Geob 402
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Feb 10 2016

Assignment 1: Assessment of Local Air Quality - Ozone Concentrations in Abbotsford

Source and Sink

Ozone (O3) is an important pollutant in the lower troposphere as it is a highly reactive gas and a strong oxidant. It is a secondary photochemical pollutant that is often formed as a result of reactions between other pollutants from biogenic and anthropogenic sources (Steyn et al. 1997). The formation of tropospheric O3 is often associated with the chemical reactions of many precursor species such as Volatile Organic Compounds (VOCs) and carbon monoxide (CO), and also greatly depends on the mixture of nitrogen oxides (NOx) in the atmosphere (McKendry, 1993, Vingarzan & Taylor, 2003). Increased concentrations in O3 may be detrimental to human health and vegetation (McKendry, 1993, Vingarzan & Taylor, 2003).

Abbotsford is located within the Lower Fraser Valley (LFV), and there are many potential sources of precursor species that contribute to the elevated concentrations of O3. Anthropogenic activities are common sources of various precursors such as NOx and VOCs. For example, vehicular combustion is known to be a common source of emission of NOx and CO, which contributes to the production of O3 through photochemical processes and reactions in the atmosphere (Steyn et al. 1997). Some studies (Steyn et al. 1997, Pryor & Steyn, 1995) suggest that the concentrations of O3 in the LFV is closely related to human activities such as emissions from mobile vehicles sources, in particular light-duty vehicles. Therefore, the use of vehicles - be it for commuting or industrial and farm use - is an important source that contributes to high O3 concentrations in Abbotsford.

However, a major source of precursor emissions in Abbotsford comes from major cities located in the West of the LFV, such as Vancouver, Burnaby, etc. The distribution of O3 and its precursor species is closely linked to the larger scale synoptic and mesoscale wind patterns, such as sea breezes and valley winds (Ainslie & Steyn, 2007, Pryor & Steyn, 1995). The persistent West-East direction of sea breeze winds tends to transport emissions from the coastal cities into the LFV, resulting in higher concentrations of O3 further inland (Ainslie & Steyn, 2007, Pryor & Steyn, 1995). The topography of the region also plays apart, such as the presence of mountain barriers (Fig. 1).

Although cities have high production of ozone precursors (e.g. NOx, VOC,), it takes time for oxidation to occur and to produce O3, which is why urban areas might in fact be a sink for O3 due to ozone scavenging in the early stages of oxidation rather than (Mckendry, 1993). This is especially so during rush hours, where NOx emissions are usually the greatest. The increase in NOx emissions by mobile vehicles can potentially act as a sink for the city to destroy O3 by NOx scavenging (Pryor & Steyn, 1995). The city can also act as a sink for ozone during the night, when there is no solar radiation available to create O3 from the chemical ‘soup’ that is collected in the city core.

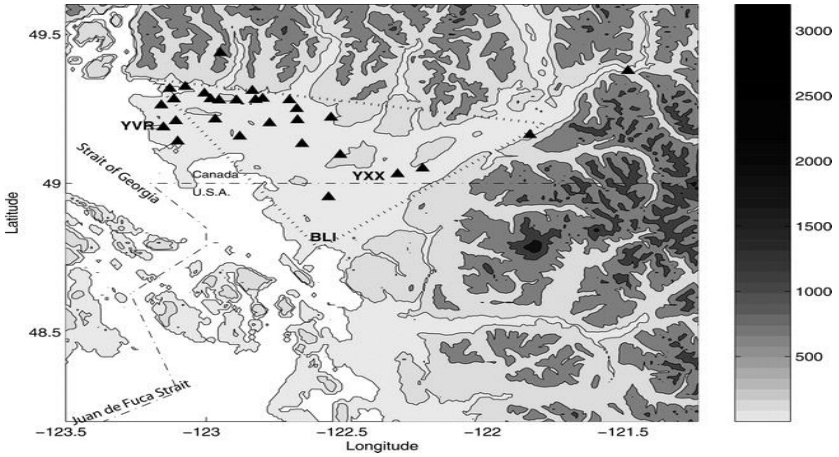

Fig. 1. A map showing the topography of the Lower Fraser Valley, YVR refers to Vancouver airport, YXX refers to Abbotsford airport. (Ainslie & Steyn, 2007).

Diurnal and Seasonal Variations

The box plots in Fig. 2, represents the data of hourly concentrations of O3 in Abbotsford over the entire year of 2008. The data collected shows patterns of diurnal and seasonal variations in O3 concentrations.

