

Background Concentrations of PM_{2.5} and Ozone in British Columbia, Canada

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Prepared for
the British Columbia Ministry of Environment
March 2006

EXECUTIVE SUMMARY

Background concentrations may be defined as those pollutants arising from local natural processes together with those transported into an airshed from afar (the latter may be both natural or anthropogenic in origin). In the absence of “pristine” monitoring sites for fine particulate matter (PM_{2.5}) and ozone (O₃) in British Columbia (B.C.), survey of the current literature, together with cursory analysis of available monitoring data, provides an estimation of the likely magnitude, and spatial and temporal variability of background concentrations across the region. In addition, it is possible to identify the likely major sources of short-term variations in background concentrations. These results are summarised below.

Table: Summary of Background PM_{2.5} and O₃ concentrations in B.C.

	Estimated Mean Background	Seasonal Background Range	Short-term Peak Background	Average Contribution to ambient	Trend
PM_{2.5}	2 µgm ⁻³	1-4 µgm ⁻³ with Summer Peak	250 µgm ⁻³ Local Forest Fire	25%	little evidence (Jaffe et al., 2005)
Ozone	20-35ppb ¹	20-35ppb with Spring Peak	40-50 ppb + Trans-Pacific fire plume (15ppb)	variable (up to 100%)	0.5-2%/ann

¹ Vingarzan, 2004a, based on nearby clean sites on the Olympic Peninsula and Mount Rainier; GVRD 2005

For PM_{2.5}:

- Mean annual background concentrations of approximately 2 µgm⁻³ are low compared to the Canada-wide Standard (CWS). They vary seasonally with a summer peak and winter minimum. It is likely that precipitation variability is a major control on background concentrations across the Province. Lower values are likely in wet coastal areas while slightly higher values might be expected in drier regions.
- Local forest fires represent the major and most frequent source contributing to short-term peak background concentrations. (Forest fires in Kelowna during 2003 had peak hourly PM_{2.5} concentrations of 250 µgm⁻³). Episodic trans-Pacific dust transport is rare but has the potential to elevate concentrations by approximately 20 µgm⁻³).
- Mean background concentrations in air masses arriving in B.C. with north Pacific trajectories are of the order of 1.5 - 2 µgm⁻³. This represents a significant proportion of the overall background concentration in B.C..
- There is little evidence of an upward trend in background concentrations. It is likely that background concentrations associated with regional or continental scale transport are decreasing due to abatement strategies in urbanised areas.

For O₃:

- The mean background is estimated to be in the range 20-35 ppb and varies seasonally with a spring maximum. This level represents approximately 50% of the CWS and given short-term variability in background sources, it is likely that the CWS will occasionally be exceeded by either background sources alone, or the additive effect of local anthropogenically generated ozone and background levels.
- There is little evidence that stratospheric intrusions of O₃-rich air contribute to exceedances of the CWS at ground level in B.C. (Bovis, 2001). However this source may contribute 20-40 ppb to short-term peak concentrations (but generally in meteorological conditions not conducive to elevated concentrations associated with local anthropogenic activities).
- Episodic trans-Pacific ozone transport (arising from either biomass burning or the anthropogenic combustion sources in Eurasia) may episodically increase short-term ground level concentrations by 5-15 ppb. In one case this has been shown to lead to exceedance of an 82 ppb 8- hour standard.
- Mean background concentrations show an upward trend of 0.5 -2.0%/year.

Based on these results it is recommended that priorities for monitoring in B.C. should include:

- establishment of a long-term pristine west coast baseline site (O₃ and PM_{2.5}, and other atmospheric constituents if possible).
- collaboration with Environment Canada to continue and enhance high altitude measurements at Whistler Peak, particularly O₃ (but other atmospheric constituents as well)
- Establishment of at least two other “clean” interior sites for O₃ and PM_{2.5} (perhaps interior plateau, and in the northeast).

