



Ministry of
Environment and
Climate Change Strategy

Patterns of Air Quality and Meteorology in Courtenay B.C. 2011-2016

August 2017

Environmental Protection Division
Regional Operations Branch

Author:

Earle Plain, Air Quality Meteorologist, Ministry of Environment and Climate Change Strategy,
Nanaimo BC

Photo:

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Executive Summary

This report examines patterns in ambient air quality and meteorology in the city of Courtenay BC for the period 2011-2016. The air pollutants that were considered include fine particulate matter less than 2.5 micrometres (PM_{2.5}), nitrogen dioxide (NO₂) and ozone (O₃).

Mean wind speeds were lowest in the winter and highest in the spring/summer, and calm wind conditions (when wind speed is below 0.5 m/s) were most frequent during the fall and winter months (up to 20% of the time). Winds were also lighter with a higher frequency of calms during the nighttime period in all seasons. The valley location of Courtenay makes it susceptible to the frequent formation of temperature inversions, particularly during the colder months. Light drainage flows off the Beaufort Mountain range (from the west through north west) are an important feature in Courtenay especially during the nighttime hours.

An analysis of NO₂ concentrations measured in Courtenay showed a clear seasonal pattern with lower NO₂ 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. NO₂ concentrations measured at the Courtenay Elementary School station were well below the BC Ambient Air Quality Objectives (AAQOs).

O₃ levels measured at Courtenay Elementary School were well below provincial AAQOs. Mean monthly O₃ concentrations at the monitoring site exhibited a springtime peak consistent with other communities in the northern hemisphere. There is not a significant mid-summer peak (July and August) in monthly average O₃ concentrations, however, the highest 1-hour concentrations are still observed in July and August which is consistent with local photochemical production.

Wood smoke sources contribute significantly to PM_{2.5} levels in the Comox Valley. A suspended particulate emissions inventory completed for the Comox Valley indicates that open burning (forestry, agriculture, commercial, and residential) and space heating activities contribute nearly 81% of the total PM_{2.5} emissions.

There were exceedances of the BC AAQO for PM_{2.5}. Air quality as measured by PM_{2.5} was generally good during the warm months but degraded during the fall and winter due to changes in meteorology and emission sources. The highest PM_{2.5} levels were observed during winter evenings, when winds were light and typically from the west to northwest. Patterns were consistent with contributions from wood burning appliances as well as from land clearing burning, residential backyard burning, and forestry operations.

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

1 Introduction

The Ministry of Environment and Climate Change Strategy (ENV) has been operating an ambient air quality monitoring station in the city of Courtenay since June of 2011. Parameters routinely measured at this site include fine particulate matter (PM_{2.5}), ozone (O₃), nitrogen dioxide (NO₂), and meteorology. The ENV has also been involved in other special short-term ambient monitoring studies in the area.

Ambient air quality data and meteorology were analyzed for patterns and trends from 2011 to 2016.

Some of the key questions considered in this report include:

- What are the meteorological characteristics in the Comox Valley?
- What meteorological conditions are associated with periods of poor air quality?
- 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 temporal patterns in CAC concentrations and when are concentrations the worst?
- What are the main sources of pollutants that contribute to fine particulate air pollution in the valley?

Conclusions and recommendations in this report are based on a weight of evidence approach involving many different pieces of information. The results of this study are intended to provide direction to air quality managers involved in future airshed management efforts in the Comox Valley.

1.1 Site Geography

The city of Courtenay is located on the east coast of central Vancouver Island approximately 180 km north of Victoria, BC. (Figure 1). The city lies in a valley bottom near sea level at the head of Comox Harbour and east of the Beaufort mountain range. The Comox Valley is susceptible to the frequent formation of temperature inversions, particularly during the colder months, which can reduce the ability of the atmosphere to disperse pollutants.

Courtenay has a population of approximately 25,000 people and is a member municipality of the Comox Valley Regional District (City of Courtenay, 2016). Other municipalities in the Comox Valley include Cumberland to southwest and Comox to the west. The population of the Comox valley was 66,527 in 2016 (Statistics Canada, 2017).

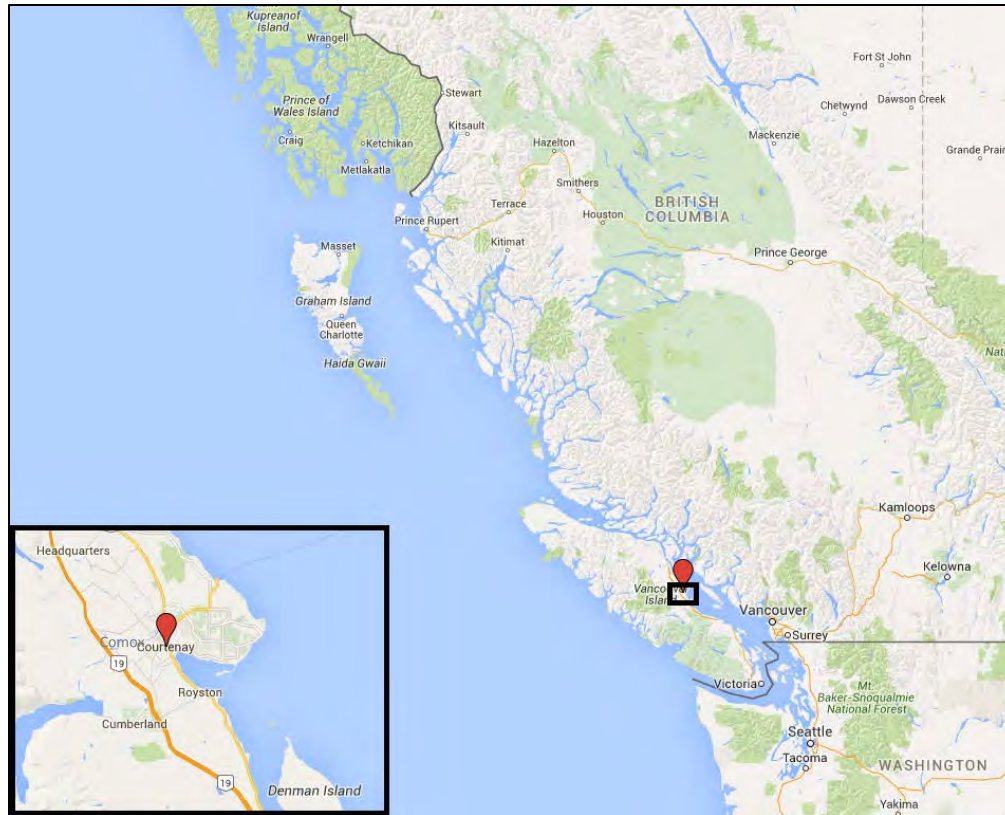


Figure 1: Location map for Courtenay, BC (Map data © 2016 Google)

1.2 Fine Particulate Matter (PM_{2.5})

Fine particulate matter that is 2.5 micrometres (one micrometre=1/millionth of a meter) or smaller in diameter is referred to as PM_{2.5}. PM_{2.5} was monitored at the Courtenay Elementary School station using a Met One Beta Attenuation Monitor (BAM 1020).

Particulate matter consists of tiny liquid or solid particles suspended in air. PM_{2.5} is a specific health concern as the particles are small enough to penetrate deep into 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; Weichenthal et al. 2017).

PM_{2.5} can also affect visibility as particles in this size range are efficient at absorbing and/or reflecting visible light (Bates and Caton, 2002).

1.2.1 Sources of Fine Particulate in the Comox Valley

An emissions inventory was completed for the Comox Valley in March of 2017 to help identify the main sources of fine particulate matter that should be managed (RWDI, 2017). In this report, the consultant examined source contributions to total particulate matter (TPM), particulate matter equal to or less than

10 micrometres in diameter (PM_{10}), and $PM_{2.5}$ for the 2015 base year. Emissions were quantified from point (industrial), area, and mobile sources.

$PM_{2.5}$ is primarily produced through combustion processes and chemical reactions in the air. In contrast, coarser particles (i.e. larger than $PM_{2.5}$) are usually formed from mechanical processes including dust resuspension, and typically contain high concentrations of crustal elements. For instance, road dust contributions to the $PM_{2.5}$ fraction are between 3-9% of the mass in speciation studies across Canada (Dabek-Zlotorzynska et al, 2010).

Figure 2 summarizes the contributions to annual $PM_{2.5}$ emissions from all sources in tonnes per year (T/Y) and as a percentage of the total in the Comox Valley.

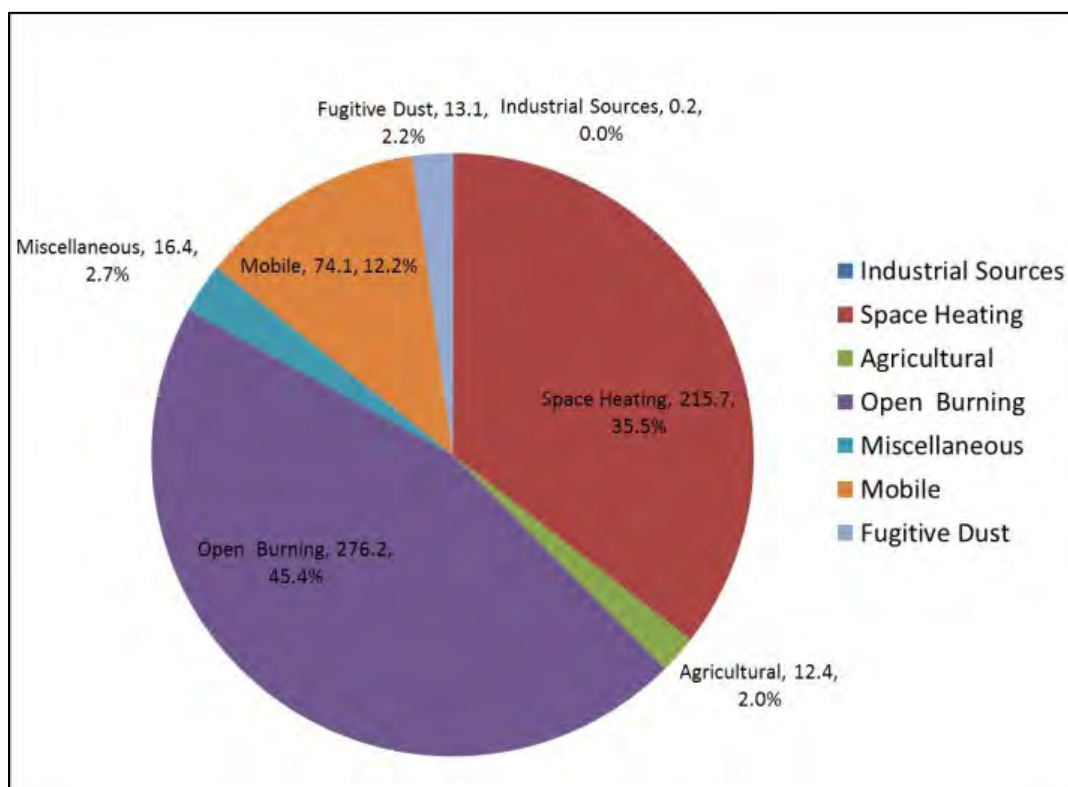


Figure 2: Source contributions to total $PM_{2.5}$ in the Comox Valley - not including road dust (T/Y and percent of total).

There is very little industry in the Comox Valley and the emissions profile is dominated by emissions from area sources (e.g. open burning and space heating) and mobile sources. Open burning and space heating activities contribute nearly 81% of the total $PM_{2.5}$ emissions in the Comox Valley. The open burning source category includes emissions from wildfires, commercial open burning (forest harvesting, agricultural land clearing, and land clearing for property development), prescribed burning, and residential backyard burning.

Figure 3 summarizes the contributions to the open burning emissions sector in further detail. Note that in the RWDI report, provincially regulated pile burning is classified into 3 categories representing forestry (Category A), and land clearing (Categories B & C). The majority of municipally regulated pile burns are also related to land clearing and have been placed into this category in Figure 3.

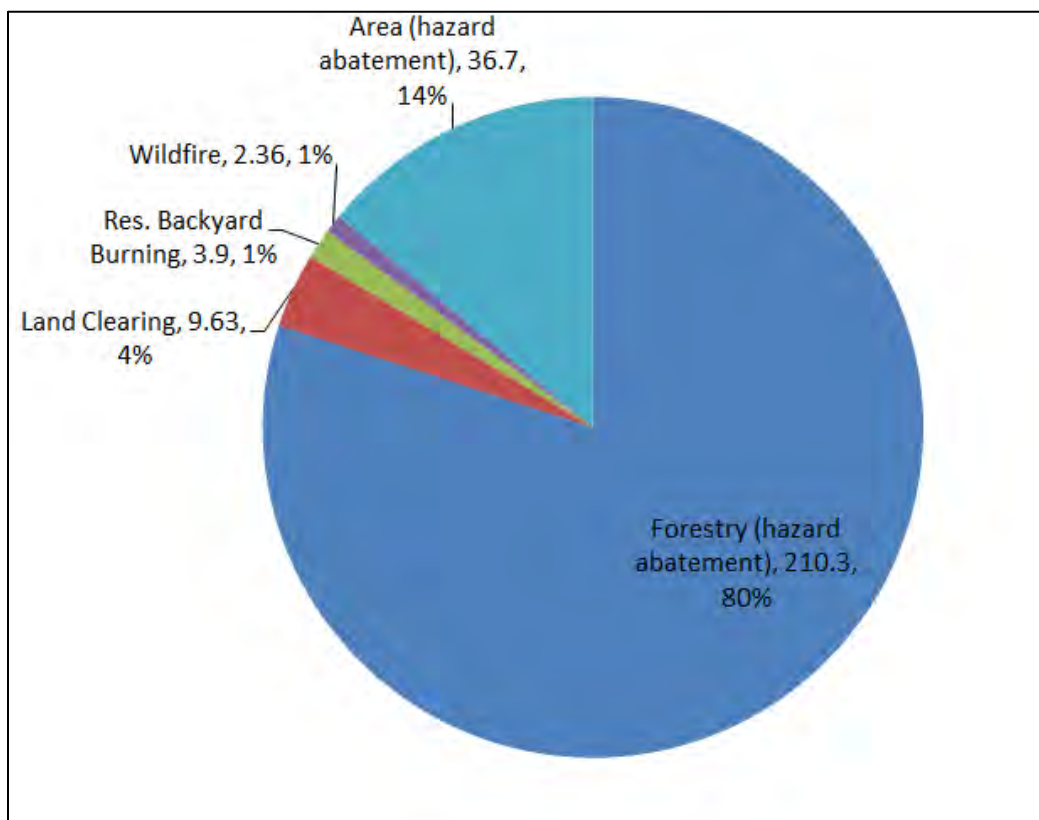


Figure 3: PM_{2.5} emissions from open burning sources in the CVRD (T/Y and percent of total).

The majority of the PM_{2.5} emissions in the open burning category come from the forestry sector in the Comox Valley. However, emission totals are only one consideration when examining which sources to target in order to manage air quality. Other factors include meteorological conditions under which ignition takes place, the cleanliness of the material being burned, moisture content of the material (green vs. cured), duration of the burn, timing of the burn (season; day vs. nighttime), and proximity of the burn to people (see Table 1).