The diurnal patterns of O3 is quite uniform throughout the year, mostly driven by the changes in temperature and amount of solar radiation throughout the day. The peak in median O3 concentrations is usually around mid-afternoon, and the lowest recorded median is sometime before sunrise. The uniform mid-afternoon peak in O3 is most likely due to the higher amounts of shortwave radiation received during this period of the day, which is an important contributor to the photochemical process that creates tropospheric ozone. Higher temperatures also act in favour for O3 production. During the night, there is no available solar radiation to aid in the process of ozone production, which is why the concentration of O3 is much lower. However, there occasional spikes in O3 during the night (e.g.0100 in Summer), which may be due to the vertical mixing between the stable nocturnal boundary layer and the upper atmosphere. During the early morning and late evening, O3 concentrations are also generally lower as compared to the peak values. This may be attributed to the peak hour period that contributes to the scavenging of Ozone through NOx emissions.

The difference in O3 concentrations is distinguishable with the variation of the seasons throughout the year. The median and maximum peak values are much higher during Spring and Summer, as compared to Autumn and Winter. The longer days and shorter nights during the Summer months suggest a greater influx of solar radiation and higher average temperature leading to higher O3 concentrations. The pattern in Fig. 1, also shows that the diurnal variation is much greater during the months of Spring and Summer, and less so during Autumn and Winter (i.e. the difference between maximum and minimum values). This might have to do with greater subsidence inversion events during the Spring and Summer months, leading to higher O3 concentrations during the day. The average diurnal median values are also generally lower for the Autumn and Winter months.