Further information on background concentrations across B.C. may also be gleaned from analysis of existing data and modelling studies.

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1. INTRODUCTION

Background concentrations may be defined as those pollutants arising from local natural processes together with those transported into an airshed from afar (the latter may be both natural or anthropogenic in origin). Ozone (O_3) is an excellent example of a pollutant that occurs both naturally in the troposphere (e.g. through photochemistry associated with biogenic emissions of hydrocarbons and oxides of nitrogen, forest fires, intrusions of ozone-rich stratospheric air into the troposphere, and lightning activity) and as a result of anthropogenic emissions of precursor species (hydrocarbons and oxides of nitrogen generated primarily by combustion). Similarly, fine particulate matter ($PM_{2.5}$) has numerous natural sources (e.g. desert dusts, sea salt, pollens) that complement the anthropogenic burden much of which is generated by combustion processes. Given the mixed natural and anthropogenic origin of these two priority pollutants deemed to have a deleterious impact on human health, it is critical to define the nature, variability and magnitude of “background” in the B.C. context.

In June 2000 the Canadian Council of Ministers of the Environment (CCME) adopted ambient standards for $PM_{2.5}$ and O_3 that commit the federal and provincial governments to reach specific ambient air quality targets by the year 2010. These Canada-wide Standards (CWS) include numeric targets for $PM_{2.5}$ and O_3 and outline their associated statistical forms:

$PM_{2.5}$: 30 μgm^{-3} , 24-hour (midnight to midnight) averaging time - 98th percentile ambient measurement annually, averaged over three consecutive years.

O_3 : 65 ppb, 8-hour averaging time - 4th highest measurement annually, averaged over three consecutive years.

In moving toward CWS for particulate matter, it is recognised that these levels are not necessarily protective of human health given scientifically-based evidence that there is no lower threshold limit for $PM_{2.5}$ effects on human mortality and morbidity. In fact, the Federal-Provincial Working Group on Air Quality Objectives and Guidelines (WGAQOG) has determined that the target which would substantially reduce the risks to human health for $PM_{2.5}$ is 7.5 μgm^{-3} (24 hour averaging time), a value significantly lower than the CWS. Given this relatively low value, and its proximity to background levels in the US and Canada, WGAQOG has suggested that background levels are appropriate targets for reducing risks to human health (CEPA, 1999).

In light of the movement to CWS, it is essential to explore the extent to which ambient pollutant concentrations across British Columbia are influenced by “background concentrations” that (a) are not amenable to “control” through local air quality management strategies, and (b) which potentially may lead to violations of the CWS.

In examining the $PM_{2.5}$ and O_3 “background” across B.C. two overarching “facts” underlie the conclusions reached herein:

(a) B.C. is relatively remote from other significant North American continental sources of pollutants and is generally exposed to Pacific air masses (with the exception of the northeast portion of the Province).

(b) B.C. is a large area with a wide range of physical environments and climatic regimes (e.g. the dry southern interior, wet forested coastal regions, and dry cold plains of the northeast). Each region has characteristic local sources of pollutants and differing exposures to marine and continental air masses. “Background” is therefore clearly airshed-specific.

2. OBJECTIVES

As monitoring in B.C. is generally conducted at sites where local anthropogenic sources are significant (e.g. the Lower Fraser Valley), determination of the exact magnitude of background concentrations based on routine ambient monitoring is problematic. Given this obstacle, it is the goal of the report to exploit all available data sources and research to:

- provide best estimates of average PM_{2.5} and O₃ “background” concentrations for B.C.,
- examine spatial and temporal variability in background concentrations,
- identify the dominant sources affecting background concentrations including those exhibiting significant short-term variability (e.g. forest fires) and
- make recommendations with respect to future monitoring priorities in order to better define the magnitude and variability of background concentrations across the Province.