For instance, hazard abatement burning by major forest companies on Vancouver Island involves burning relatively clean piles of woody debris (no stumps or dirt) that have been cured for 6+ months. These burns generally take place in October and early November (before heavy winter rains set in), are well away from populations and are regulated by the provincial Open Burning Smoke Control Regulation (OBSCR, B.C. Reg. 145/93) which stipulates burn duration, setback from residences, and the atmospheric conditions under which ignition can take place. Other forms of pile burning such as land clearing for land development are also regulated by the OBSCR but these burns generally involve disposing of dirtier, green material and stumps (typically generates more smoke for longer periods) and are located closer to populated areas. Residential backyard burning takes place in close proximity to people, can involve wet or green material (e.g. can generate large volumes of smoke), and is unregulated in the Comox Valley Regional District (CVRD). Even though the latter two categories generate a smaller emissions total when compared to forestry burns, they have a greater potential to impact on residents because of proximity, fuel quality, and in the case of backyard burning, no restrictions on when this activity can occur.

Table 1: Air quality impact potentials from different types of open burning activities

Open burning type	Applicable regulations	Fuel Quality	Proximity to populations	Typical smoke release period	Impact potential	Comments
Forestry: major licensees	OBSCR (venting, setbacks, release duration, prohibited materials list, etc.)	Good using BMPs: fire-wooding; cured fuels; no stumps; well-built piles; hot short burns	Varies – generally 5km+ from population centers.	1-4 days per burn as per OBSCR and SMP. Late Sept to mid-Nov. Generally complete by end of Oct.	Low to moderate if managed under the Fuel-smoke management plan (SMP).	Major forestry companies are SMP signatories. Developed BMPs to reduce wildfire risk while maintaining acceptable air quality
Forestry: BCTS; woodlots; smaller operators	OBSCR	Varies depending on operator. No stumps in piles; No BMPs	Varies – can be close to populations. Set-back as per OBSCR	1-4 days per burn under OBSCR. Oct-May	Moderate. Fuel quality/proximity dependent	Generally smaller operations; lack of knowledge about OBSCR requirements
Agriculture land clearing	OBSCR	Varies; can be poor including green material, dirt, and stumps. No BMPs	Varies but can be within or next to population centers. Set-back as per OBSCR	1-4 days per burn under OBSCR. Oct - May	Moderate to High. Fuel quality/proximity dependent. Stump burning leads to multi-day burns.	Overnight burns during the cold season can create AQ issues if smoke excessive
Development land clearing	OBSCR (in CVRD) & Municipal bylaws	Generally poor. Green material, dirt and stumps. No BMPs	Close to or within population centers. Set-back as per OBSCR	1-4 days per burn under OBSCR. Oct-May	Moderate to High. Fuel quality/proximity dependent. Stump burning leads to multi-day burns.	Overnight burns during the cold season can create AQ issues if smoke excessive
Residential backyard	Not regulated in CVRD. Some Municipal bylaws. Burning of prohibited materials illegal under provincial law.	Variable. Can include green, wet material and prohibited materials. No BMPs	Very close. Directly in populated areas. No setback from neighbours required.	24/7 release. No release period limits in unregulated areas. Oct-May	Moderate to High. Fuel quality/proximity dependent. Activity can occur under any meteorological conditions.	Exempt from OBSCR. Emissions from small fires cool rapidly and come to ground quickly.

It should be noted that the City of Courtenay and the Town of Comox have bylaws in place that regulate open burning within their respective municipal boundaries. The Village of Cumberland is also moving in this direction. It should also be noted that major forestry companies on Vancouver Island all participate in smoke management planning (SMP) and have all signed onto Fuel-Smoke Management Burn Plans with the Wildfire Management Branch and the Ministry of Environment and Climate Change Strategy. A component of these plans includes developing best management practices for piling, curing, and burning woody debris within their operating areas. In addition, much research has been completed around optimal

burn timing to reduce potential air quality impacts and these findings have been incorporated into the burn plans. This work has resulted in enhanced burning techniques and improved emission quality for this sector.

Figure 4 summarizes PM_{2.5} contributions to the Space Heating category displayed in Figure 2.

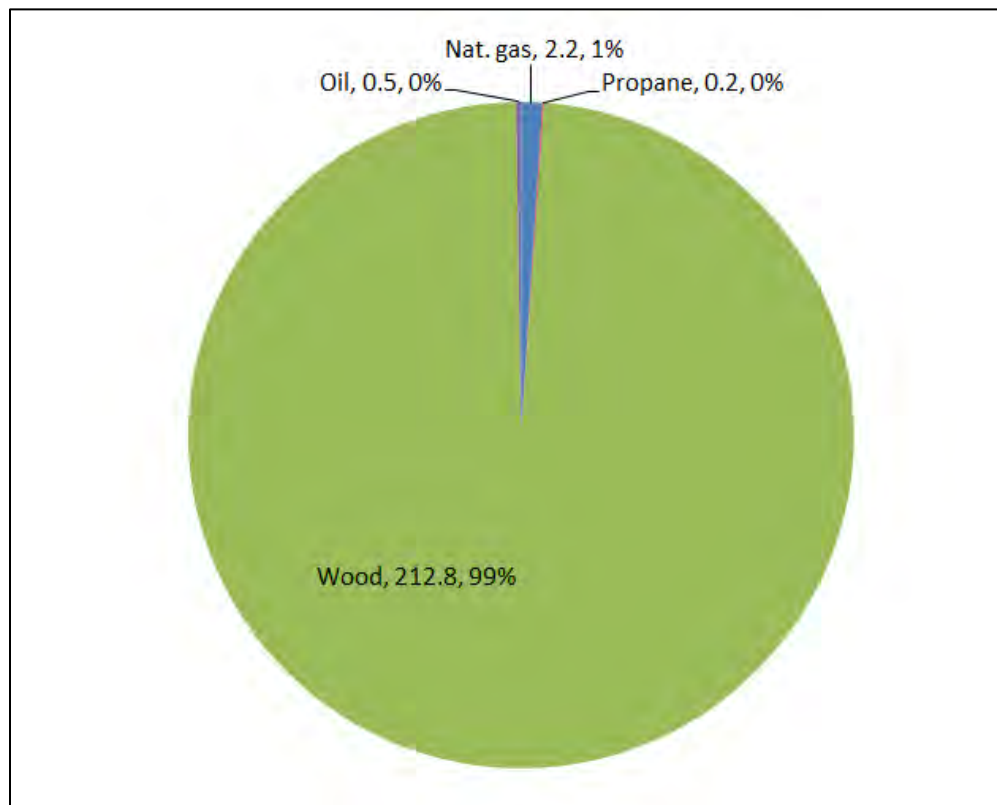


Figure 4: PM_{2.5} source contributions to the Space Heating Sector (T/Y and percent of total).

PM_{2.5} emissions from wood heat make up 99% of the space heating category. Wood stove emissions occur right where people live and play and subsequently, can have a large impact on air quality at the neighbourhood level.

Other research also points to wood smoke sources as being significant in the Comox Valley. Hong et Al, (2016) completed a province-wide analysis of PM_{2.5} data in 2016 which indicated that Courtenay is the 2nd most wood smoke impacted community in the province.

In order to provide better resolution on where there might be opportunities to better manage wood stove emissions in the valley, it is recommended that community-specific wood stove surveys be considered in the future.

1.3 Nitrogen Oxides (NO and NO₂)

NO_x (nitrogen oxides) refers to NO (nitric oxide) and NO₂ (nitrogen dioxide), both of which are produced primarily through high temperature 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 gases react with other substances in the atmosphere to produce

ozone, and acid rain. NO_x gases can also contribute to the formation of secondary fine particles such as nitrates that scatter light and degrade visual air quality.

NO reacts quickly with ozone to form NO₂. NO₂ is a reddish-brown, toxic gas with a sharp odour, the inhalation of which can cause acute and chronic respiratory effects (Godish, 1997; Bates and Caton, 2002; WHO, 2005). Major anthropogenic sources of NO_x include mobile sources such as vehicle and marine vessel exhaust, and stationary sources such as industrial boilers, and residential home heating.

Ambient NO and NO₂ concentrations were continuously monitored at the Courtenay Elementary School station using an API T200 gas analyzer.

1.4 Ozone

Ozone (O₃) is a pale blue gas with a pungent smell. It 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 atmosphere (the troposphere), O₃ is a photochemical oxidant that is formed in the atmosphere from chemical reactions involving NO_x and hydrocarbons (HC) in the presence of sunlight. Ground level ozone can irritate the respiratory system, impair lung function and cause chronic respiratory illnesses. 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 sources.

Ambient ozone concentrations were continuously monitored at the Courtenay Elementary School station using an API T400 gas analyzer.

2 Data Sets

Climate Normals data that provides information on regional climate was obtained for the Environment Canada Comox Airport monitoring station (Environment Canada, 2017). Meteorological and ambient air quality data for Courtenay was obtained for the Ministry of Environment and Climate Change Strategy (ENV) monitoring station located at the Courtenay Elementary School. More station details can be found in Table 2, Figure 5 and Figure 6. The variables contained in these data sets are discussed below.

Table 2: Monitoring station details in Courtenay BC

Station Name:	Latitude (decimal degrees)	Longitude (decimal degrees)	Elevation (m)	Period of Operation
Courtenay Elementary School (ID= 414) Station: E285829	49.6825	-124.9961	28.00	June 1, 2011 – Present (meteorology installed in Sept of 2012)
Comox Airport (Climate Normals) (Environment Canada, 2015)	49.7200	-124.9000	25.60	1981 - 2010

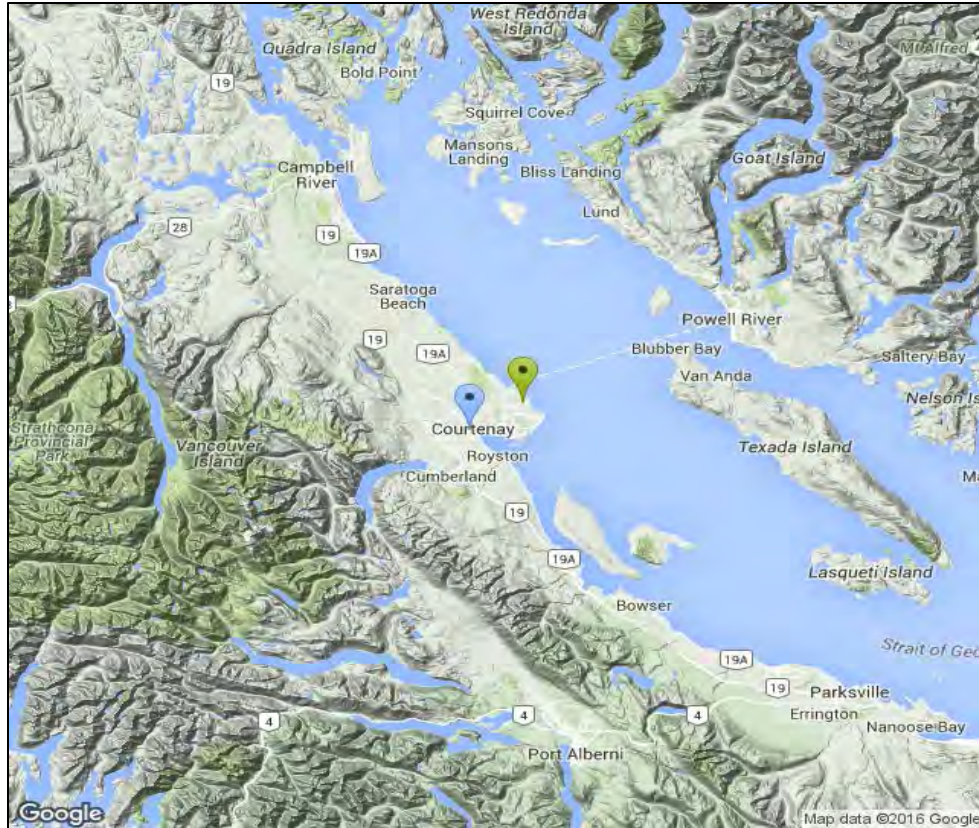


Figure 5: Location of air quality and meteorological monitoring stations in the Comox Valley. Courtenay Elementary School  and Comox Airport  (Map data ©2016 Google)



Figure 6: Monitoring station locations in the Comox Valley (Map data ©2016 Google).

2.1 Climate and Short-Term Meteorological Data

Climate refers to the long term average of meteorological 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 – parameter averages of at least 15 years of data over a 30 year period. Historical climate data for the Comox Valley was summarized for the Comox Airport.

Meteorological data was also collected at the ENV Courtenay Elementary School air quality monitoring station since September 2012. This data was collected to help determine the weather conditions that coincide with poor air quality, as well as providing information that could assist with source identification. Table 2 identifies the key meteorological parameters measured at both sites.

Table 3: Meteorological parameters measured at the Comox Airport and Courtenay Elementary

Station Name:	Meteorological Parameters Measured				
	Wind Speed	Wind Direction	Temperature	Relative Humidity	Precipitation
Comox Airport Environment Canada (1981-2010)	✓	✓	✓	✓	✓
Courtenay Elementary School - ENV (Sept. 2012-2016)	✓	✓	✓	✓	X
Sensors – ENV site	RM Young 05305		Vaisala HMP45C		N/A

2.2 Air Quality Data

The ENV ambient air monitoring station at Courtenay Elementary School began operation in mid-2011. This is the core air monitoring site in the Comox Valley. The parameters measured and instrumentation used at this location are summarized in Table 3. The data from this monitoring site is reported out to the public on a near real-time basis through the BC ENV Air Quality website (see: <http://www2.gov.bc.ca/gov/content/environment/air-land-water/air>).

Table 4: Air quality parameters measured at Courtenay Elementary School

Station Name:	Air Quality Parameters Measured (Instrumentation)		
	PM 2.5	NO ₂	O ₃
Courtenay Elementary School (June 2011-2016)	✓ (Met One BAM 1020)	✓ (API T200)	✓ (API T400)

2.3 Data Quality Assurance and Validation Criteria

All ambient air quality and meteorological instruments at the Courtenay Elementary School site were maintained, calibrated and audited by ENV staff as per Ministry guidelines and instrument manufacturer requirements. Instrument calibration and audit records are available on request to ENV.

The ENV requires at least 75% data availability in order for a data set to be considered valid. Valid daily averages (midnight to midnight) require at least 18 hourly measurements. When considering seasonal variability, annual data sets of PM_{2.5} require at least 75% of calendar days for each quarter to be valid in order for that year's data to be considered a valid data set. The quarters are broken up as follows: Quarter 1 (Q1) = January, February, March; Quarter 2 (Q2) = April, May, June; Quarter 3 (Q3) = July, August, September; Quarter 4 (Q4) = October, November, and December. For Ozone data requirements, 75% completeness for the combined 2nd and 3rd quarters (April 1 to September 30) is required. See the CCME site for further information on data completeness guidance (CCME, 2012).

Data sets that did not meet data validation criteria have been flagged in this report.

3 Results and Discussion

3.1 Climate

The Comox Valley is located in a Temperate Mediterranean Climate (Csb classification) under the Köppen Climate Classification System (Pidwirny, 2011). The area experiences 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 the fall, the North Pacific High shifts southward and the westerly jet stream strengthens, directing 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 region, resulting in a much smaller temperature range than that of continental regions of BC east of the Coast Mountains.

3.1.1 Precipitation and Temperature Data

Long-term average precipitation and temperature data as found in the Climate Normals station data from the Comox Airport (1981-2010) are summarized in Figure 7 and in Table A-1 (see Appendix A). On average, the least amount of precipitation occurs in July with an average of 26.7 mm while the greatest amount occurs in November at 200.5 mm. Snowfall can occur from October through to April.

Average daily temperatures in the Comox Valley are warmest in July and August at 18.0 °C and coolest in December at 3.5 °C.