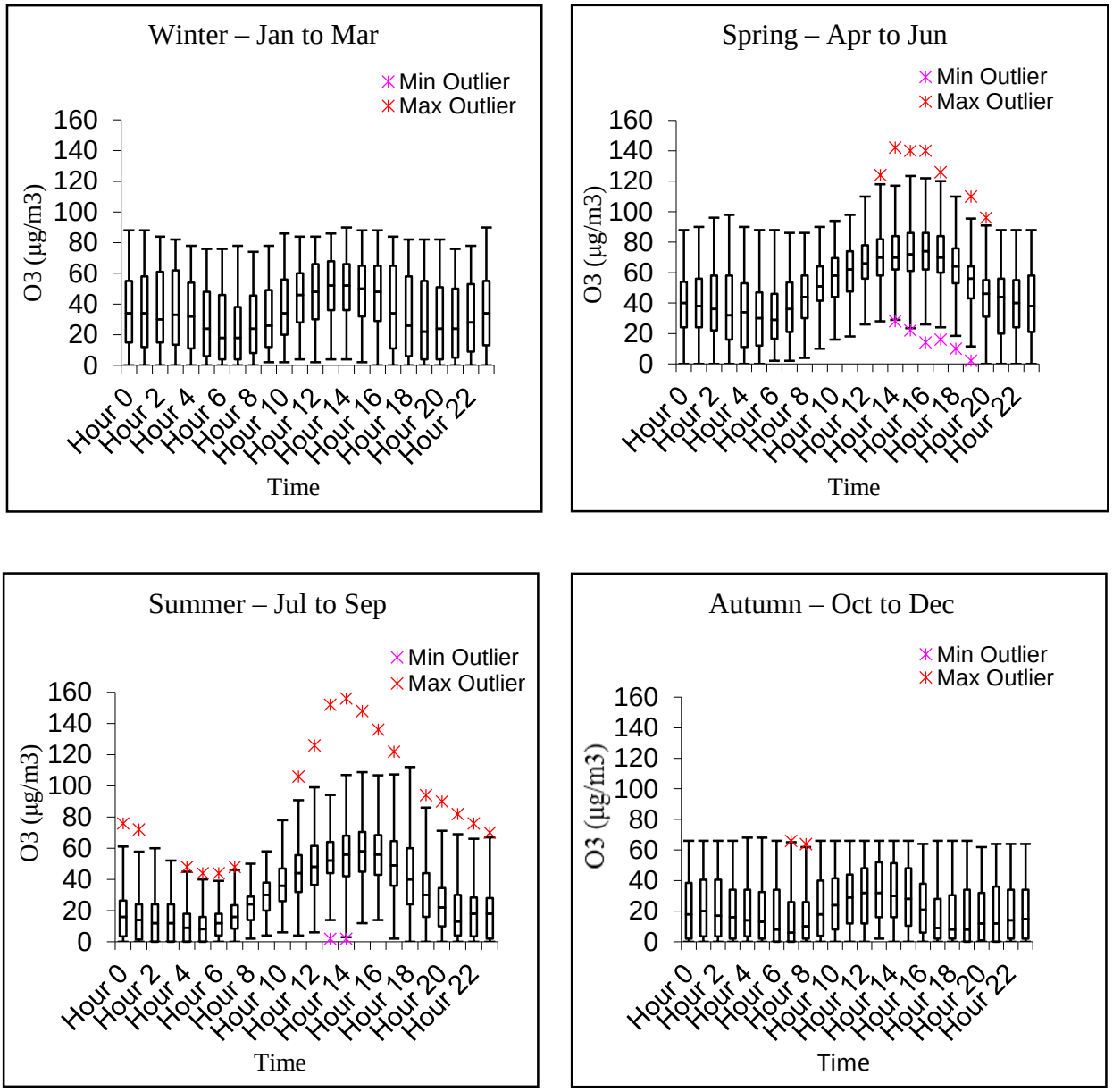

Fig. 2. Box plots showing diurnal and seasonal variation of Ozone (O3) concentrations in Abbotsford, based on hourly recorded data over the entire year of 2008.

Exceedances of Ozone standards

Looking at Fig. 3, it is clear that there are no exceedances of O3 concentrations according to the Canada-wide standards (CWS) of 130µg/m^3. We have to take note that this standard is based on an eight hour averaging time, which will affect the maximum and minimum values observed.

The concentrations of O3 are closest to exceeding the CWS during Spring and Summer, where the peak values may reach up to 120µg/m^3. This may have to do with the higher average insolation and temperature during those months, and greater episodes of

strong subsidence inversions. During those months, it is also possible that the mesoscale winds (sea breeze) are intensified due to greater pressure gradients, increasing the amounts of precursors transported to Abbotsford from the cities upwind.

The lowest frequency of O3 tends to occur around the early morning (0700 to 1000), coinciding with the morning rush hour period. The 8-hour average peak concentrations for winter months tends to be around 80µg/m^3, and 60µg/m^3 for Autumn months. They show very little variations of diurnal peak concentrations, unlike Spring and Summer.

