began. Air quality as measured by $PM_{2.5}$, was generally good at both measurement locations during the warm months but degraded during the fall and winter due to changes in meteorology and emission sources. While annual average $PM_{2.5}$ concentrations were the same for the two monitoring locations, more frequent daily exceedances of the BC AAQO occurred at the Alberni Elementary School site, and extreme values were higher in magnitude at this location. Analysis suggests that wood smoke from sources such as large-scale (land clearing and forestry operations) and small-scale (residential) open burning activities as well as from residential/commercial wood burning appliances are main contributors to these episodes. Analysis indicates that local smoke sources are important at both sites but that sources from outside of the City can have a significant effect on local $PM_{2.5}$ concentrations. Analysis also suggests that industrial contributions can be important, particularly in central Port Alberni.

5 Recommendations

Based on the seasonal and spatial patterns found in $PM_{2.5}$ levels measured at monitoring sites in Port Alberni, the following recommendations are made:

1. Additional measures to address sources of wood smoke in the Alberni Valley should be considered. Action is needed to manage smoke impacts from both large-scale open burning and residential back yard burning, as well as emissions from wood-burning appliances.
2. Additional measures to address both large-scale open burning and residential back yard burning, as well as smoke impacts from wood-burning appliances in the Cherry Creek area and North Port need to be explored and implemented.
3. All levels of government need to continue to effectively manage all sources of fine particulate in the valley with a goal of continuous improvement from all source sectors – e.g. mobile, commercial, industrial, and residential.

6 References

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Appendix A Mobile Nephelometer Study

Methods

Residential complaints made to the City of Port Alberni were used as the basis for selecting the driving route for the mobile Nephelometer study (please see Results section below for route directions). Monitoring was done with a Radiance Research M903 Nephelometer (Figure 50) operated from the backseat of a Toyota Forerunner. A fan was used to draw external air into the Nephelometer intake. A sample line heater was used to adjust intake air to a constant temperature and humidity.

The Nephelometer intake tube extended out of the car from a slightly opened window, as seen in Figure 50. A GPS device was used to track sampling locations as the vehicle moved along the driving route. The intent of this study was to make runs on cold clear evenings from December 18, 2012 to February 25, 2013. Weather conditions were sometimes limiting, however, resulting in deviations from this timeframe. The route was always driven in the same direction and generally had the same start and stop location. There were adjustments to the driving route based on the results gathered from the first trips, but the majority of the route remained the same throughout the study.

Figure 50: Photo of the installation of the Nephelometer in the back seat of the vehicle with sampling intake out the side window.

The Nephelometer measures light scatter, with higher $PM_{2.5}$ concentrations resulting in higher light scatter readings. An equation developed from studies in Seattle, WA, was used to convert light scatter into $PM_{2.5}$ concentrations in micrograms per cubic metre: $PM_{2.5}$ ($\mu g/m^3$) = ((100,000 x light scatter value) – 0.01) / 0.28). This formula was also used in a University of Victoria study on backyard burning in the Capital Regional District (Setton et al., 2007).

The Nephelometer and GPS device both logged data every 15 seconds. However, while the Nephelometer logged at 0, 15, 30, and 45 second marks of each minute, the GPS device started from the time it was turned on and obtained a satellite signal. The maximum time differential between the GPS and Nephelometer was 7 seconds. The Nephelometer’s internal clock was found to drift over time. It was calibrated at the start of the study and re-adjusted on Feb 25. After each run the Nephelometer data was downloaded in text format using the program HyperTerminal. The GPS data was downloaded and converted to text format using the Garmin program Mapsource. The Nephelometer and GPS data was then imported into Microsoft Excel. The backscatter formula was applied and Nephelometer and GPS data were matched up by time. The resulting dataset was then mapped out for each run using the geographic information system ArcMap. These maps were then analyzed to look for reoccurring $PM_{2.5}$ hotspots in Port Alberni.