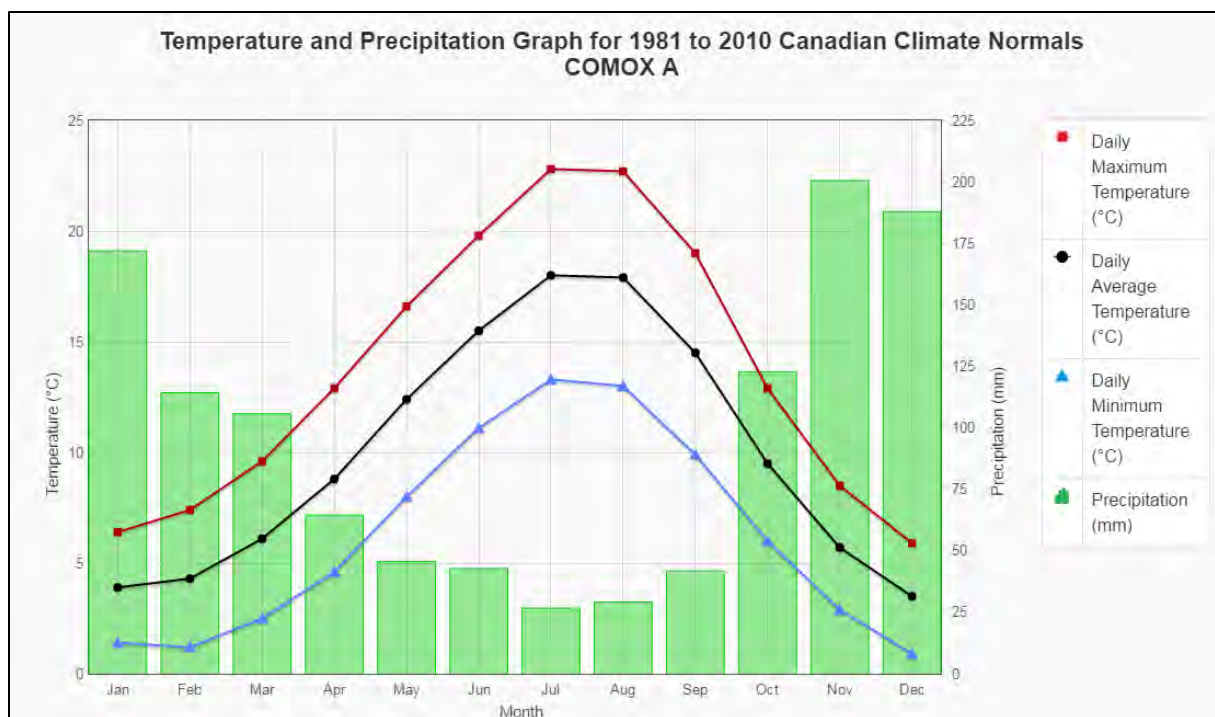


Figure 7: Climate Normals Data for daily average temperature and precipitation from the Comox Airport (1981-2010) - Environment Canada (2017).

Table A-2 (Appendix A) summarizes the mean monthly temperatures measured at the Courtenay Elementary School monitoring site compared to long-term averages from the Comox Airport. The Courtenay Elementary School site shows a similar temperature pattern to the long-term climate station (Figure 8) which is expected given the close proximity to the airport (approximately 8 km away).

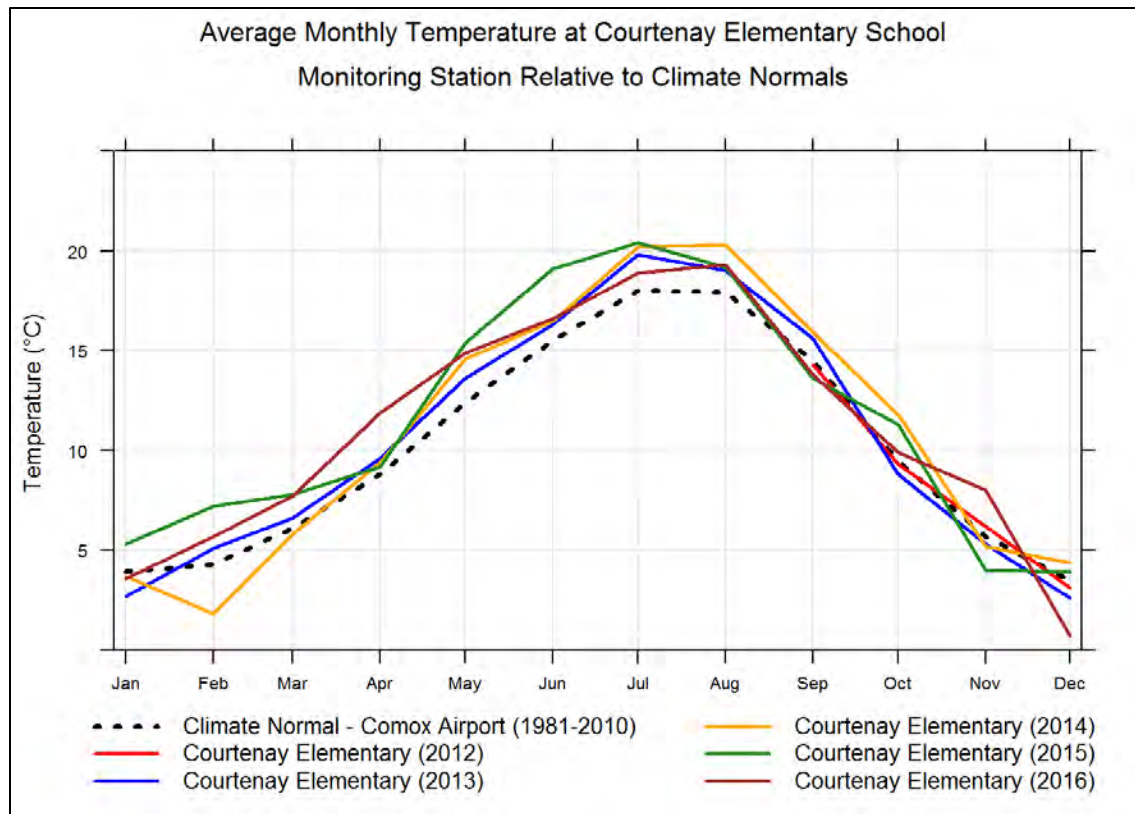


Figure 8: Average monthly temperature at the Courtenay Elementary station relative to the climate station

3.2 Meteorology

Airborne pollutants are transported and dispersed by wind, and therefore air movement is critically important to understanding air quality. For example, elevated ambient particulate levels that coincide with calm or very light wind speeds may be indicative of local pollutants accumulating near the point of origin (e.g. wood stove smoke, re-suspended road dust and automobile exhaust). The same levels of particulate associated with a moderate wind may indicate transport of pollutants from a source outside of the local area (e.g. forest fires, open burning, industrial emissions, etc.).

Weather systems approach the Pacific Northwest from the southwest through northwest, depending on the season (Environment Canada and U.S. Environmental Protection Agency, 2014). Weather systems are often embedded in a well-defined band of winds in the mid-levels of the atmosphere called the jet stream (sometimes called the storm track). The direction of approach and the frequency of these systems depend on the location of the jet stream, which shifts north in summer and south in winter. The stronger flows associated with large weather systems coming from the Pacific are mainly channelled through the Strait of Georgia which is oriented in a northwest to southeast fashion. Local wind direction patterns in Courtenay are also influenced in large part by the mountainous topography to the west of the city and by the Puntledge River drainage that carves out much of the valley.

Wind speed and direction have been monitored at Courtenay Elementary School since September 2012. These variables were measured with RM Young meteorological sensors attached to a 10-meter tilt-over tower.

A wind rose is a common way of expressing and determining wind patterns. 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. It is also useful to separate wind datasets by season, and by daytime and nighttime for display in the wind rose format.

The hourly data collected from 2013-2016 was used to construct the annual wind rose for the Courtenay Elementary School site shown in Figure 9. The strongest winds, associated with large weather systems, were predominantly from the southeast sector with a secondary peak out of the northwest. It is notable that light winds were most frequent out of the northwest sector and the west. On an annual basis, winds are calm about 12% of the time. Calm wind conditions are defined by wind speeds that are less than 0.5 meters per second (m/s) and are especially important from an air quality perspective. Calm and light wind conditions are generally indicative of stable atmospheric conditions and either elevated (i.e. frontal) or ground-based inversions (Angle and Sakiyama, 1991). Temperature inversions (where temperature increases with height above the ground) can trap air emissions near ground level and lead to a build-up of pollutants in the area.

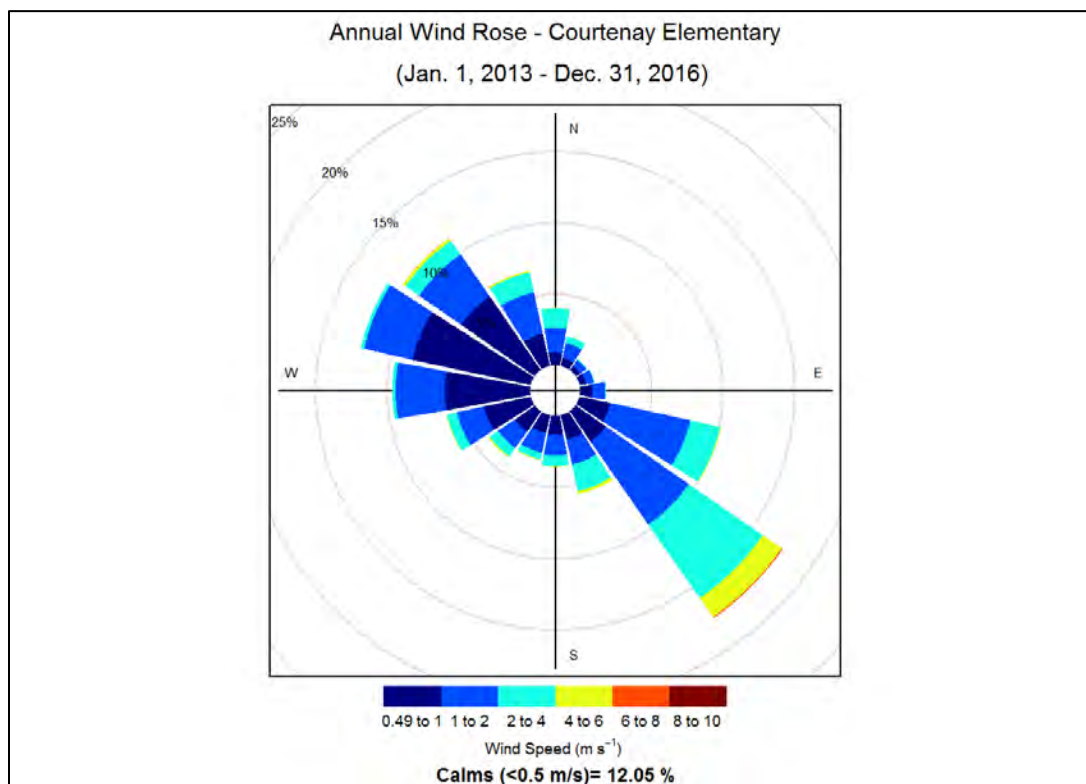


Figure 9: Annual wind rose for Courtenay Elementary School based on 2013-2016 hourly data

When examined by season, it can be seen that the strongest winds were associated with winter and autumn storm events (Figure 10). These winds were channelled along the Georgia Strait predominantly from the southeast and the northwest quadrants.

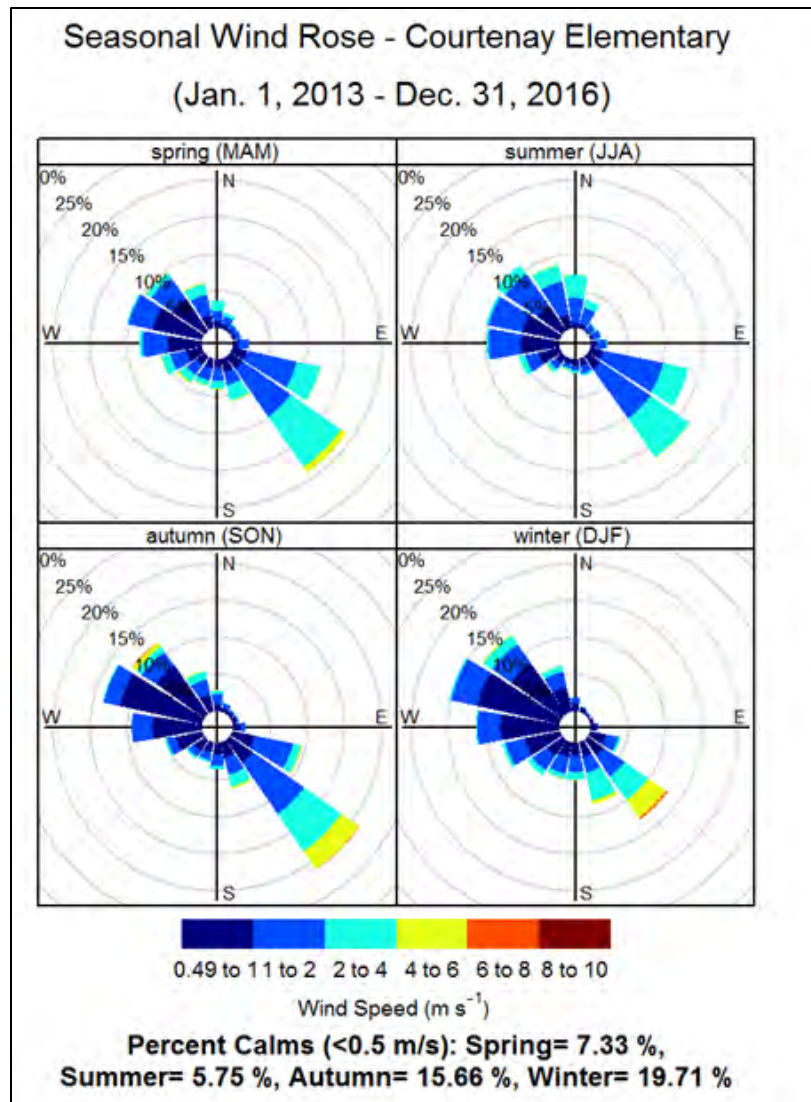


Figure 10: Seasonal wind roses for Courtenay Elementary, 2013-2016

Calm conditions occurred with the highest frequency during the winter months at 19.71% of the time followed by autumn at 15.66%, spring at 7.33%, and summer at 5.75%. Table 5 summarizes average wind speeds measured at the Courtenay Elementary School on an annual and seasonal basis. The mean wind speeds were lowest in the winter and highest in the spring. The high frequency of calms and light wind speeds in winter suggests that this period experiences poor atmospheric dispersion more often than in other months.

Table 5: Average wind speed and frequency of calms on an annual and seasonal basis 2013-2016

Wind Rose Type	Average Wind Speed (m/s)	Average Calm Winds (%)
Annual (Figure 9)	1.33	12.05
Spring (MAM) (Figure 10)	1.47	7.33
Summer (JJA) (Figure 10)	1.43	5.75
Fall (SON) (Figure 10)	1.18	15.66
Winter (DJF) (Figure 10)	1.11	19.71

Annual and seasonal wind roses were also produced for daytime vs. nighttime hours to examine differences in diurnal wind patterns (Figure 11 and Appendix A). Sunrise and sunset times were calculated using the longitude and latitude information for Courtenay. A summary of diurnal wind speeds and the frequency of calm winds annually and by season is also provided in Table 6.