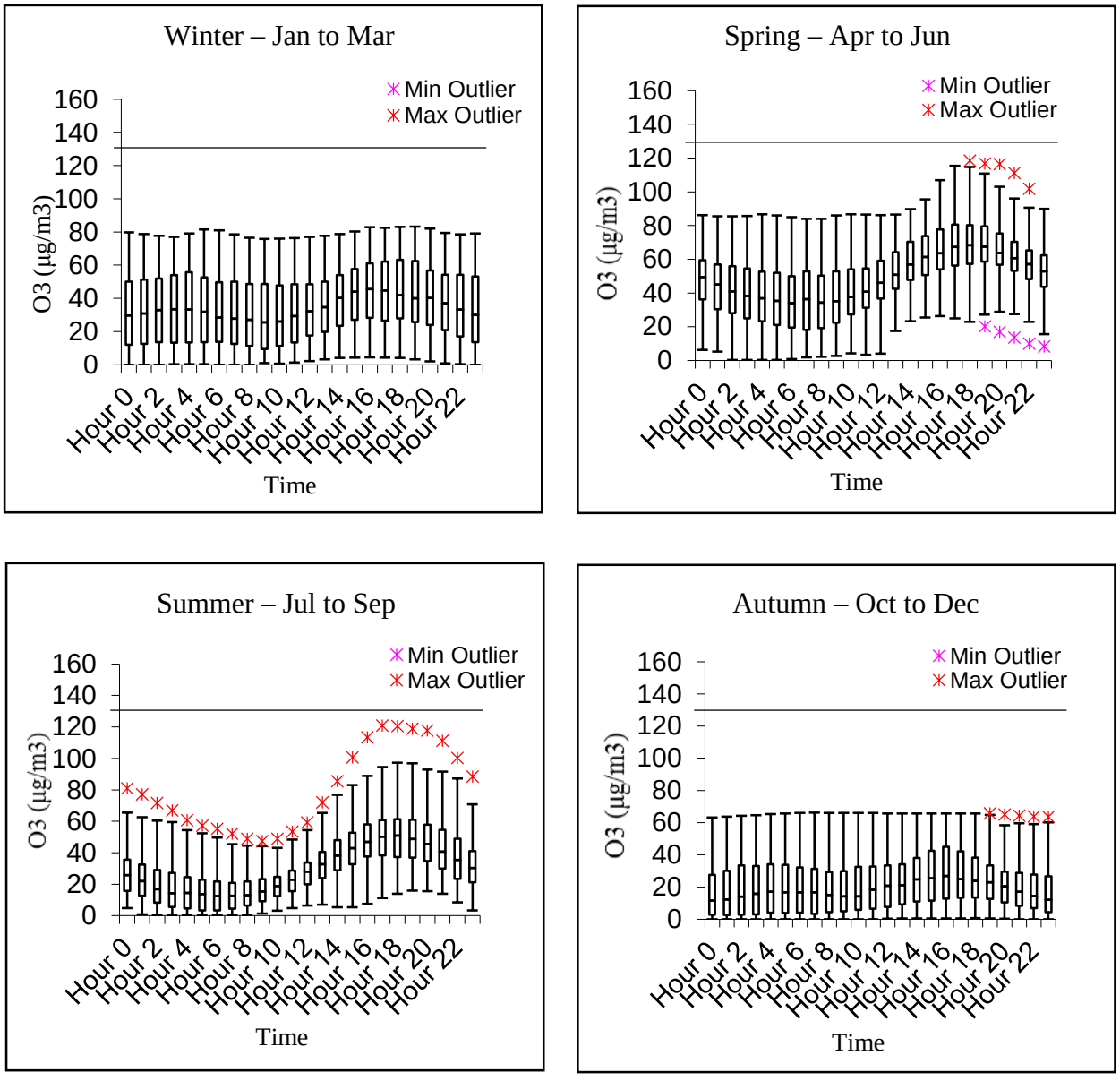

Fig. 3. Box plots showing the frequency of ozone exceedances over an 8 hour averaging time. The solid line on the graph shows the 130µg/m^3 standard based on the CWS recommendation.

Influence of meteorology and topology on O3 concentrations

Many studies suggest that the influence of mesoscale and synoptic scale winds can greatly determine and affect the amount of O3 concentrations in Abbotsford and the LFV (Ainslie & Steyn, 2007, Vingarzan & Taylor, 2003, McKendry, 1994). One of the most commonly associated process is the effect of sea breeze in the LFV. The formation of sea breeze due to pressure gradients between the land and water often drives predominant westerly winds from the coast towards the inlands of the LFV (Steyn et al. 1997). This is especially so during the Summer months, where temperature gradients are often the greatest. These westerly winds transport the emissions of precursor species from the more coastal cities (e.g. Vancouver) eastwards into Abbotsford, contributing to the increasing amounts of O3 concentrations within the LFV (Ainslie & Steyn, 2007). Due to the time needed for the transportation of the (precursor) pollutants to occur, we tend to see the peak in O3 concentrations sometime in the mid to late afternoon. This is more obvious during Spring and Summer months where the sea breezes are stronger due to greater pressure gradients (See Fig. 2 & 3).

Apart from sea breezes, valley and mountain winds can also affect the concentrations of O3 in the LFV as well, especially due to the unique topography of the region. The anabatic and katabatic winds that frequently dominate the LFV may contribute to the re-circulation of pollutants, by venting of pollutants out of the valley, and vice versa (Pryor & Steyn, 1995). This means that the pollutants are not effectively 'flushed out' from the region, but is recirculated. This is further enhanced due to the fact that the LFV is bounded by mountain barriers in the North and South, limiting horizontal advection of pollutants (Pryor & Steyn, 1995). Furthermore, mountain barriers can also create inversion layers during events of katabatic and anabatic flows or due to the heating and cooling of the valleys. This may affect reduce the depth of the mixing layer and tends to lead to an increase in concentration of O3.

The stability of the atmosphere is a considerable factor as well. An instable atmosphere can be conducive for "stratospheric intrusion" and a deeper tropospheric mixing (Vingarzan & Taylor,2003). The increase in mixing between the troposphere and upper atmosphere may increase ground levels of O3, due to processes such as entrainment. Under fair weather conditions, strong winds may "flush" out effective O3 scavengers such as NOx which are locally produced, and increase O3 concentrations (Vingarzan & Taylor, 2003). Large scale processes such as "stratus surge" are also often associated with the ending of ozone exceedance episodes, due to the incursion of cool marine air (Ainslie & Steyn, 2007).

O3 concentrations can be affected by the synoptic scale processes such as the formation of low and high pressure systems. Concentrations of O3 tends to be higher when conditions are stagnant with lower wind speeds and warmer air temperatures. This is common during Summer months where strong anticyclonic conditions tends to decrease dispersion and create subsidence capping inversions (Vingarzan & Taylor, 2003). These conditions can be coupled with the geographic barriers of the region. However, the synoptic influence in the LFV is unique, as the elevated concentrations of O3 is also closely associated with a persistent surface low-level thermal trough along the coast, accompanied with an upper level ridge that tends to align with the coast of British Columbia (McKendry, 1994). During the Summer months, the formation of thermal lows along the coast of the LFV tends to inhibit the advection of westerly winds and result in poor ventilation and less mixing (Mckendry,

1994). The upper level ridge of high pressure is also responsible for the advection of warm air into the LFV (McKendry, 1994). Therefore, the poor air quality in LFV is not restricted to traditional stagnant surface anticyclonic conditions, but rather, the synoptic effects of the thermal lows and upper level ridge.

References

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