Results

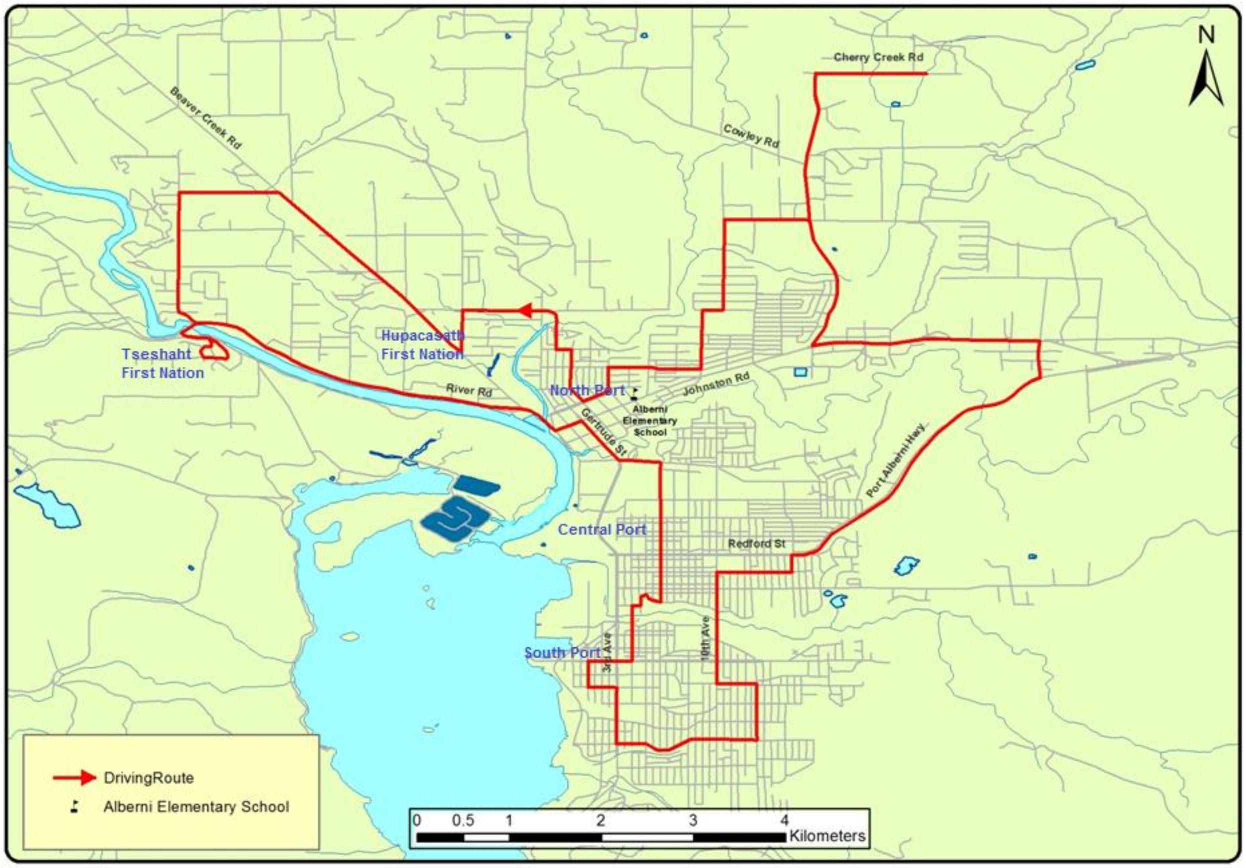

Figure 51: Mobile Nephelometer driving route in Port Alberni (Dec. 18, 2012 to Feb. 25, 2013).

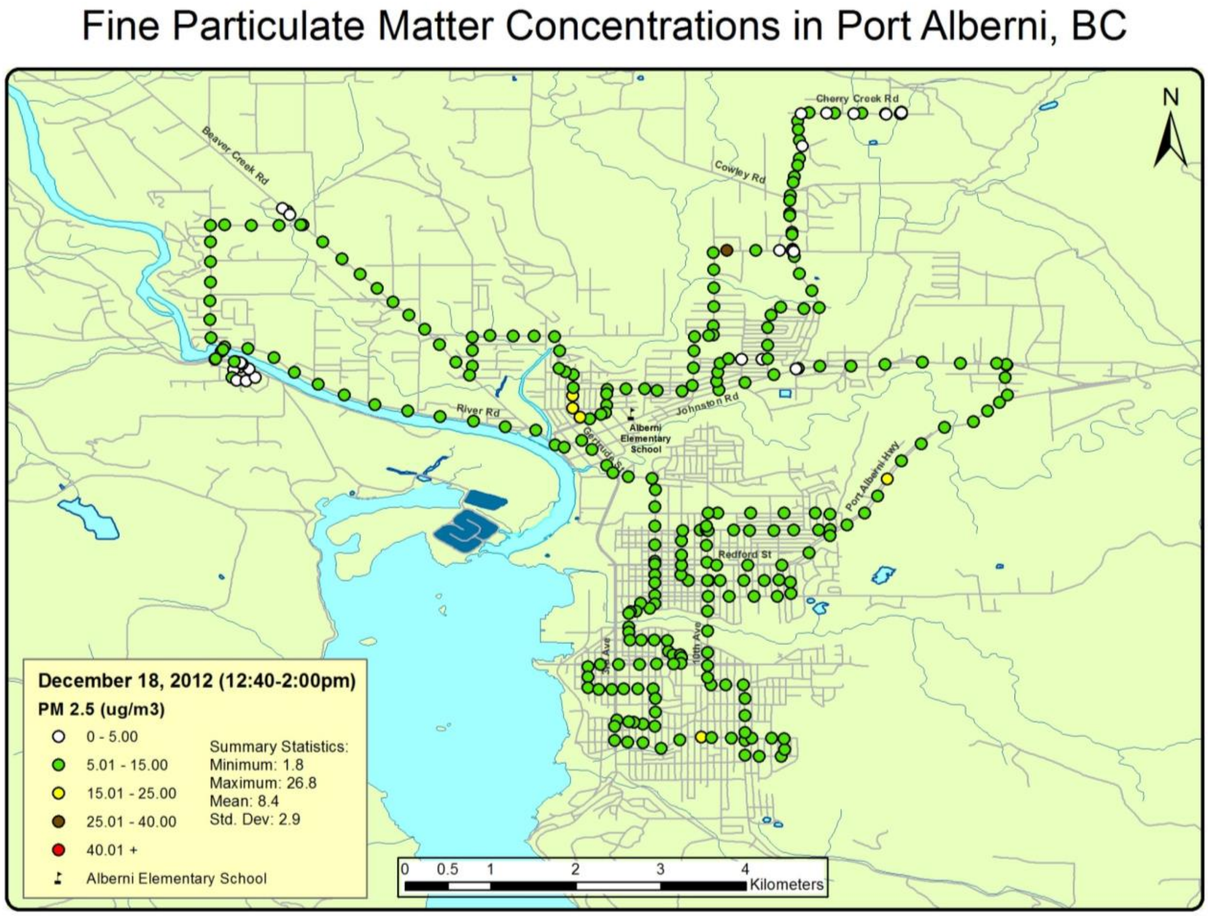

Figure 52: Mobile Nephelometer results for Tuesday, Dec. 18, 2012. From 12-2 PM, the Alberni Elementary station recorded average hourly average $PM_{2.5}$ of 24 µg/m^3 at noon which dropped to 8 µg/m^3 by 2 PM. Light winds from the NW at ~0.5 m/s. Temperature data was not available.