Figure 11 presents the annual wind roses from the Courtenay Elementary School site by day and nighttime hours. During the daytime, prevailing winds were from the southeast (from the Strait of Georgia) and the northwest. While stronger wind speeds are generally associated with large scale weather events, the high frequency of light onshore winds during the day is driven by a sea breeze effect. Nighttime flows are almost the reverse of the daytime flows and suggest a land breeze driven by light katabatic winds or slope flows coming off the Beaufort Mountains to the west of the monitoring site. On average, calm winds occurred 8.1% of the time during the day and 16.3% of the time at night.

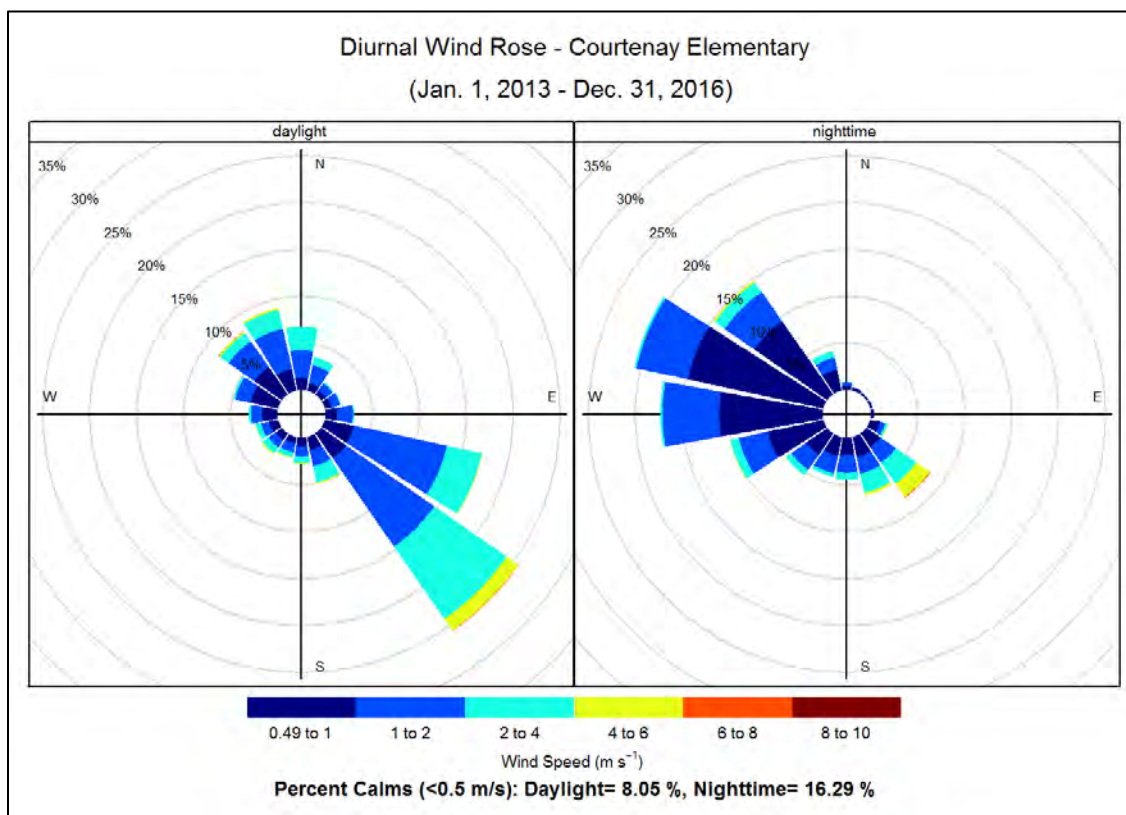


Figure 11: Annual average day vs. night wind roses for Courtenay Elementary, 2013-2016

Diurnal wind patterns in the spring through winter (Appendix A) were quite similar to annual average patterns, with stronger winds blowing predominantly from the southeast, and, to a lesser degree, north/northwest during the day, and lighter winds being directed from the surrounding terrain from the west/northwest during the night. 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 typical in the summer.

As shown in Table 6, higher frequencies of calm winds and lower wind speeds occur at night during all seasons when compared to the daytime hours.

Table 6: Summary of mean wind speeds and frequency of calm winds by day and night, 2013-2016

Season	Day	Night	Day	Night
	Mean Wind Speed (m/s)		Calm Winds (%)	
Annual (Figure 11)	1.55	1.09	8.05	16.29
Spring (Figure 12)	1.71	1.15	4.23	11.5
Summer (Figure 13)	1.61	1.08	4.29	8.59
Fall (Figure 14)	1.43	1.06	11.53	19.07
Winter (Figure 15)	1.33	1.08	16.8	21.4

3.3 Air Quality

3.3.1 BC Ambient Air Quality Objectives

The Government of BC has developed Ambient Air Quality Objectives (AAQOs) to help inform decisions on air quality management in BC communities and airsheds. There are also federal air quality targets (Canadian Ambient Air Quality Standards – CAAQS). This report compares concentrations of PM_{2.5} and NO₂ to provincial AAQOs and O₃ concentrations to the CAAQS (there are no provincial O₃ criteria). The ambient objectives for the air contaminants measured in Courtenay are provided in Table 7.

Table 7: BC Ambient Air Quality Objectives

Pollutant of Concern	Averaging Period	Criteria	Date Adopted	Objective (AAQOs)
PM _{2.5}	24 hour	BC AAQO	2009	25 µg/m ³ ⁽¹⁾
	Annual	BC AAQO	2009	8 µg/m ³
NO ₂	1 hour	Interim BC AAQO	2014	100 ppb ⁽²⁾
	Annual	Interim BC AAQO	2014	32 ppb
O ₃	1 hour	NAAQO Maximum Acceptable Level	1989	82 ppb ⁽³⁾
	8 hour	CAAQS	2013	63 ppb ⁽⁴⁾

Foot Notes:

¹ Achievement based on annual 98th percentile of daily average, over one year

² Achievement based on annual 98th percentile of daily 1-hour maximum, over one year

³ Replaced by CAAQS but still used to inform decisions on ozone advisories

⁴ Achievement based on annual 4th highest daily 8-hour maximum, averaged over three consecutive years

3.3.2 PM_{2.5}

Fine particulate matter (PM_{2.5}) has been measured at the Courtenay Elementary School Monitoring Station since July 2011 using a Met One Model 1020 Beta-Attenuation Monitor (BAM). The BAM 1020 is a USEPA approved Federal Equivalent Method (FEM) for continuous PM_{2.5} measurements.

A summary of PM_{2.5} concentrations measured at Courtenay Elementary and compared to the BC AAQOs is provided in Table 8. Annual average concentrations ranged from a low of 7.7 µg/m³ in 2016 to a high of 11.4 µg/m³ in 2013. Annual average PM_{2.5} concentrations exceeded the BC AAQO of 8.0 µg/m³ in 4 out of 5 years since monitoring began at this location but there appears to be an improving trend in values since 2013. However, meteorology plays a large role in air quality and the fall of 2016 was considerably wetter and windier than previous years. This would have the effect of lowering pollutant concentrations from open burning activities that typically take place at that time of year.

The daily 98th percentile PM_{2.5} AAQO of 25 µg/m³ was exceeded in every year since monitoring began and concentrations ranged from a low of 29.7 µg/m³ in 2012 to a high of 36.6 µg/m³ in 2015. Daily average exceedances of the BC AAQO ranged from a low of 3.3% of the time in 2012 to a high of 7.5% of the time in 2013. No trend is evident in either the 98th percentile concentrations or in the number of exceedances experienced at the site on an annual basis.

Table 8: PM_{2.5} measurements relative to Provincial Objectives at the Courtenay Elementary monitoring station 2011 to 2016. Exceedances of annual and daily Objectives in Bold.

PM _{2.5}	Courtenay Elementary Monitoring Station							
Year	Annual Mean (µg/m ³)	24-hr 98 th Percentile (µg/m ³)	Max daily values (µg/m ³)	# of days ≥25 µg/m ³	% of days ≥25 µg/m ³	# of Valid Hours	# of Valid Days	Valid Days (%)
2011 ¹	----	28.4	32.08	10	4.8	5042	210	57
2012	9.2	29.7	39.21	12	3.3	8666	360	98
2013	11.4	33.4	42.83	26	7.5	8352	347	95
2014	9.2	30.8	42.62	19	5.4	8510	353	97
2015	8.4	36.6	50.62	17	4.9	8344	349	96
2016	7.7	31.8	36.12	17	4.6	8661	366	100

¹In 2011, Quarters 1 and 2 do not meet data completeness, so the annual data set is not considered complete.

Figure 12 shows the 2016 annual average PM_{2.5} levels from a number of air quality monitoring stations across the province (BC Lung, 2017). The Courtenay Elementary School site ranked 7th highest out of 49 communities reporting PM_{2.5} concentrations in that year. The Courtenay site also recorded a higher annual average value in 2016 than any other monitoring location on Vancouver Island.

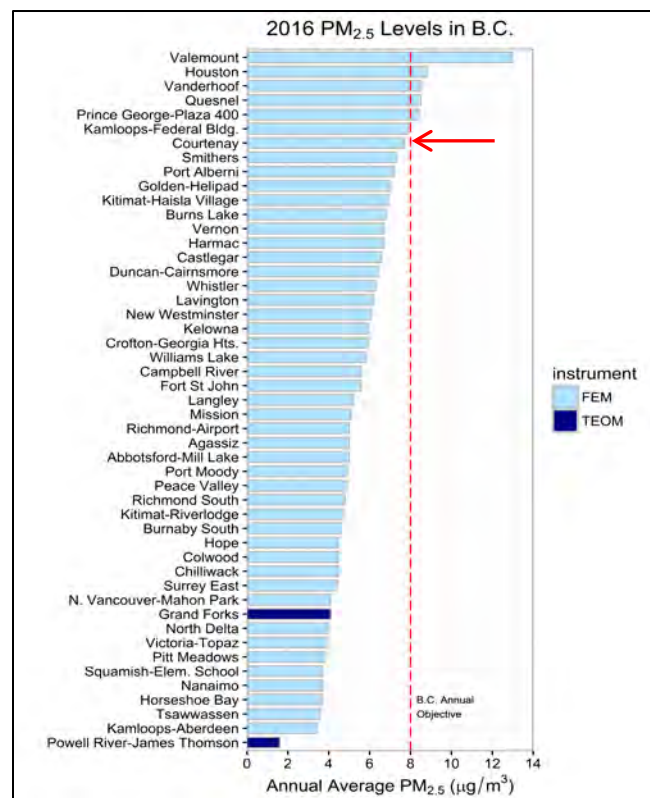


Figure 12: 2016 Annual Average PM_{2.5} concentrations across BC (BC Lung, 2017)

An examination of the time series of daily $PM_{2.5}$ values measured from June 2011 to December 2016 (Figure 13) shows that concentrations were relatively low (good air quality) during the spring and summer months, but increased during the fall and winter months of all years. With the exception of the wildfire impacts during the summer of 2015, all exceedances of the daily AAQO occurred during the colder months. Higher levels of $PM_{2.5}$ concentrations are expected at this time of the year because dispersion meteorology is much poorer and there are additional sources of $PM_{2.5}$ in the airshed – e.g. residential/commercial/industrial heating, open burning, increased idling, etc. (see section 1.2.1).

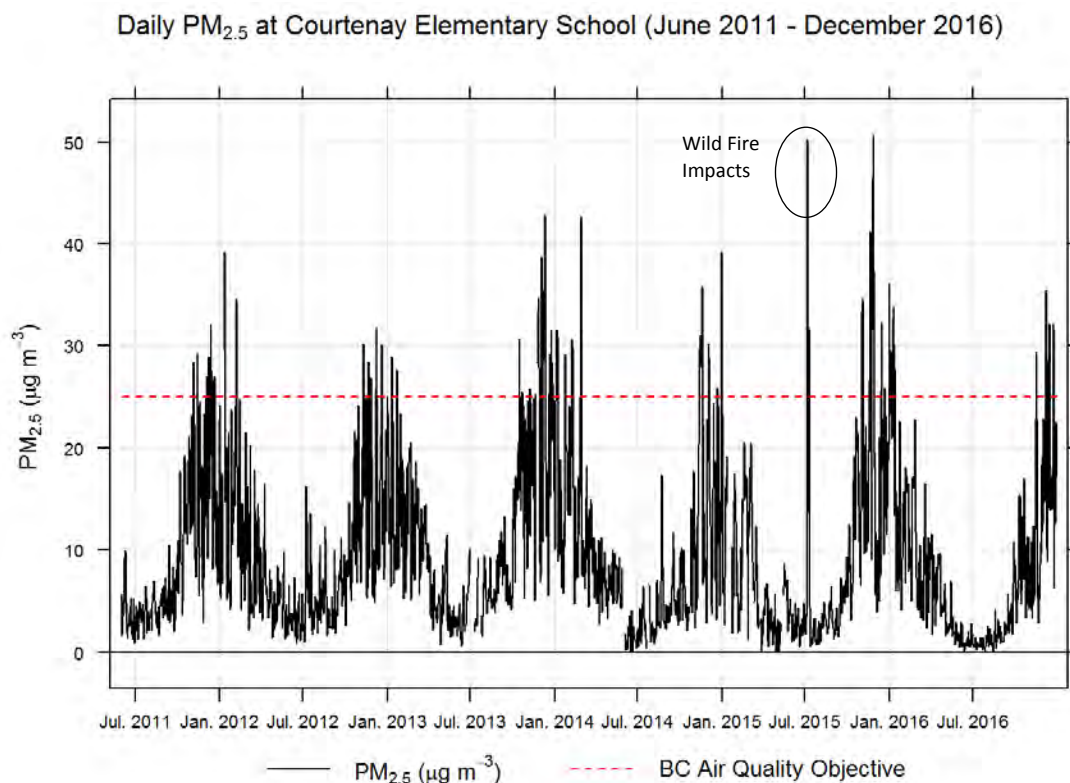


Figure 13: Daily $PM_{2.5}$ at Courtenay Elementary June 2011 to December 2016.

The same daily average $PM_{2.5}$ information is presented in the monthly box plot as shown in Figure 14. The center of each box is the median (50th percentile) value, while the lower and top edges of each box represent the 25th and 75th percentile values respectively – a 75th percentile value means that three-quarters of the values for that month are lower than this value and one-quarter is larger. The top of the upper whiskers represents the highest value that is less than the value at the top of the box plus 1.5 times the interquartile range (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 interquartile range. 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.

Monthly average $PM_{2.5}$ concentrations in Courtenay were highest from November to February and lowest in June. It is notable that the largest source of $PM_{2.5}$ in the valley (forestry hazard abatement burning – see section 1.2.1) is active mainly in October and early November while wood stove emissions, land clearing burns, and residential backyard burning (in the CVRD) continue throughout the winter months. This highlights the fact that emissions inventories only provide one part of the answer. Source proximity to people, quality of the emissions, and timing of the release are other important factors to consider.