Several approaches may be used to provide reasonable estimates of background levels in the absence of monitoring from “clean” or “pristine” sites. These include:

- (a) Survey of the extant literature on background levels in the region or in similar settings: Published studies include special observational studies as well as regional/global chemical modelling studies. Of relevance to this report are observations at the coastal Cheeka Peak site (Washington State – western Olympic Peninsula) and Crater lake (Oregon), and model “experiments” in which sources (both natural and anthropogenic) may be varied in order to determine background concentrations.
- (b) Examination of routine monitoring data: Observations from relatively clean sites provide indications of background concentrations. Furthermore, episodic cases of elevated background concentrations may be identified (e.g. concentrations experienced during known forest fires).

In this report, information from each of these sources is used to estimate background concentrations across the region.

3. DEFINITIONS

The terms “background”, “natural background” and “baseline” concentrations are used widely, and sometimes with subtle nuances in meaning, in the literature. In Atmospheric Chemistry **background concentration (level)** is formally defined as:

“The concentration of a given species in a pristine air mass in which anthropogenic impurities of a relatively short lifetime are not present. The background concentrations of relatively long-lived molecules, methane,

carbon dioxide, halocarbons (CF₃Cl, CF₂Cl₂, etc.) and some other species continue to rise due to anthropogenic input, so the composition of background air is undergoing continual change. Background concentration of a given species is sometimes considered to be the concentration of that impurity in a given air mass when the contribution from anthropogenic sources under study is absent. Synonymous with baseline concentration.”
1990, 62, 2175
IUPAC Compendium of Chemical Terminology 2nd Edition (1997)

In general usage, and for the purposes of this report, “background” concentrations are defined as those ambient pollutant concentrations in an airshed that would occur in the absence of local anthropogenic emissions. Thus “background” is the sum of local natural emissions and those pollutants (generally long-lived species) advected into an area that are of both natural and anthropogenic origin. This definition is somewhat broader than some definitions that exclude all anthropogenic sources (including those arising from landuse change and practices, e.g. forest fires).

In defining the nature of “background”, an important related concept is that of “chemical weather”, a term that is gaining increasing acceptance and assuming greater importance in the Atmospheric Chemistry community. **Chemical Weather** is defined as:

“local, regional and global distributions of important trace gases and aerosols and their variabilities on time scales of minutes to hours to days, particularly in light of their various impacts, such as on human health, ecosystems, the meteorological weather and climate”.
- Lawrence et al. 2005

This definition arises from recognition that focus has previously been on the chemical climate -- the long term mean concentrations of important trace gases and aerosols. However, “Chemical Weather” recognises the tremendous short-term variability of the atmospheric composition, resulting from the strong influence of meteorological variability, chemical complexity, and regional and temporally varying emissions. In the context of this report “chemical weather” implies that “background” concentrations are not constant but instead are highly variable both spatially and temporally. Consequently, events such as dust storms in Asia/Sahara, or forest fires in Siberia/Okanagan Valley, or stratospheric ozone down-folding events over the North Pacific all contribute to the short variability (chemical “weather”) of background concentrations.

4 BACKGROUND PM_{2.5}

4.1 Sources

Particulate Matter (PM) originates from a wide variety of sources and includes particles having diverse physico-chemical characteristics. Natural sources include forest fires, windblown soil and dust, volcanic dust, sea spray, pollen, spores and bacteria. Associated particles are typically found in the coarse fraction (PM_{2.5-10}), although forest fires produce predominantly fine particles (PM_{2.5}). Anthropogenic sources of PM include fossil fuel combustion, industrial processes, prescribed burning, wood stoves, and fugitive dust from roads, construction sites and agriculture. PM derived from fossil fuel or biomass

combustion is predominantly composed of fine particles, whereas fugitive dust is characterized by coarse particles. In addition to the *primary particles* emitted directly into the atmosphere, *secondary particles* are formed from physical or chemical transformations that occur in the atmosphere, and are most often found in the fine fraction (PM_{2.5}). Precursor gases involved in secondary formation include sulphur dioxide (SO₂), oxides of nitrogen (NO_x), ammonia (NH₃) and various hydrocarbons referred to as volatile organic compounds (VOCs).