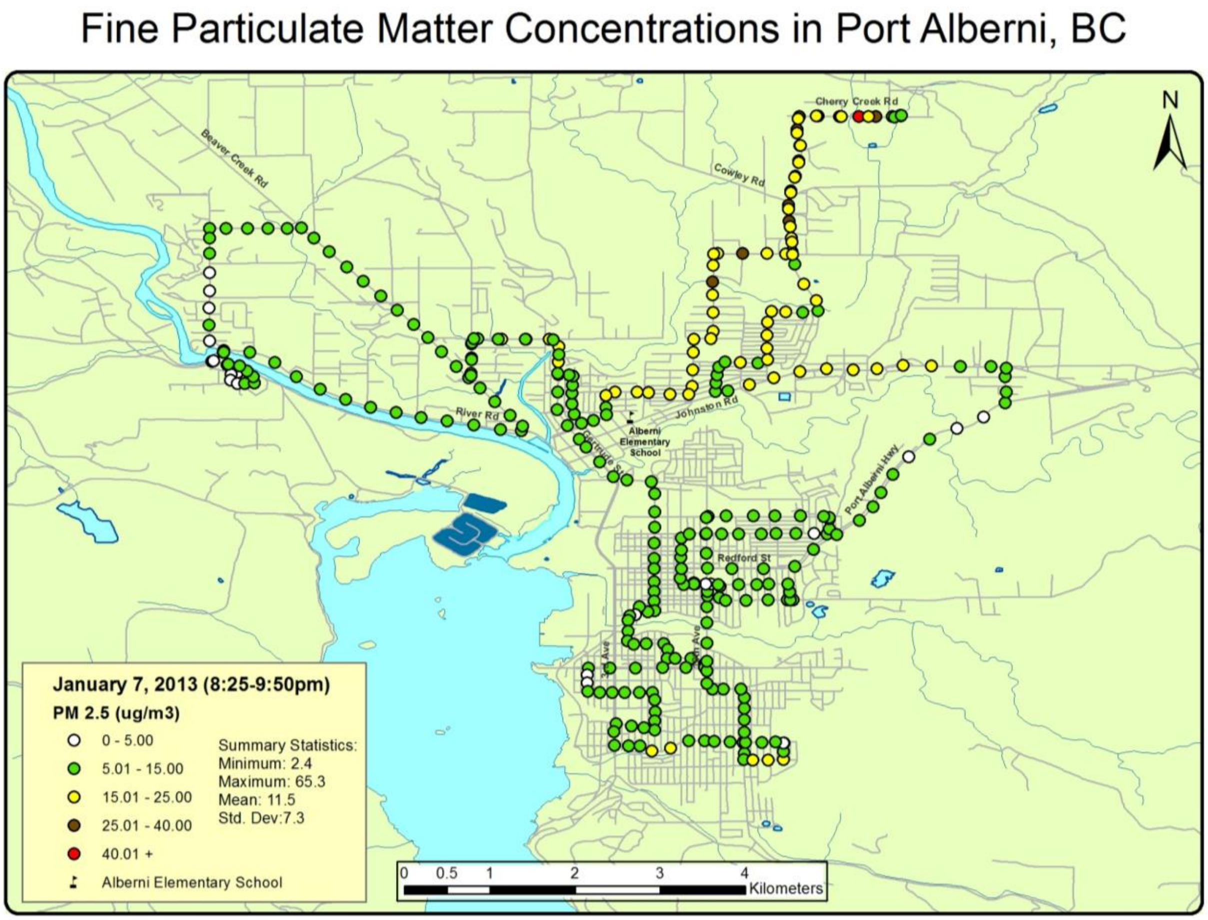

Figure 53: Mobile Nephelometer results for Monday, Jan. 7, 2013. From 8-10 PM, the Alberni Elementary station recorded temperatures were 2-3 °C and winds at ~1 m/s from the NW. $PM_{2.5}$ data was not available from Alberni Elementary. The Nephelometer recorded fair $PM_{2.5}$ levels across much of the city, other than in Cherry Creek, where values were higher, including one measurement above 40 µg/m^3.