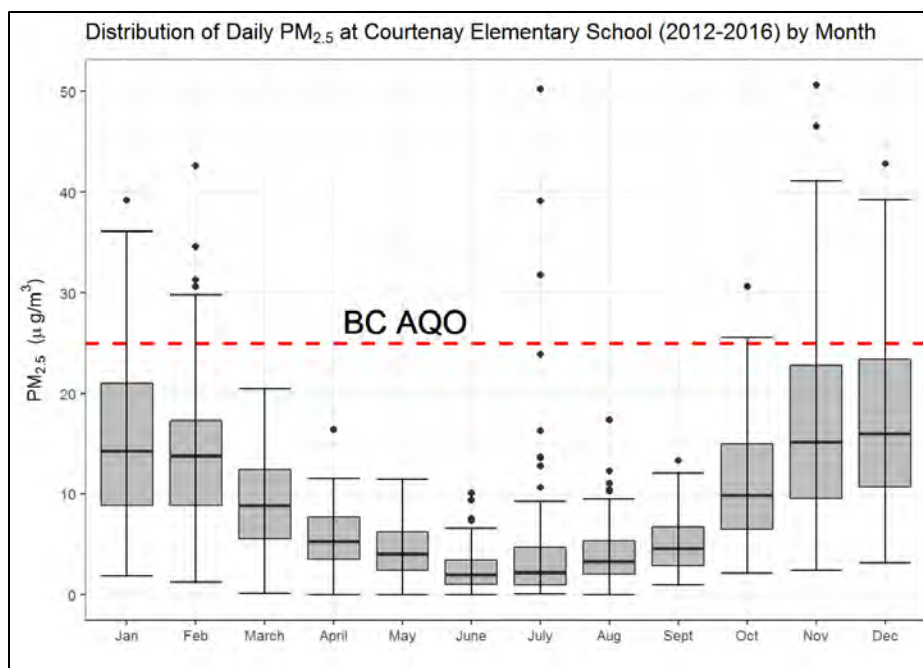


Figure 14: Distribution of daily PM_{2.5} at Courtenay Elementary by month (2012-2016).

Seasonal diurnal (hour of the day) concentration plots generated from all data collected from 2012-2016 at the Courtenay Elementary site are presented in Figure 15. PM_{2.5} concentrations were higher for all hours of the day during the winter months, followed by autumn, spring and summer. PM_{2.5} patterns in the autumn, winter and spring showed an afternoon minimum due to surface heating (and associated good atmospheric ventilation) and an evening maximum near midnight.

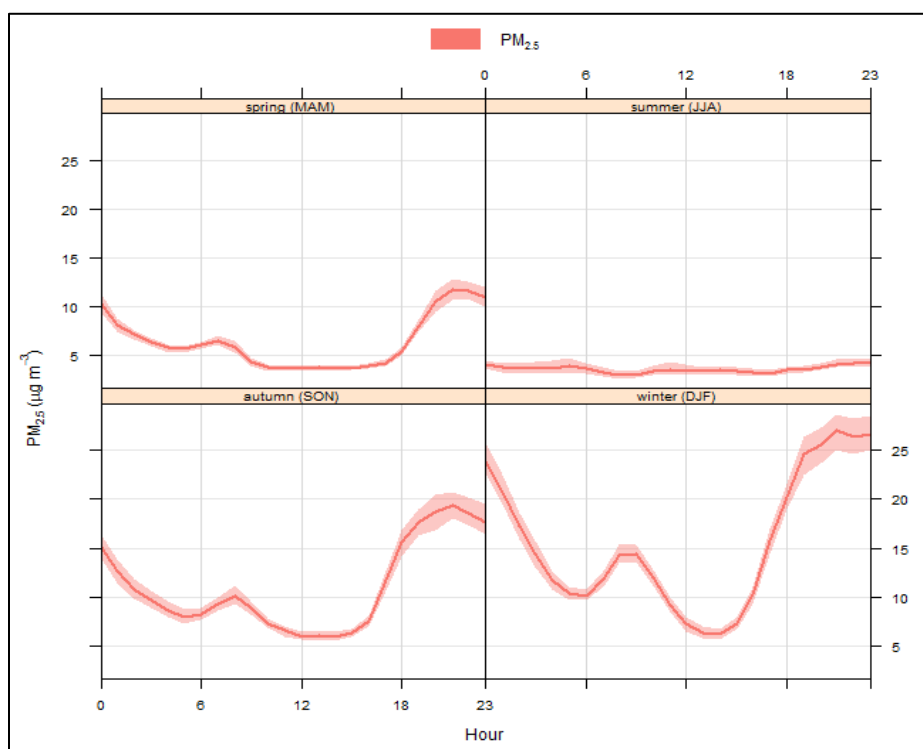


Figure 15: Seasonal diurnal patterns in PM_{2.5} at Courtenay Elementary (2012-2016).

During the winter period, the afternoon venting window is quite narrow due to reduced surface heating as the daylight period is shorter and the sun angle is lower. The maximum overnight values during the winter months tended to be higher and last for longer. This suggests that fresh emissions such as wood stove smoke were added to the stable layer that is in place during the overnight hours. Concentrations then gradually declined over the early morning hours until a secondary maximum occurred during the mid-morning. Secondary morning peaks typically occur once surface heating is sufficient to break down the nocturnal inversion and short-term fumigation events occur. However, given the timing of this peak during the winter (0800-0900), it is more likely to reflect additional sources at this time of day such as wood smoke from morning wood heating emissions and commuter traffic.

A day of the week (hebdomadal) analysis is presented in Figure 16. There is much variability in the observed patterns depending on season. For instance, during the spring, concentrations tended to be highest on the weekend with maximum average concentrations on Saturday and Sunday. The higher concentrations on the weekend during the spring months suggest that additional $PM_{2.5}$ sources came into play over and above what is experienced during the week. The City of Courtenay and the Town of Comox have open burning bylaws in place that restrict open burning. These additional sources may have included residential backyard burning in the surrounding CVRD which is more prevalent while people are at home on weekends. It should be noted that concentrations are relatively low during the spring however, as atmospheric ventilation is generally good at this time of the year and emissions are dispersed quickly.

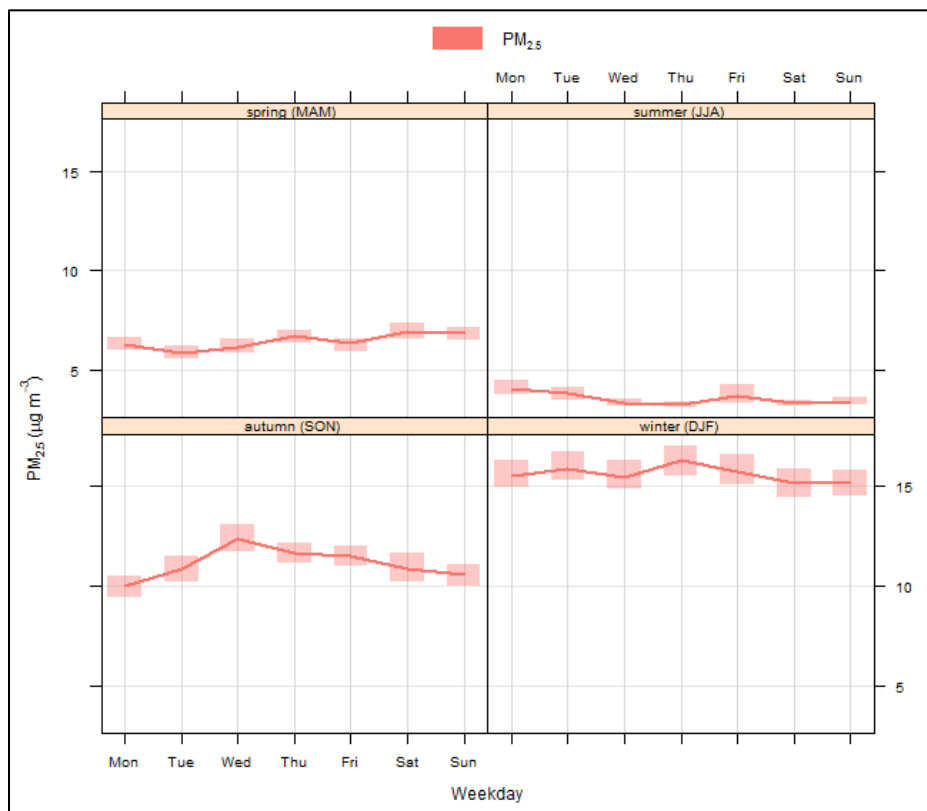


Figure 16: Seasonal hebdomadal plots for $PM_{2.5}$ at Courtenay Elementary 2012-2016.

The same patterns are not in evidence during the fall or winter months when overall $PM_{2.5}$ levels are much higher. Weekend concentrations are similar or slightly lower than weekday concentrations at this time of the year. Based on known activity patterns in the Comox Valley, the higher concentrations during the week in autumn suggest possible impacts from multi-day open burning activities. The Ministry of

Forests generally lifts province-wide burn bans in mid-September once the risk of wildfire has subsided. Forest companies in the area complete hazard abatement burning in October and commercial land clearing operators (land development and agriculture) and residents in the CVRD that wish to burn generally take advantage of this period to complete burning while material is still relatively dry. Late autumn is also a transitional period for woodstove use depending on temperatures. During the winter months, there is a much more consistent hebdomadal profile. Wood stove use during the winter is very common in the older residential areas of Courtenay, particularly in the valley bottom. However, the hebdomadal pattern indicates that in addition to wood stove smoke, other emissions also contribute to the slightly higher PM_{2.5} levels during the work week. This suggests commercial and mobile source (vehicles) emissions as they are generally higher during the work-week than on weekends.

A pollution rose shows the distribution of pollutant concentrations as a function of wind direction at a given location. 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. Given known information about sources and activities in an area, this additional tool can be helpful for source apportionment and to help guide source management.

Pollution roses for the Courtenay Elementary School were constructed from four full years of hourly meteorological and PM_{2.5} data that comprised the 2013-2016 periods. The annual pollution rose (Figure 17) shows that the highest frequency of elevated PM_{2.5} concentrations were recorded when wind was blowing from the west to northwest.

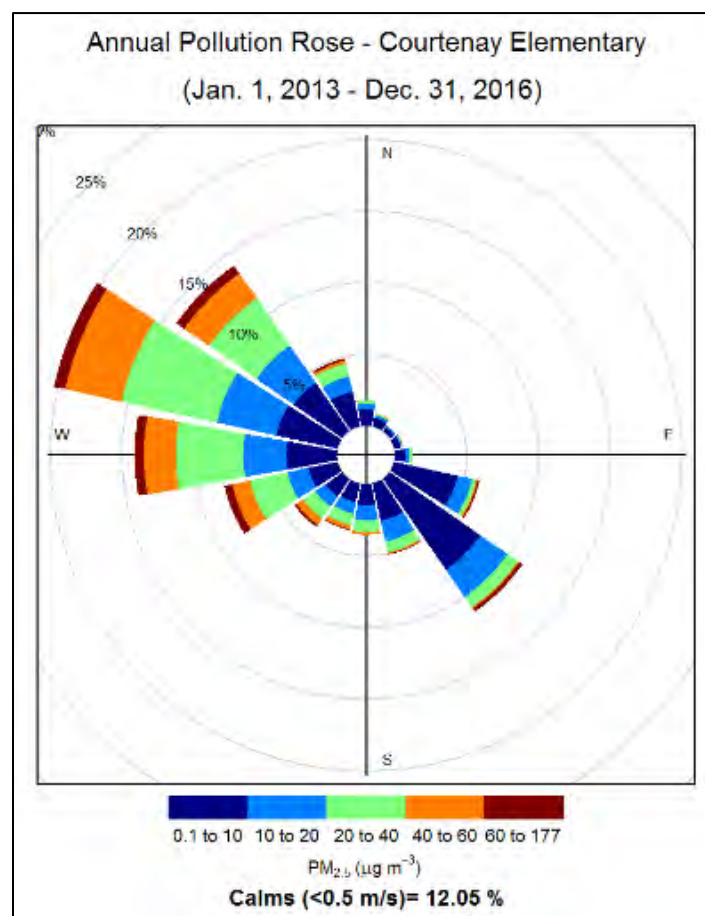


Figure 17: Annual PM_{2.5} pollution rose for Courtenay Elementary based on 2013-2016 hourly data.

When examined by season (Figure 18), most of the highest $PM_{2.5}$ concentrations were recorded during the autumn and winter when winds were blowing from the west to northwest - wind speeds from these directions tended to be light (see section 3.2). There is a dense residential area to the west and northwest of the monitoring site that includes older areas of the City of Courtenay and the CVRD where wood stove use is common during the late autumn and through the winter months. In terms of other fine particulate sources that are active at these times of the year, land development and agricultural operations are common on the north side of the Puntledge River and forestry operations are active near the Beaufort range to the west, southwest, and northwest of the monitoring site. The local terrain also slopes from west to east from the Beaufort Mountain range to the Strait of Georgia so nighttime drainage flows are common. Smoke emitted during the nighttime hours from large scale open burning associated with these operations would tend to drain into the valley bottom.

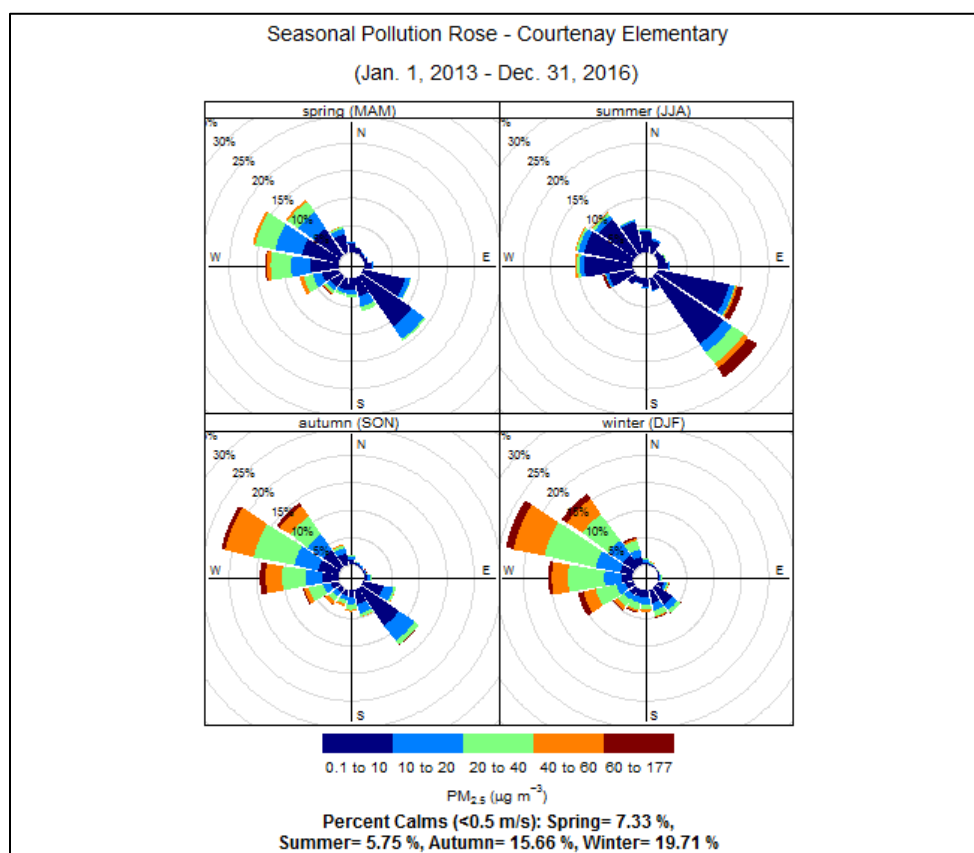


Figure 18: Seasonal $PM_{2.5}$ pollution rose for Courtenay Elementary based on 2013-2016 hourly data.

Low frequencies of elevated $PM_{2.5}$ concentrations also occurred during the summer months and were associated with wildfire activity in 2015 (Figure 18). Wildfire smoke was transported up the Strait of Georgia from the Sechelt area and an air quality advisory was issued during this period. The highest frequency of low $PM_{2.5}$ concentrations tended to come from the southeast during the spring months. Outside of the wildfire impacts of 2015, the summertime pollution rose would be very similar in this respect. This makes intuitive sense as there are open burning bans during the late spring and summer months (e.g. no wood smoke sources outside of wildfire activity), and wind speeds tended to be higher from this direction providing good pollutant dispersion.