4.2 Mean Background Levels - Relevant Literature

A recent report on monitoring of PM in B.C. (Suzuki and Taylor, 2003) notes the dearth of information on natural background levels of PM in Canada due to the tendency for monitoring to be concentrated in urban centres, or in the case of B.C., in resource-based communities where local anthropogenic sources dominate. Consequently, few pristine monitoring stations exist. However, an indication of the likely magnitude of background concentrations is provided by a study of six remote rural locations in Alberta showing PM_{2.5} concentrations between 1.7 to 3.8 µgm⁻³ with an average of 3.2 µgm⁻³ (Cheng et al., 2000). In the western United States, natural background levels of 1 to 4 µgm⁻³ for PM_{2.5} have been reported (US EPA, 1996; Trijonis et al. 1990). In B.C., emissions inventories suggest that away from the Lower Fraser Valley (the major urbanised region) natural sources of PM comprise ~25% of emissions of both PM_{2.5} and PM₁₀ (Suzuki and Taylor, 2003). Based on mean PM_{2.5} concentrations of approximately 5- 6 µgm⁻³ observed across B.C. this would indicate a “first guess” estimate of mean background PM_{2.5} of approximately 1- 1.5µgm⁻³, a value at the low end of estimates cited above for Alberta and the western United States (see Table 5, Suzuki and Taylor (2003) – note: values in this table have been subsequently adjusted downward by 3 µgm⁻³, Suzuki, pers. comm).

Vingarzan (2004b) provides a comprehensive analysis of ambient PM concentrations and background levels in Canada based on measurements from the Canadian National Air Pollutant Surveillance (NAPS) Network from 1996-2001. Mean annual values are presented in Figure 1 and are compared with estimated mean background levels for Canada (2.5 µgm⁻³) and western North America (1-4 µgm⁻³). Vingarzan (2004b) notes that for annual average PM_{2.5} concentration for the fourteen stations in B.C., two of the stations, Powell River, Wildlife, and Victoria, Sooke Rd., fall within the range of background levels cited above for Canada and the western United States. It is noteworthy that these stations are in coastal non-urban settings where precipitation is relatively high. At the urbanised and/or resource-based communities of Nanaimo, Victoria, Quesnel, Kamloops, Chilliwack and Kelowna, concentrations are still within 2 µgm⁻³ of estimated background levels. Prince George has the highest PM_{2.5} annual concentration at 9.2 µgm⁻³ (this relatively high value may be attributed to a combination of local industrial/resource-based sources and the topo-meteorological factors affecting dispersion in the region).