Fine Particulate Matter Concentrations in Port Alberni, BC

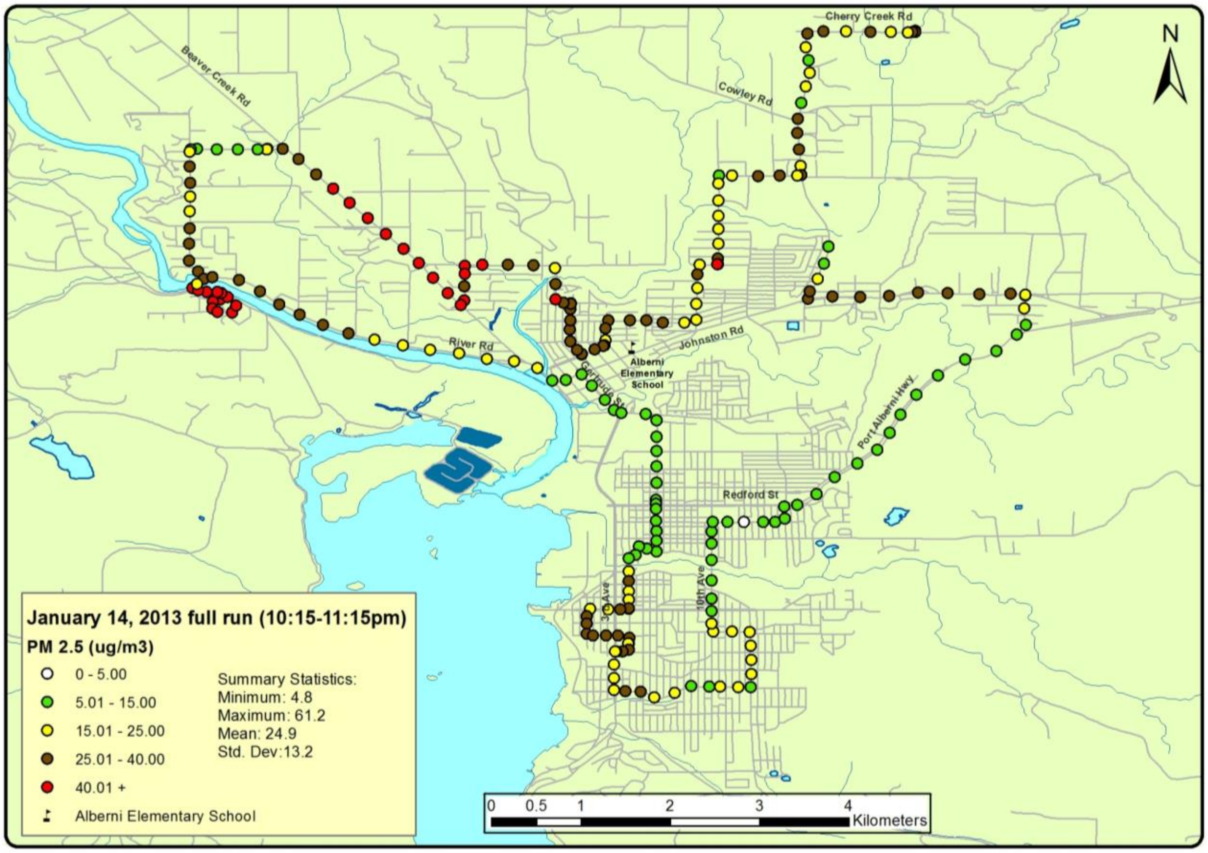

Figure 54: Mobile Nephelometer results for Monday, Jan. 14, 2013. From 10-12 PM, the Alberni Elementary station recorded hourly average $PM_{2.5}$ at 20-34 µg/m^3, temperature at ~1 °C, and wind at ~0.5 m/s from the NE. The mobile Nephelometer measured elevated $PM_{2.5}$ levels in three areas of the city on January 14th – Cherry Creek in the north, along Beaver Creek Rd. and River Rd. to the West, and by the Harbour Quay to the South, suggesting various sources across the city.