An examination of the annual diurnal (daytime vs. nighttime) pollution roses for Courtenay Elementary indicates that the majority of the higher $PM_{2.5}$ concentrations occurred at night (Figure 19). This strongly suggests that wood smoke from sources like wood stoves is the primary cause of elevated $PM_{2.5}$ values.

However, any source of fine particulate emissions emitted into the stable layer during the evening hours would also contribute to these patterns by varying degrees (e.g. overnight burning, commercial and mobile emissions, etc.). During the day, air coming from the Georgia Strait (southeast direction) up to the school had relatively low $PM_{2.5}$ concentrations outside of the wildfire impacts of 2015.

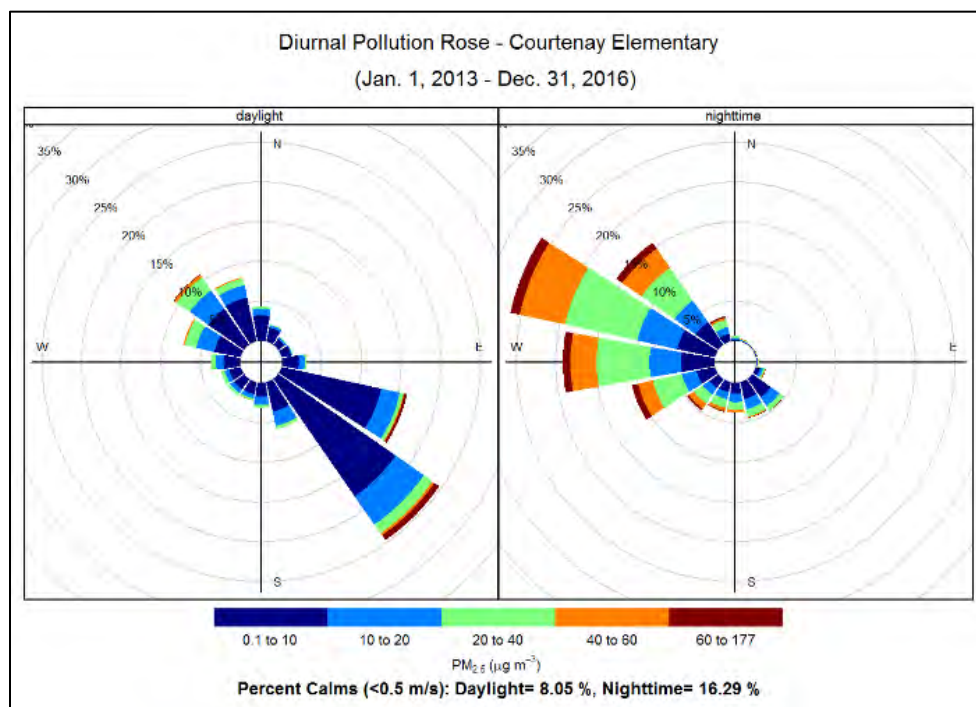


Figure 19: Day vs. night $PM_{2.5}$ annual pollution roses for Courtenay Elementary based on 2013-2016 hourly data.

A seasonal breakdown of diurnal pollution roses are provided in Figure 20. Hourly concentrations of $PM_{2.5}$ above $60 \mu\text{g}/\text{m}^3$ occurred more frequently at night in the fall and winter months when light drainage flows were coming from the west or northwest of Courtenay Elementary. It is notable in winter that $PM_{2.5}$ values above $20 \mu\text{g}/\text{m}^3$ occurred during the day from all directions suggesting diffuse sources in the valley. At nighttime, measured values above $60 \mu\text{g}/\text{m}^3$ were recorded from all directions except for the northeast sector, although the highest frequency of elevated readings was associated with light winds from the west/northwest.

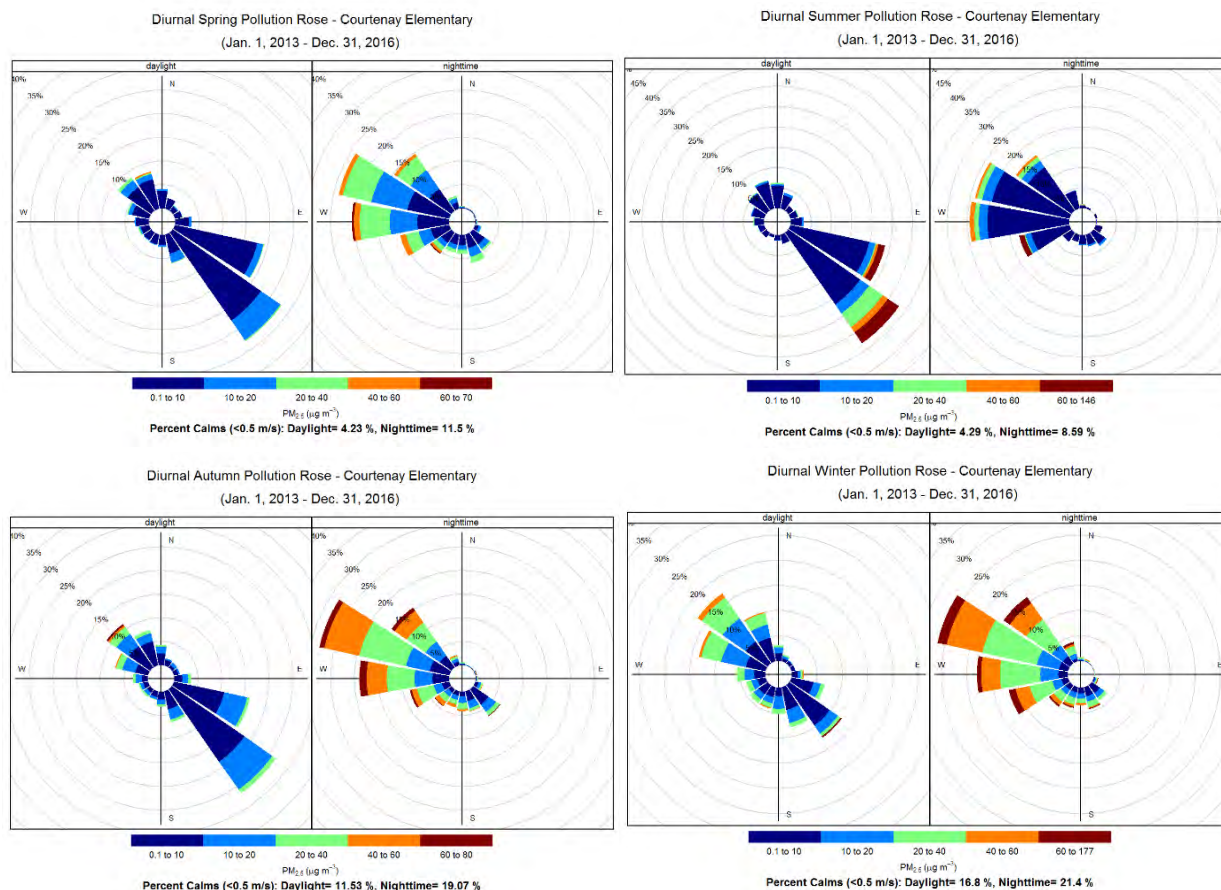


Figure 20: Seasonal PM_{2.5} pollution roses showing day and nighttime patterns for Courtenay Elementary based on 2013-2016 hourly data.

Given the seasonal nature of the highest values, likely sources include emissions from residential wood heating, emissions from residential backyard burning (CVRD), and emissions from open burning (agricultural/developer land clearing, and forestry operations) – see section 1.2.1 for more information on emission sources. Forestry wildfire hazard abatement (slash burning) activities occur throughout the region during the fall as does land clearing and residential backyard burning. Most forestry hazard abatement burning is complete by early November while development/agricultural land clearing burning can occur all winter if venting conditions are suitable. The City of Courtenay and the Town of Comox have bylaws in place that regulates open burning within their respective municipal boundaries. The Village of Cumberland is also moving in this direction. However, there are no open burning restrictions in the Comox Valley Regional District other than provincial regulations (OBSCR) which do not cover residential backyard burning. Open burning is the dominant source of wood smoke during the fall months in the Comox Valley. Once colder temperatures settle in, people begin to heat their residences using woodstoves and this becomes the leading wood smoke source in the valley, especially in older residential areas. The particulate matter emissions inventory for the Comox Valley prepared by RWDI estimated that 36% of households in the Comox Valley use wood for residential heating (RWDI, 2017).

Table 9 summarizes mean PM_{2.5} concentrations during calm conditions (wind speed <0.5 m/s). Mean PM_{2.5} concentrations during calm wind conditions were highest in the winter (daytime – 17.4 µg/m³, nighttime – 27.2 µg/m³), followed by fall (daytime – 12.9 µg/m³, nighttime – 20.7 µg/m³), Spring (daytime – 7.8 µg/m³, nighttime – 13.8 µg/m³) and summer (daytime – 6.3 µg/m³, nighttime – 5.8 µg/m³).

Table 9: PM_{2.5} concentrations during calm periods (wind speed below 0.5 m/s) for each season (2013-2016).

Season	Day	Night	Day	Night
	Calm Winds (% of time)		Mean PM _{2.5} (µg/m ³) during calms	
Annual (Figure 22)	8.05	16.29	12.6	21.0
Spring (Figure 23)	4.23	11.5	7.8	13.8
Summer (Figure 24)	4.29	8.59	6.3	5.8
Fall (Figure 25)	11.53	19.07	12.9	20.7
Winter (Figure 26)	16.8	21.4	17.4	27.2

Elevated PM_{2.5} concentrations when winds are calm suggest that local sources (ie. wood stoves) are also important near the measurement site during the cold season. 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.

3.3.2.1 Additional PM_{2.5} Studies in the Comox Valley

Additional special studies in the Comox Valley have confirmed that wood smoke is a significant contributor to PM_{2.5} concentrations.

- A mobile PM_{2.5} monitoring study was undertaken by the University of Victoria in partnership with the Vancouver Island Health Authority and the Ministry of Environment in the winter of 2008/2009 to examine spatial patterns of PM_{2.5} across the Comox Valley (Poplawski and Setton, 2009) as part of a larger study focussing on wood smoke impacts. Findings suggested that there were consistent fine particulate hotspots in Cumberland, western portions of Comox, and the commercial/residential areas of Courtenay. These hotspots were indicative of residential wood heating impacts across the valley but could also be influenced by local traffic emissions.
- Hong, et al. (2016) examined PM_{2.5} data across the province along with woodsmoke biomarkers to identify and prioritize communities impacted by wood smoke in the province. This work identified Courtenay as the 2nd most wood smoke impacted community in province.
- In early 2017, the University of British Columbia led a project aimed at validating a new monitoring method to more effectively measure the impact of residential wood smoke in B.C. communities using high resolution mobile monitoring equipment. The communities of Courtenay, Comox, Royston and Cumberland were included in the study (Henderson, 2017) along with some areas of the CVRD. The work established further empirical evidence for residential wood smoke pollution in all communities examined in the CVRD.

The results from these studies largely confirm the results of the analysis in this report.

In addition, a study recently completed in B.C. examined the association between short-term changes in ambient PM_{2.5} concentrations and hospital admissions for heart attacks (Weichenthal, S. et al. 2017). By comparing pollution data from three cities in British Columbia (Prince George, Kamloops and Courtenay/Comox) with hospital admissions, researchers from McGill and Health Canada found that rising concentrations of fine particulate air pollution caused by wood burning were associated with increased hospitalization for heart attack. During the cold season, when pollution from woodstoves is at its highest, the risk of heart attacks among subjects of 65 years and older increased by 19%. This study highlights the added health benefits of managing wood smoke sources in the Comox Valley.

3.3.3 Nitrogen Dioxide

Nitrogen dioxide (NO₂) has been continuously monitored at the Courtenay Elementary School Monitoring Station since July 1, 2011. Sufficient data was collected at the station for all years, except 2011.

A summary of NO₂ concentrations measured at Courtenay Elementary and compared to the BC AAQOs is provided in Table 10. Annual average concentrations ranged from a low of 4.1 ppb in 2016 to a high of 5.0 ppb in 2014. Annual average NO₂ concentrations remain well below the Interim BC AAQO of 32 ppb and no trend is apparent.

An examination of the 1-hour maximum NO₂ values indicates that concentrations were well below the interim BC AAQO of 100 ppb (Table 11). Maximum 1-hour average values ranged from a low of 26.3 ppb in 2015 to a high of 36.9 ppb in 2016. As with the annual average values, no trend is discernable.

Table 10: NO₂ concentrations at Courtenay Elementary compared to BC AAQOs. Exceedances of annual and hourly Objectives in Bold.

Year	Annual Mean (ppb)	Maximum 1-hour value (ppb)	98 th Percent of 1-hr BC AAQO (ppb)	# of Valid Hours	# of Valid Days	Percent of Days Valid
2011 ¹	---	36.7	30	3886	170	47
2012	4.7	35.3	28	7786	351	96
2013	4.8	32.1	25	8067	358	98
2014	5.0	34.4	24	7572	345	95
2015	4.5	26.3	22	7810	355	97
2016	4.1	36.9	28	8372	365	100

¹In 2011, Quarters 1 and 2 do not meet data completeness, so the annual data set is not considered complete.

Temporal patterns in NO₂ concentrations at Courtenay Elementary are presented in Figure 21. NO₂ concentrations were lowest during the summer months and highest over the winter. This is likely due to an increase in combustion sources (heating, increased idling, etc.) and poor dispersion meteorology during the winter and more rapid removal rates by photochemical reactions during the summer. The average diurnal profile exhibited an early morning peak that coincides with morning rush hour traffic. Concentrations then decrease through late morning and early afternoon as traffic emissions decrease and solar heating causes increased mixing in the atmosphere.

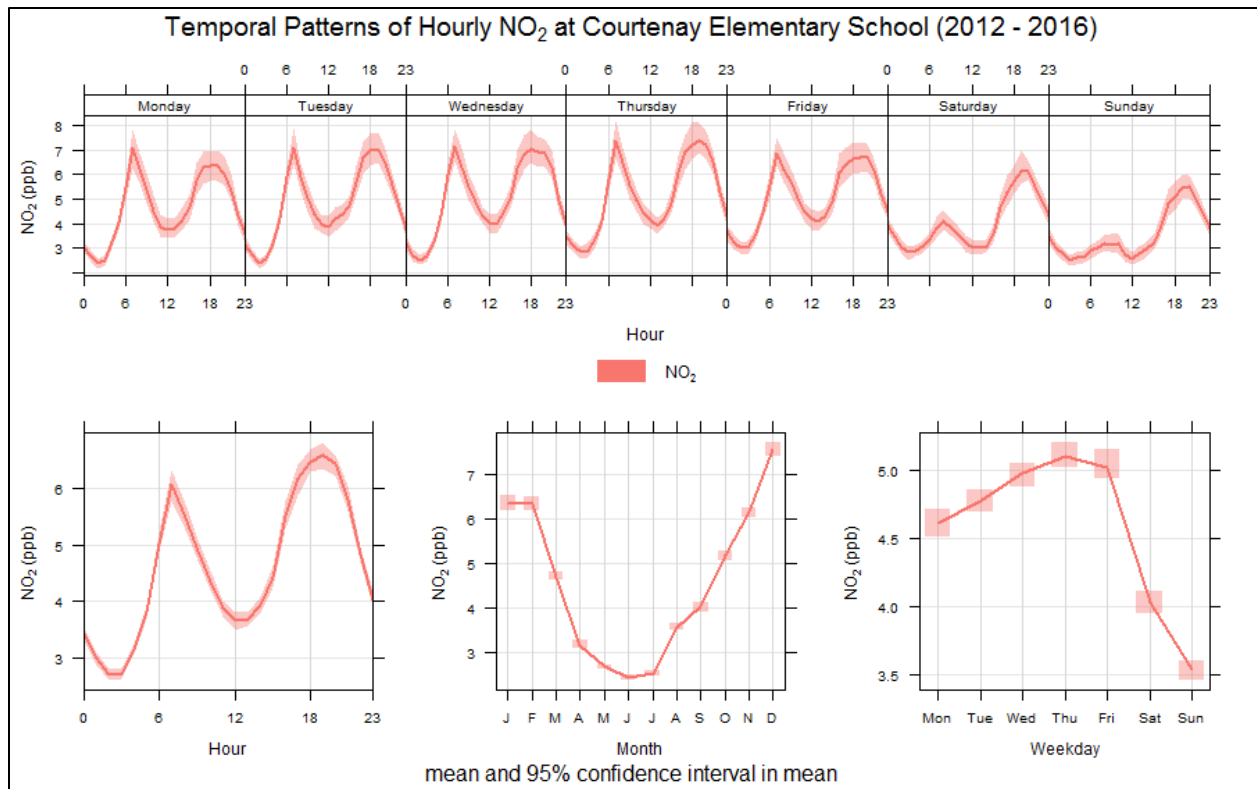


Figure 21: Temporal patterns for NO₂ concentrations at Courtenay Elementary 2012-2016.

Hourly NO₂ concentrations peak again later in the day, due in part to additional emissions from traffic and residential space heating. Concentrations then drop to overnight minimums due to a reduction in emissions, surface deposition, and atmospheric transformation.

Day of the week patterns indicate that NO₂ concentrations build gradually from Monday to Friday before dropping off to minimum values on Sunday. This pattern highlights the contributions of traffic emissions during the work week to overall NO₂ levels.

NO₂ concentrations were well below provincial AAQOs in Courtenay and were low relative to concentrations found in many other communities in British Columbia. Figure 22 shows the 2016 one-hour NO₂ concentrations from a number of air quality monitoring stations across the province (BC Lung, 2017). The Courtenay Elementary School site ranked 26th highest out of 38 communities reporting NO₂ concentrations in that year.

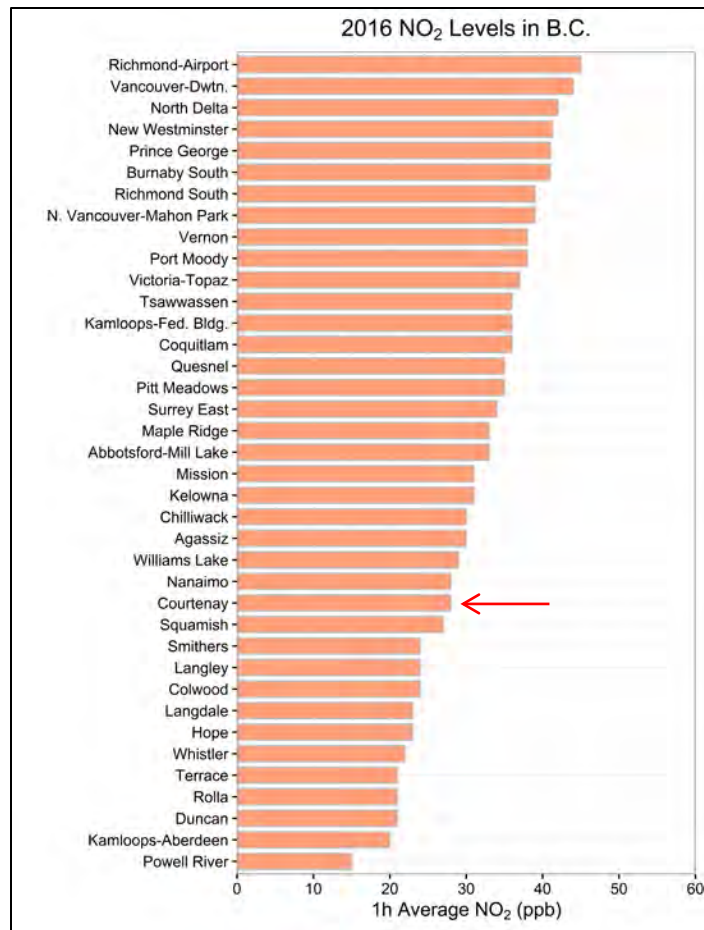


Figure 22. NO₂ levels across B.C. in 2016 – based on annual 98th percentile of the daily 1-hour maximum (BC Lung, 2017).

3.3.4 Ozone

Ozone (O₃) has been continuously monitored at the Courtenay Elementary School Monitoring Station since June, 2011. Sufficient data was collected at the station for all years except for 2011. A summary of O₃ concentrations measured at Courtenay Elementary and compared to the BC AAQOs is provided in Table 11.

There were no exceedances of the one hour average AAQO of 82 ppb or of the 8-hour average AAQO of 63 ppb during the period of monitoring.

Table 11: O₃ concentrations compared to BC AAQOs. Exceedances of annual and 8-hour Objective levels in Bold.

Year	Max 1- hour values (ppb)	Annual Mean (ppb)	Max 8-hour values (ppb)	4 th Highest (ppb)	Rolling 3 Year Average (ppb)	# of Valid Hours	# of Valid Days
2011 ¹	46.4	----	44.2	36.9	NA	4752	206
2012	59.4	21.1	53.1	48.4	NA	7659	331
2013	53.6	17.1	48.2	46.1	44	8204	355
2014	53.7	19.1	49.5	46.2	47	8357	365

2015	59.6	17.8	53.7	47.5	47	8290	361
2016	56.0	18.9	51.2	45.2	46	8326	362

¹In 2011, Quarters 1 and 2 do not meet data completeness, so the annual data set is not considered complete.

Temporal patterns in O₃ concentrations at Courtenay Elementary are examined in Figure 23. The diurnal cycle of ozone concentrations reached a peak in the afternoon (between 2pm and 4pm) and a low by morning (5-6am). During the week, all days show the same diurnal cycle with very similar concentrations for all peaks and lows. However, when comparing average O₃ for each day of the week, O₃ reaches higher values on Saturday and Sunday, with the lowest averages occurring in the middle to end of the week (Wednesday, Thursday, and Friday).

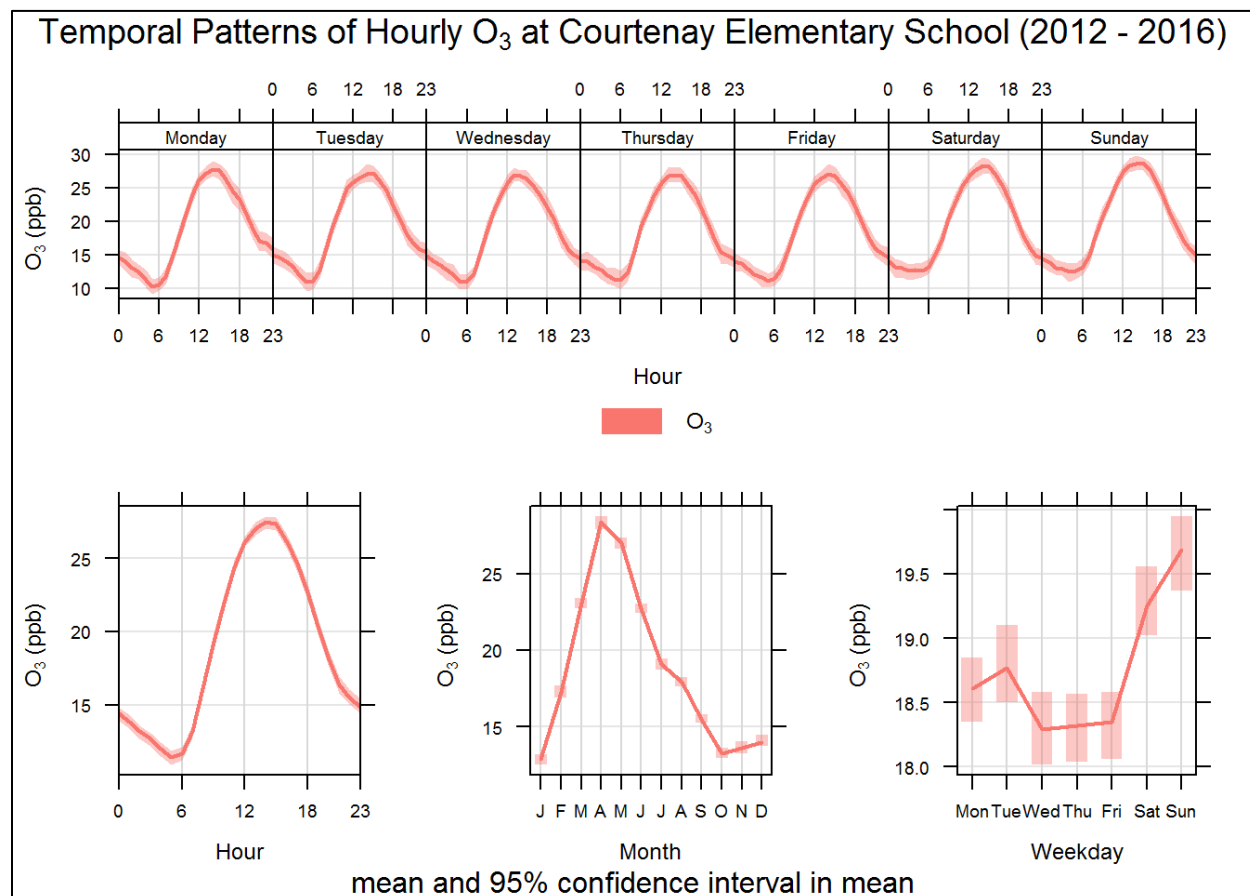


Figure 23: Temporal patterns for Ground-level Ozone at Courtenay Elementary 2012-2016.

On a seasonal basis, highest average ozone concentrations occur in the spring (April) with lowest concentrations occurring in late fall and winter (Figure 23). 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).

Hourly distributions of O₃ measurements over the entire monitoring period at the Courtenay Elementary School site are provided in the monthly box plot in Figure 24. It is interesting to note that although there

is not a significant mid-summer peak (July and August) in monthly average O_3 concentrations, the highest 1-hour concentrations are still observed in July and August. This type of pattern can be indicative of local photochemical production.

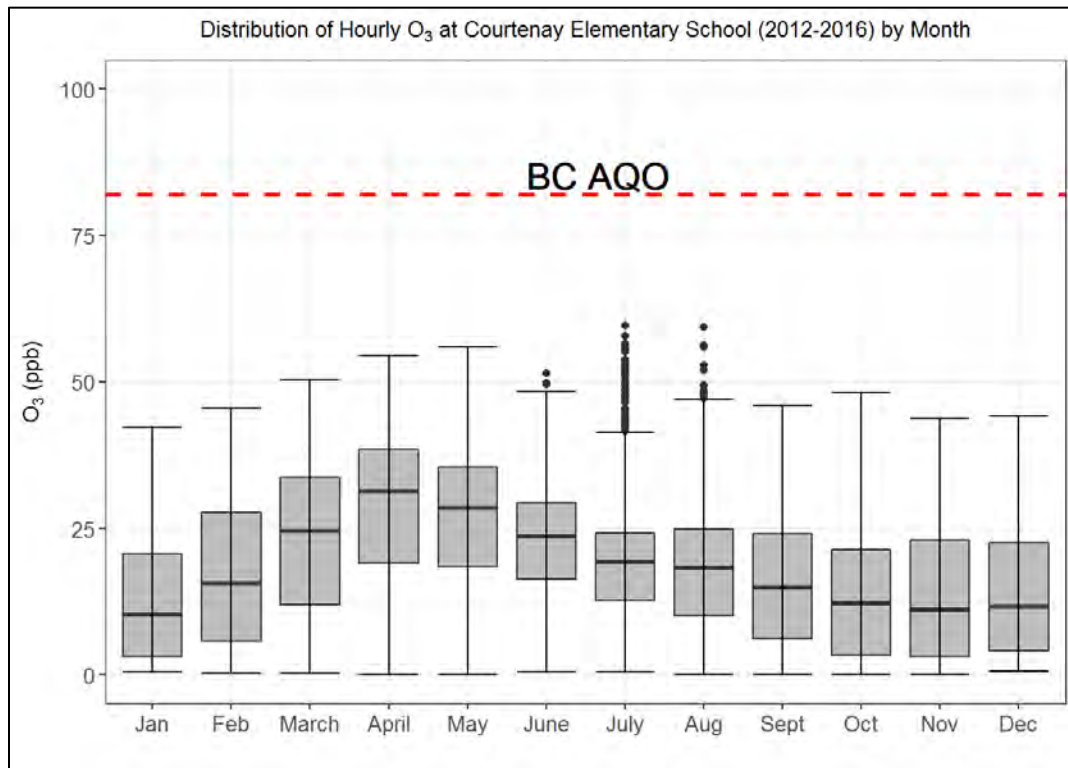


Figure 24. Monthly distribution of hourly ozone values at Courtenay Elementary (2012-2016).

Ground-level ozone concentrations were well below the CAAQS level and were low relative to concentrations found in other BC communities. Figure 25 shows the 8-hour average O_3 levels from a number of air quality monitoring stations across the province for 2016 (BC Lung, 2017). The Courtenay Elementary School site ranked 21st highest out of 37 communities reporting O_3 concentrations in that year.

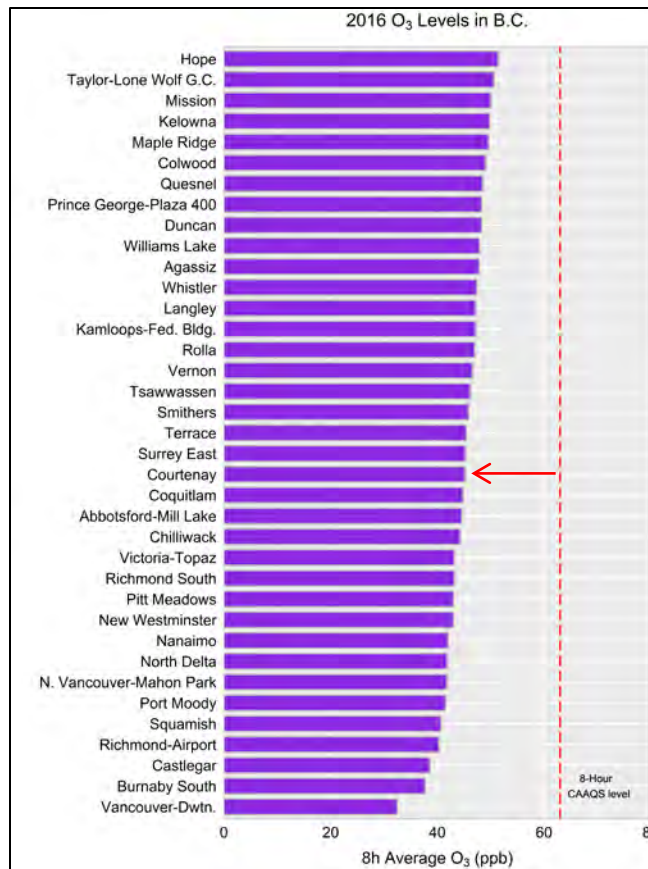


Figure 25. 8-hour average ozone levels across B.C. in 2016 (BC Lung, 2017).