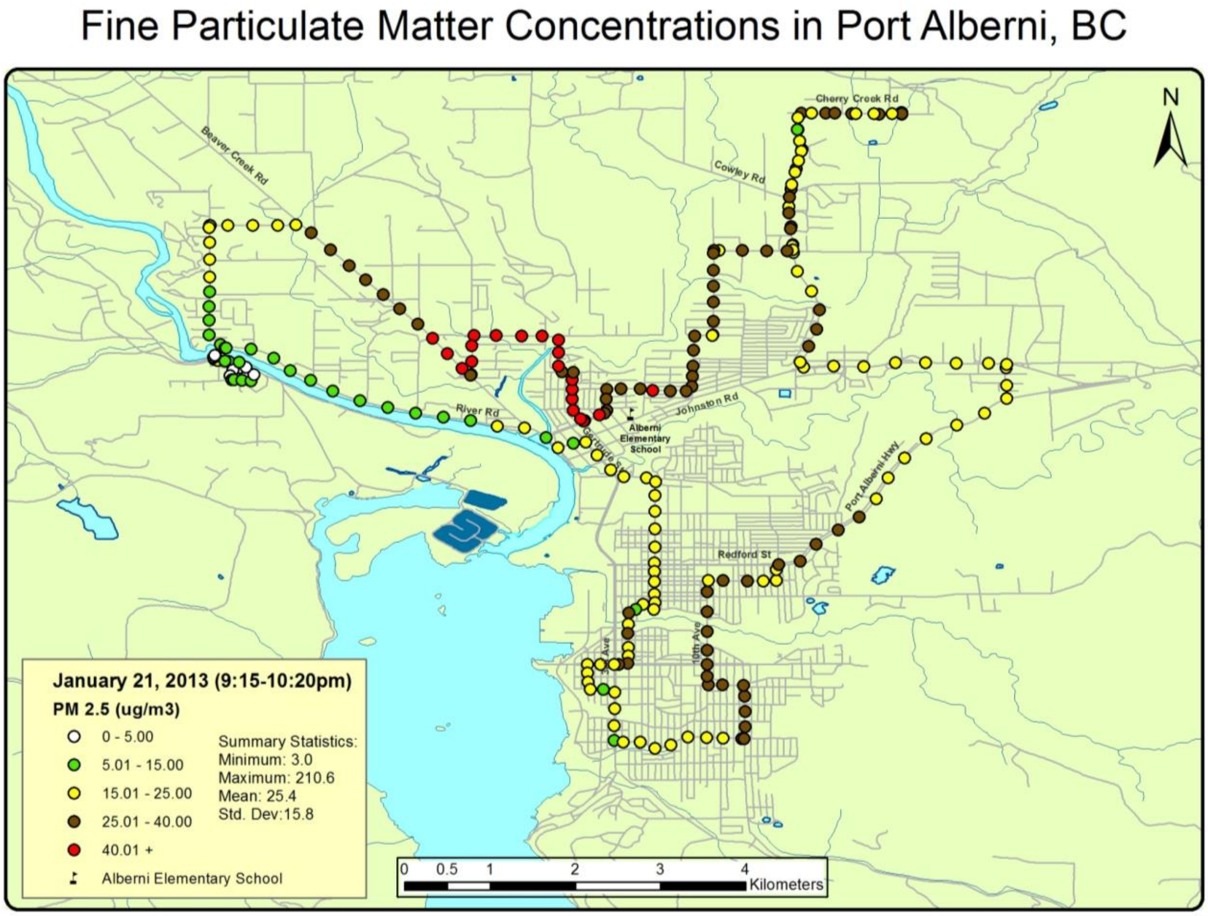

Figure 55: Mobile Nephelometer results for Monday, Jan. 21, 2013. From 9-11 PM, the Alberni Elementary station recorded average hourly $PM_{2.5}$ at 32-53 µg/m^3, temperature at ~-1 °C, and wind at ~0.5-1 m/s from the NW. Variable $PM_{2.5}$ levels across the city on the 21st suggest various sources.

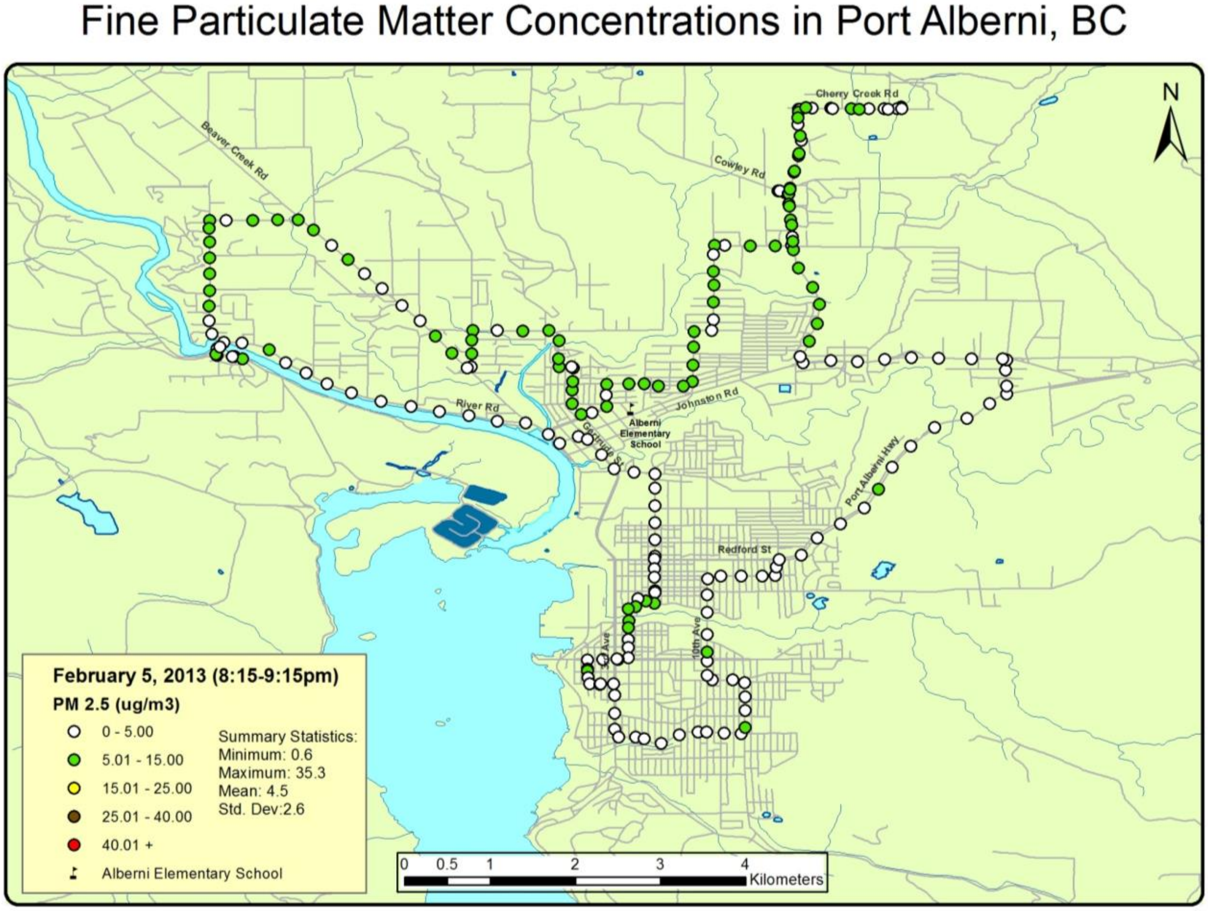

Figure 56: Mobile Nephelometer results for Tuesday, Feb. 5, 2013. From 8-10 PM, the Alberni Elementary station recorded average hourly $PM_{2.5}$ at 1-2 µg/m^3, temperature at ~6 °C, and wind at ~1.5 m/s from the NW. $PM_{2.5}$ concentrations were low across the city.