4 Conclusions

A particulate matter emissions inventory completed for the Comox Valley indicates that open burning (forestry, agriculture, commercial, and residential) and space heating (wood stoves) activities combine for nearly 81% of the total PM_{2.5} emissions. However, emission totals are only one consideration when examining which of these sources has the largest impact on air quality in Courtenay. Other considerations include such things as proximity of the emissions source to people, emission quality and quantity, duration and timing of the activity, and meteorological factors. In this report, source contributions to PM_{2.5} in Courtenay were determined through an analysis of ambient air quality data coupled with meteorology and source activity information.

Mean wind speeds in Courtenay were lowest in the winter and highest in the spring/summer, and 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 higher frequency of calms during the winter period (up to 20% of the time) results in poor atmospheric dispersion that can lead to a build-up of pollutants in the area. Winds were also lighter with a higher frequency of calms during the nighttime period in all seasons. The valley location of Courtenay makes it susceptible to the frequent formation of temperature inversions, particularly during the colder months. Light drainage flows off the Beaufort Mountain range are an important feature in Courtenay especially during the nighttime hours.

PM_{2.5} is the pollutant of concern in Courtenay. It is the only parameter for which both annual and daily exceedances of BC's AAQOs were observed. The 2016 annual average for the Courtenay Elementary School monitoring location ranked the site 7th highest out of 49 communities reporting PM_{2.5} concentrations across the province. Daily average AAQO exceedances occurred up to a maximum of 7.5% of the time in 2013 and occurred in every year since PM_{2.5} monitoring began. PM_{2.5} concentrations showed a clear seasonal pattern with lower concentrations being measured in the spring/summer and higher concentrations measured in the fall/winter, associated with changes in emissions and meteorology. The highest PM_{2.5} concentrations occurred during the winter months. The majority 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. Based on known activities during the fall and winter months, smoke from open burning associated with forestry operations, commercial operations (land clearing) and residential backyard burning can be a significant source of PM_{2.5} during the fall, while smoke from wood burning appliances is the dominant PM_{2.5} source during the winter months.

There was a bimodal pattern in peak diurnal PM_{2.5} concentrations during the winter months with maximums occurring during the overnight and early morning hours. These patterns are consistent with space heating emission impacts, especially woodstove operation. Day of the week PM_{2.5} patterns indicated that average weekend levels were slightly higher than average mid-week levels during the spring months; however, this was not the case during other seasons. This suggests that during the springtime, residential open burning outside of city limits on weekends may be an important source of PM_{2.5}. During the fall months open burning sources are important. During the winter months, day of the week patterns suggest that while wood stove smoke is the dominant source, other sources such as commercial and mobile (vehicles) emissions may also contribute smaller amounts.

When examined by season and by time of day, most of the highest PM_{2.5} concentrations were recorded at night during the fall and winter when winds were blowing from the west to northwest. These light nighttime drainage flows off the Beaufort Mountain range can transport emissions from sources located at higher elevations to residential areas located in the valley bottom. Analysis indicates that smoke from residential heating (wood stoves) and from open burning are significant sources at the monitoring location depending on the time of year. The highest PM_{2.5} levels were recorded during the winter months and at nighttime. During the daytime, air coming from the Georgia Strait (southeast direction) to the monitoring location had relatively low PM_{2.5} concentrations.

The results of the PM_{2.5} analysis are largely confirmed by a number of additional special studies conducted in the Comox Valley. In these studies, wood burning sources contributed significantly to PM_{2.5} concentrations in Courtenay and across the valley.

An analysis of NO₂ concentrations measured in Courtenay showed a clear seasonal pattern with lower NO₂ 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. NO₂ concentrations measured at the Courtenay Elementary School station were well below the BC AAQOs.

O₃ levels measured at Courtenay Elementary School were well below provincial AAQOs. Mean monthly O₃ concentrations at the monitoring site exhibited a springtime peak consistent with other communities in the northern hemisphere. There is not a significant mid-summer peak (July and August) in monthly average O₃ concentrations, however, the highest 1-hour concentrations are still observed in July and August. This type of pattern can be indicative of local photochemical production.

In summary, an examination of ambient air quality data in the City of Courtenay found that there were no exceedances of the BC AAQO for NO₂, or O₃ between 2011-2016 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 during the warm months but degraded during the fall and winter due to changes in meteorology and emission sources. The highest PM_{2.5} levels were observed during winter evenings, when winds were light and typically from the west to northwest. The findings were consistent with contributions from wood burning appliances (late fall and winter), land clearing/residential backyard burning (fall and winter), and forestry burning (fall months). Analysis indicates that local smoke sources are important but that sources from outside of the City can also have an effect on local PM_{2.5} concentrations depending on meteorological factors.

5 Recommendations

1. Additional measures to address sources of wood smoke in the Comox Valley should be considered. Action is needed to manage smoke emissions from both large-scale open burning and residential back yard burning, as well as emissions from wood-burning appliances.
2. 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. commercial, industrial, mobile and residential.
3. In order to provide better resolution on where there might be opportunities to better manage wood stove emissions in the valley, it is recommended that community-specific wood stove surveys be considered.

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Appendix A Meteorological Data

Supplemental temperature and wind data are provided below for the Comox Airport and for the Courtenay Elementary School.

A.1 Temperature

Table A-1. Climate Normals data for temperature and precipitation from the Comox Airport (1981 to 2010)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation												
Rainfall (mm)	159.1	107.8	95.7	64.4	45.6	42.8	26.7	29.2	41.8	122.7	191.9	168.9
Snowfall (cm)	11.9	6.0	9.9	0.2	0.0	0.0	0.0	0.0	0.0	0.1	8.2	18.7
Temperature (°C)												
Daily Avg.	3.9	4.3	6.1	8.8	12.4	15.5	18.0	17.9	14.5	9.5	5.7	3.5
Daily Avg. Maximum	6.4	7.4	9.6	12.9	16.6	19.8	22.8	22.7	19.0	12.9	8.5	5.9
Daily Avg. Minimum	1.4	1.2	2.5	4.6	8.0	11.1	13.3	13.0	9.9	6.0	2.9	0.9
Extreme Minimum	-21.1	-16.1	-13.9	-4.4	-2.8	0.5	5.0	3.3	-1.7	-4.8	-13.3	-15.0
Extreme Maximum	16.7	16.3	19.0	26.8	31.7	34.4	25.2	33.6	30.6	22.9	17.8	17.4

Table A-2. Mean monthly temperature (oC) measured at the Courtenay Elementary School monitoring station and the Comox Airport station

Station Name:	Comox Airport	Courtenay Elementary	Courtenay Elementary	Courtenay Elementary	Courtenay Elementary	Courtenay Elementary
Year(s) Monitored	1981-2010 (°C)	2012 (°C)	2013 (°C)	2014 (°C)	2015 (°C)	2016 (°C)
January	3.9		2.7	3.7	5.3	3.6
February	4.3		5.1	1.8	7.2	5.7
March	6.1		6.6	5.8	7.8	7.8
April	8.8		9.6	9.4	9.2	11.9
May	12.4		13.6	14.6	15.4	14.9
June	15.5		16.3	16.5	19.1	16.6
July	18		19.8	20.2	20.4	18.9
August	17.9		19.0	20.3	19.2	19.3
September	14.5	14.3	15.6	15.9	13.6	13.8
October	9.5	9.3	8.8	11.8	11.3	9.9
November	5.7	6.2	5.3	5.2	4.0	8.0
December	3.5	3.1	2.6	4.4	3.9	0.7

B.1 Wind

Hourly wind datasets were partitioned into day and night periods based on sunrise and sunset times for each day of the month (used R 'daylight' function with latitude/longitude information provided for monitoring station location). The following figures show seasonal wind roses for day and night periods at the Courtenay Elementary School station.

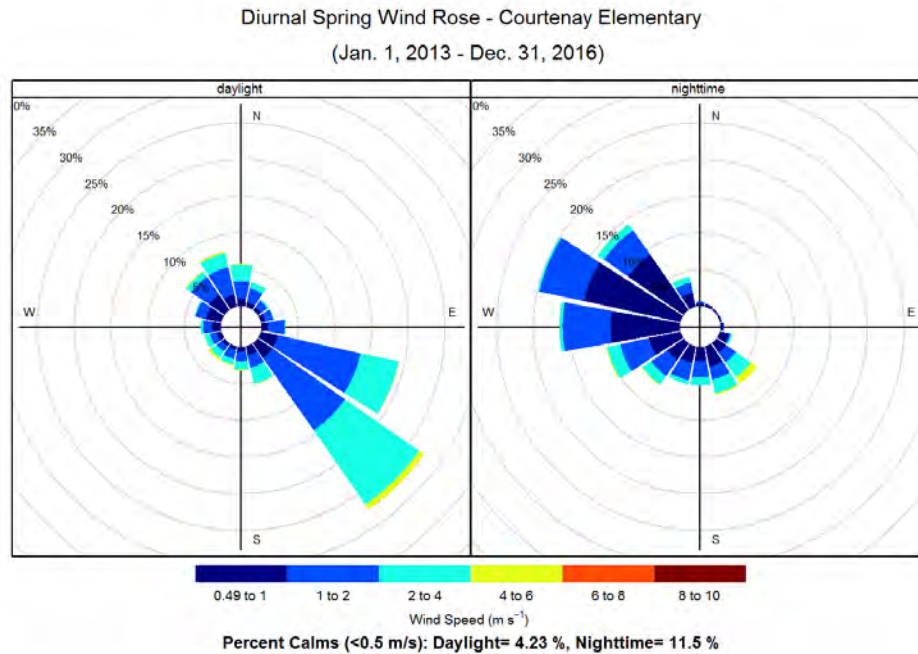


Figure A-1. Spring day and night wind roses for Courtenay Elementary 2013-2016

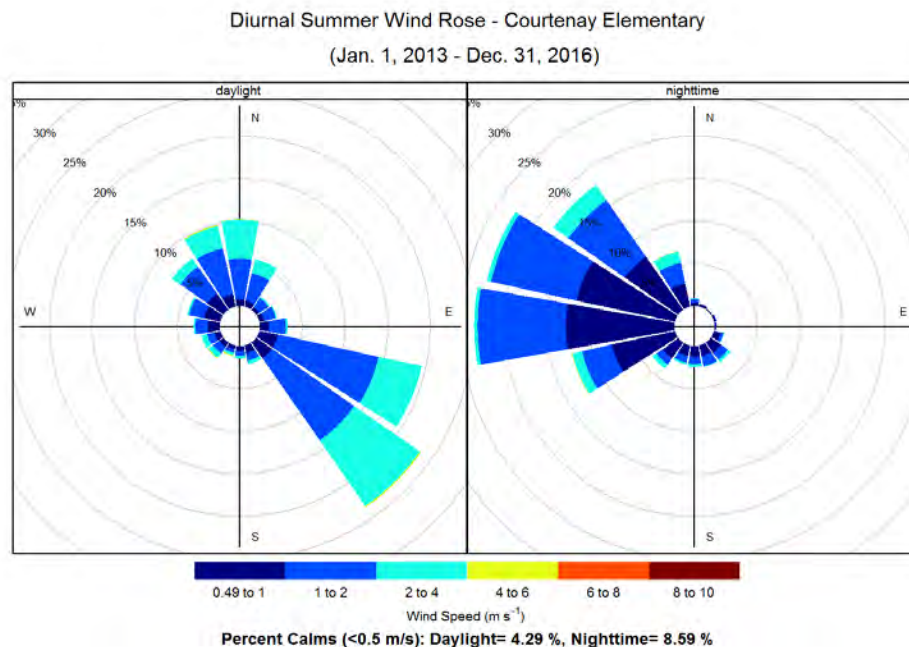


Figure A-2. Summer day and nighttime wind roses for Courtenay Elementary 2013-2016

Diurnal Autumn Wind Rose - Courtenay Elementary
(Jan. 1, 2013 - Dec. 31, 2016)

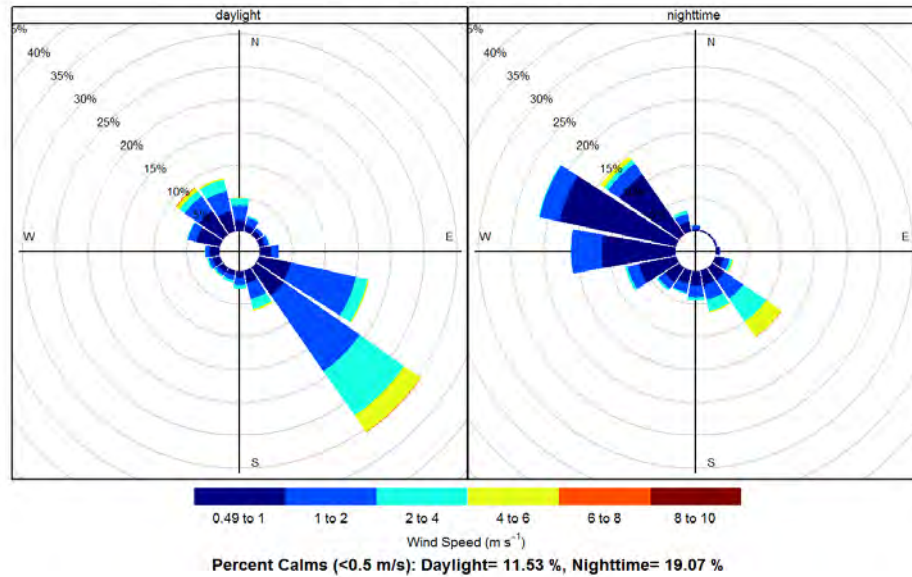


Figure A-3. Autumn day and nighttime wind roses for Courtenay Elementary 2013-2016

Diurnal Winter Wind Rose - Courtenay Elementary
(Jan. 1, 2013 - Dec. 31, 2016)

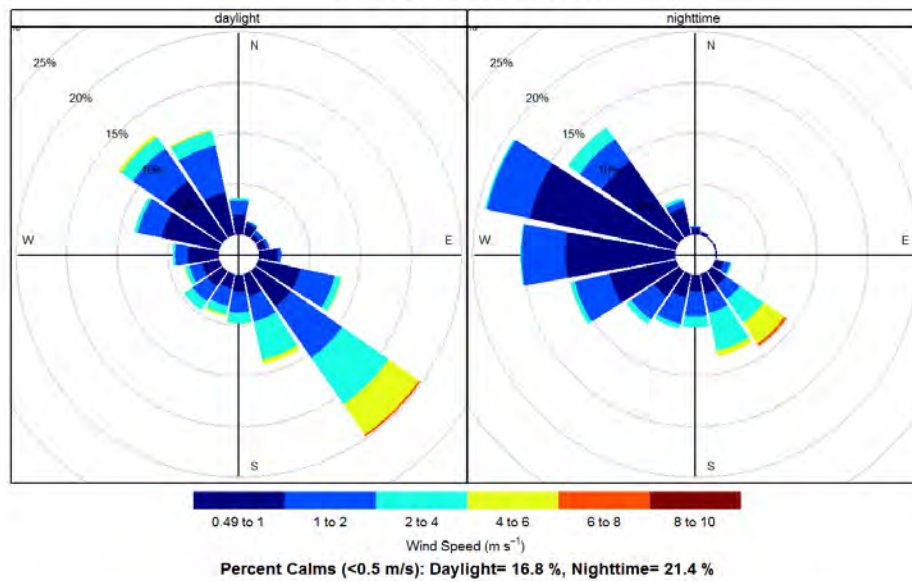


Figure A-4. Winter day and nighttime wind roses for Courtenay Elementary 2013-2016