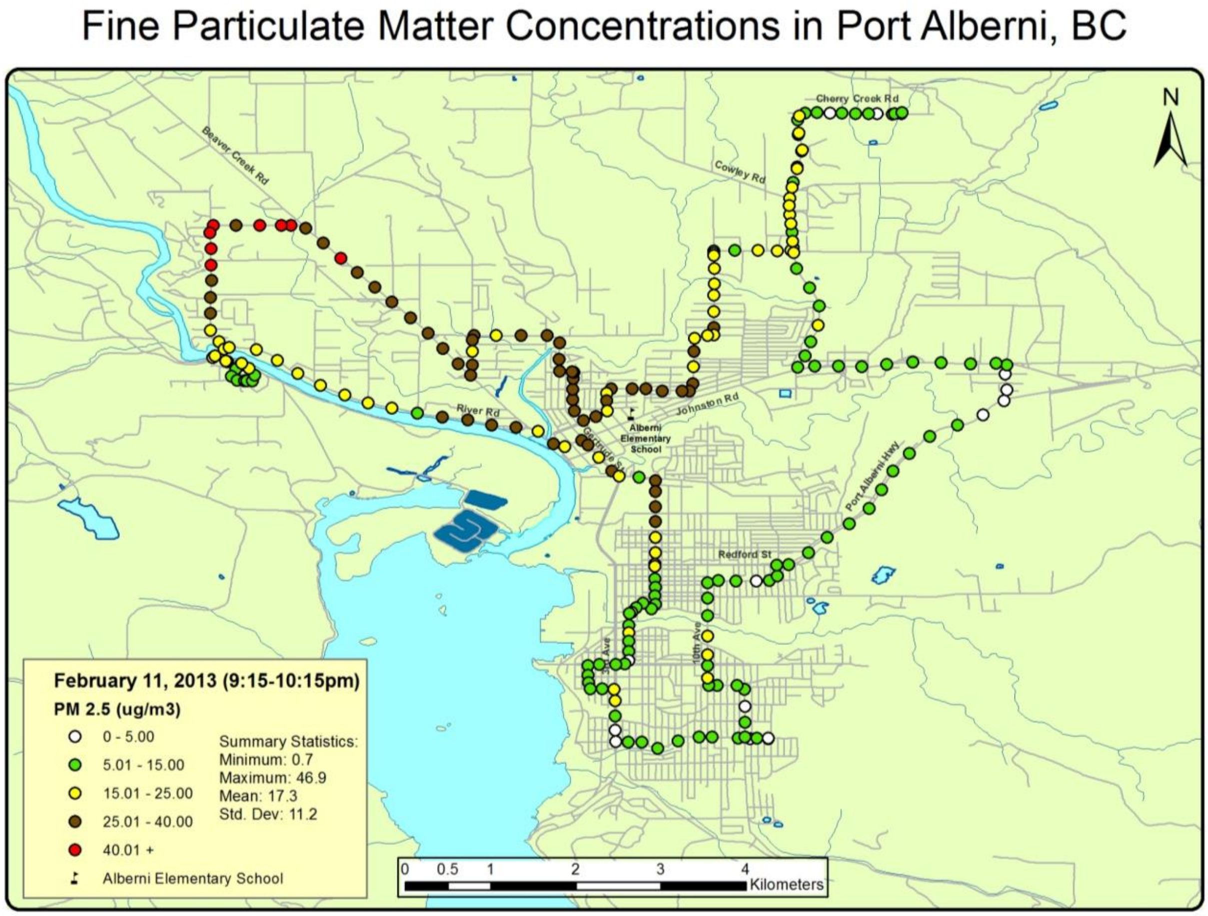

Figure 57: Mobile Nephelometer results for Monday, Feb. 11, 2013. From 9-11 PM, the Alberni Elementary station recorded average hourly $PM_{2.5}$ at 22-34 μg/m^3, temperature at ~6 °C, and wind at ~0.5 m/s from the NW. Higher $PM_{2.5}$ concentrations were observed near and to the West of Alberni Elementary.

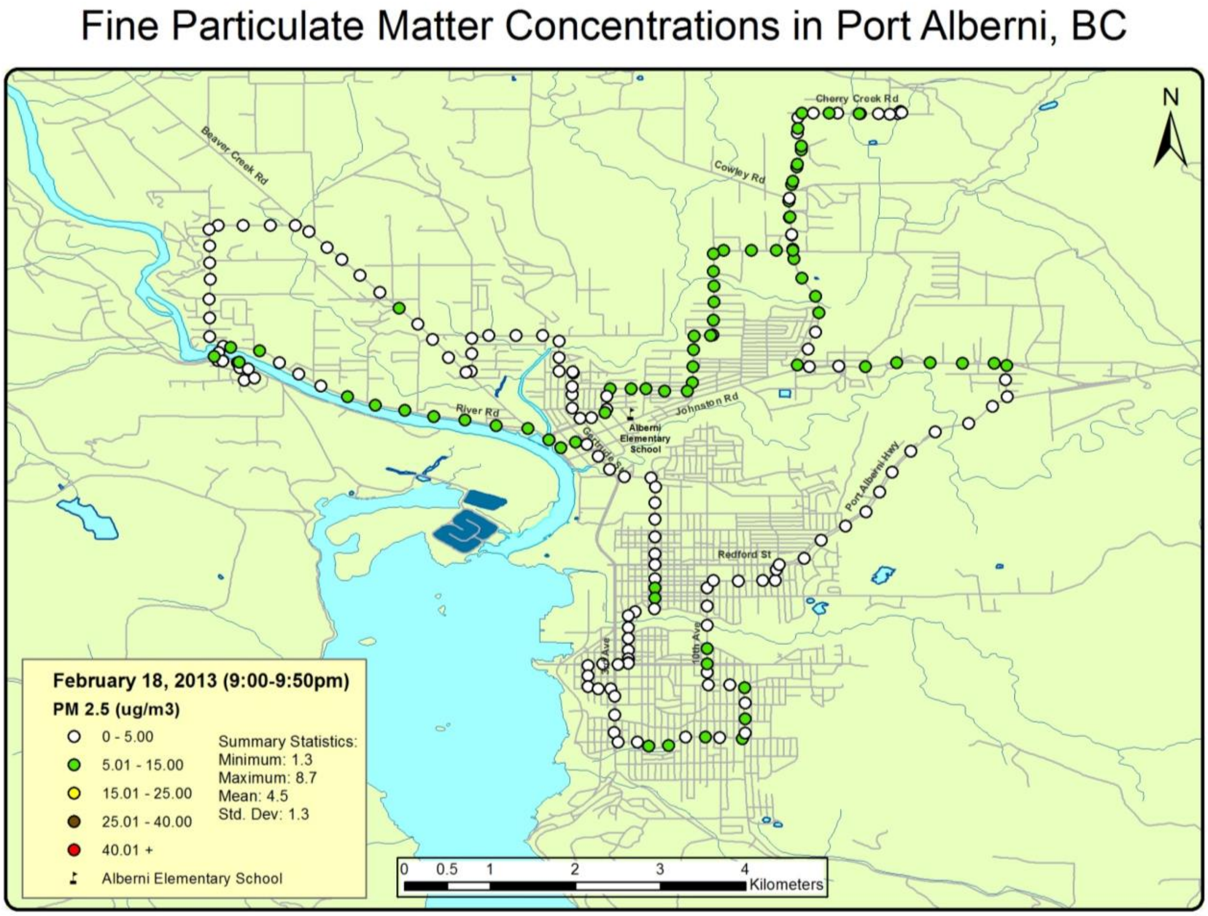

Figure 58: Mobile Nephelometer results for Monday, Feb. 18, 2013. From 9-10 PM, the Alberni Elementary station recorded $PM_{2.5}$ hourly averages of 5-8 µg/m^3, temperature at 2-3 °C, and wind at 1-2 m/s from the NW. Warmer temperatures and stronger winds in the evening likely contributed to improved air quality during the evening of February 18, 2014.

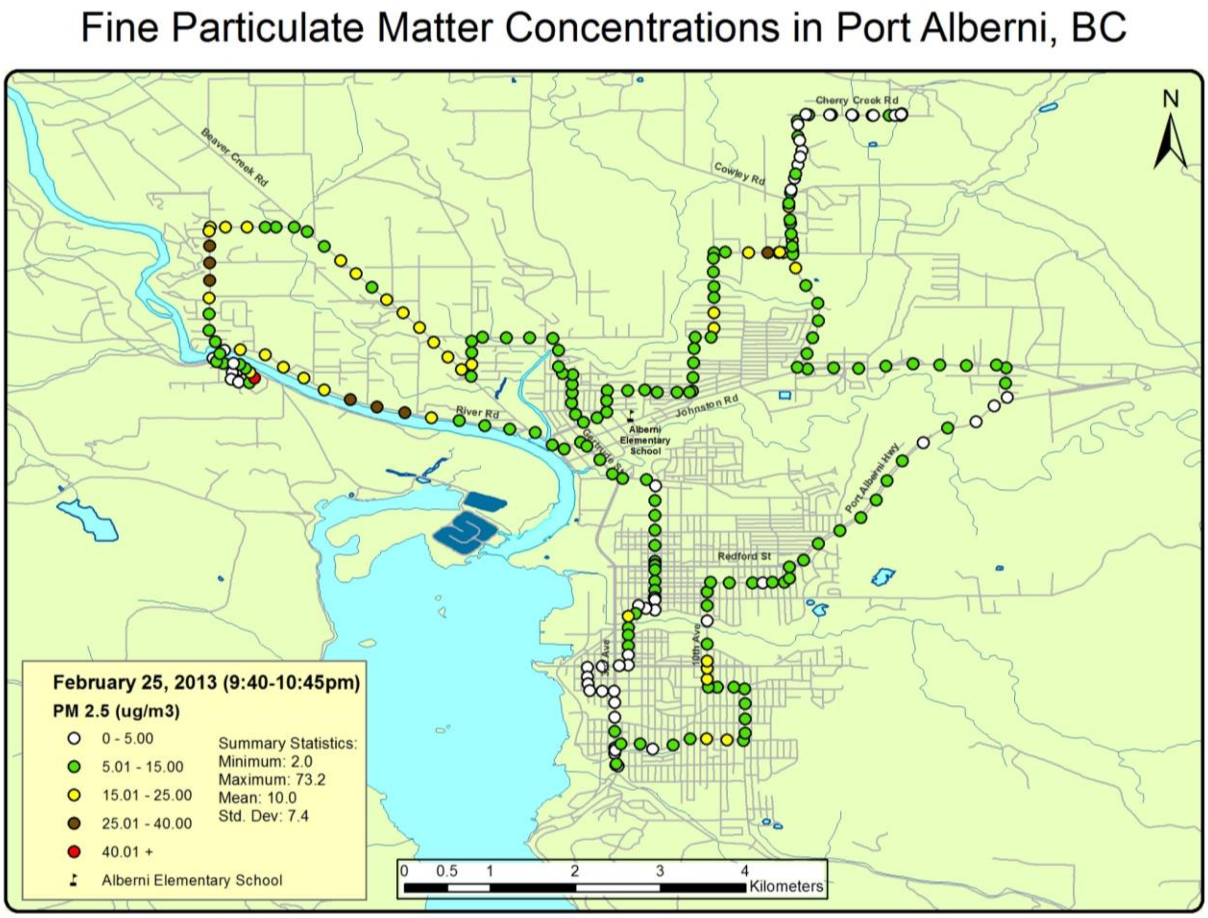

Figure 59: Mobile Nephelometer results for Monday, Feb. 25, 2013. From 9-11 PM, the Alberni Elementary station recorded average hourly $PM_{2.5}$ of 12-15 μg/m^3, temperature at 1-4 °C, and wind at ~1.5 m/s from the NE. Despite similar conditions to Feb. 18th, $PM_{2.5}$ concentrations were elevated in small pockets throughout the area. Highest values were measured to the west of the city and in Cherry Creek.

Route

1. Start at 6865 Cherry Creek Rd.
2. Take Cherry Creek Road West and then South
3. Turn right onto Moore Rd.
4. Turn left onto Strathcona St.
5. Turn right onto Compton Rd.
6. Turn left onto Ian Ave.
7. Turn right onto Lathom Rd.
8. Turn left onto Helen St.
9. Turn right onto Burke Rd.
10. Turn right onto Elizabeth St.
11. Turn left onto Glenside Rd.
12. Turn right onto Gertrude St.
13. Turn left at Compton Rd.

14 Turn left onto Indian Ave.
15 Turn right onto Beaver Creek Rd. Travel for about 2 km.
16 Turn left onto Malabar Rd.
17 Turn left onto Falls St.
18 Turn right (over the bridge) onto Pacific Rim Highway
19 Turn right onto Mission Rd.
20 Turn slightly right onto Somass Crescent E.
21 Turn right onto Thomas Rd.
22 Turn right onto Ekooth Rd.
23 Turn left onto Gallic Rd.
24 Turn left onto Mission Rd.
25 Turn right onto Pacific Rim Highway (over the bridge)
26 Turn right (East) onto River Rd. Travel for about 3 km.
27 Turn left onto Johnston Rd.
28 Turn right onto Gertrude St.
29 Turn slightly left onto Roger St.
30 Turn right onto 6th Ave.
31 Turn right onto N. Park Dr.
32 Turn left onto The Quadrant (West)
33 Turn left onto The Quadrant (South)
34 Turn right onto Napier St.
35 Turn left onto 4th Ave.
36 Turn right onto Argyle St.
37 Turn left onto 1st Ave.
38 Turn left onto Mar St.
39 Turn right onto 3rd Ave.
40 Turn left onto Bruce St. (East)
41 Turn left onto Anderson Ave.
42 Turn left onto China Creek Rd.
43 Turn right onto 10th Ave.
44 Turn right onto Bute St. (East)
45 Turn left onto 16th Ave.
46 Turn right at Redford St. (turns into Port Alberni Highway). Follow for about 2.5 km.
47 Turn left at Maebelle Rd.
48 Turn left onto Alberni Highway (West)
49 Turn right onto Cherry Creek Road. Travel for about 1.5 km.
50 Follow Cherry Creek Road North and then East until reaching the starting point at 6865 Cherry Creek Rd.

Appendix B How to Read a Boxplot

In a box-plot, all the hourly average data or daily average data are separated into groups (e.g. annual, monthly, weekly, daily, etc.). All the measurements for a particular group are then plotted as a box with whiskers. The line in the centre of each box is the median (half the values are larger and half smaller than this value). This is not the same as the average or mean value of the group; in air quality statistics the median is usually slightly larger than the mean. The top of the box is the 75th percentile (three-quarters of the values are lower than this value and one quarter are larger). Similarly the bottom of the box is the 25th percentile (one-quarter of the points are lower and three-quarter larger). The top of the upper whiskers represents the highest value that is less than the value of the top of the box plus 1.5 times the difference in values of the top and bottom of the box. Similarly the end of the lower whisker is the largest value greater than the value of the bottom of the box minus 1.5 times the difference between the top and bottom of the box. All the data values that are larger or smaller than the ends of the whiskers are shown as individual points. In simple terms, half of the values fall within the box, all the values beyond the ends of whiskers can be considered the extreme values or outliers. In air quality statistics, it is often these outlying values that are responsible for degraded air quality. Boxplots can help supply information that may be useful to identify possible sources and develop mitigation plans.