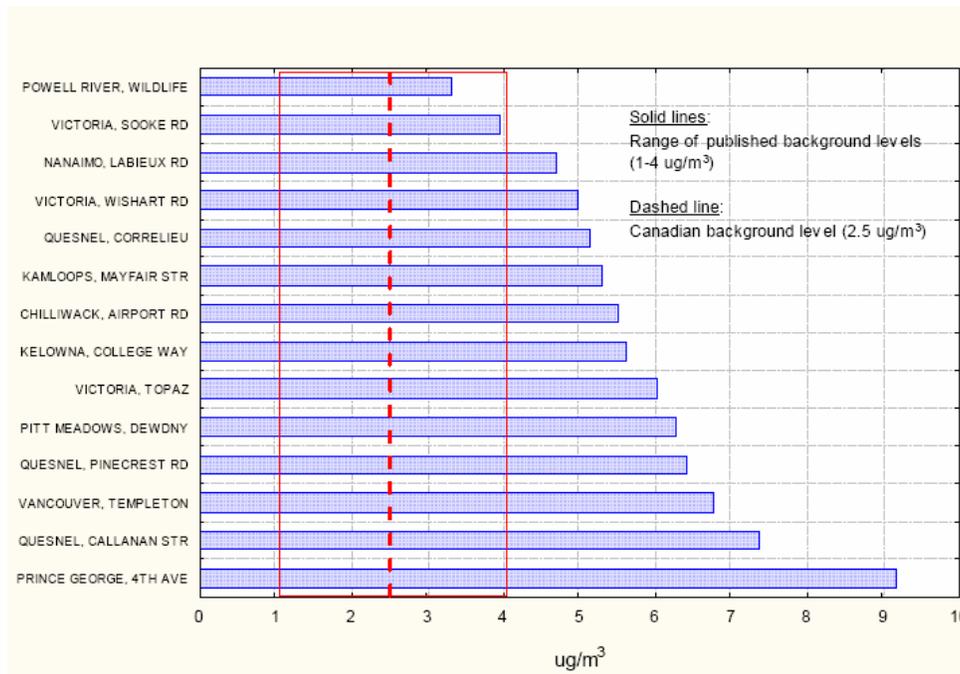


Figure 1: **PM_{2.5} Annual Means for B.C. NAPS Stations - from Vingarzan (2004b)**

Recently, the discovery that western North America is influenced by the trans-Pacific transport of Eurasian aerosols (including desert dust) and Saharan dust (Husar et al. 2001; Jaffe et al. 2005, McKendry et. al. Submitted) has prompted studies designed to measure the magnitude and frequency of this background input. Jaffe et al. (2005) utilise a trajectory approach to segregate data from the pristine Crater Lake (Oregon) IMPROVE (Interagency Monitoring of Protected Visual Environments) site in order to define marine background concentrations of PM_{2.5} along the west coast of North America. This background component is assumed to reflect some combination of contributions from Eurasian anthropogenic sources, natural marine emissions (including sea salt and non-sea salt sulfate, from marine biogenic emissions of dimethyl sulfide), Eurasian vegetation and/or Eurasian biomass burning. Background marine aerosol (referred to as CMA – “Combined Marine/Asian”) is shown to have annual mean and median concentrations of 2.0 and 1.5 $\mu\text{g m}^{-3}$, respectively, for PM_{2.5}. These values are very close to those obtained for Cheeka Peak, on the west side of the Olympic Peninsula, Washington. This broad spatial consistency provides support for the view that these values are applicable also to B.C.. When trajectories are “local”, reflecting North American sources, annual mean and median concentrations are somewhat higher at 3.7 and 3.2 $\mu\text{g m}^{-3}$, respectively. It is important to note that there is a seasonal pattern in all components of the aerosol mass (shown in Figure 2), with a summer maximum and winter minimum. This pattern is most likely due to the strong seasonal pattern in precipitation, which peaks in winter, combined with enhanced sources in summer.

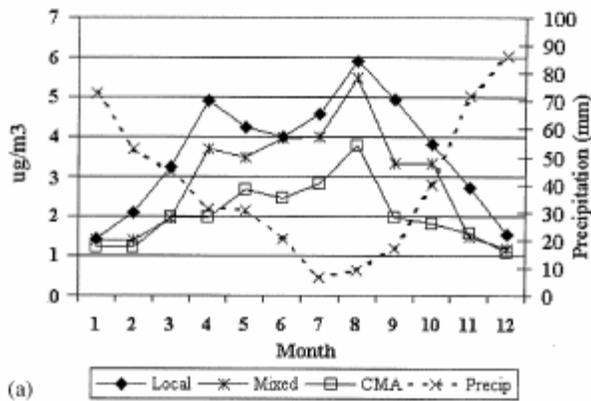


Figure 2: From Jaffe et. al (2005) - Mean concentration by month for local, mixed and CMA sample types as defined in text for fine particle mass ($\mu\text{g}\text{m}^{-3}$)

On an annual basis, Keating et al. (2005) suggest that annual average background $\text{PM}_{2.5}$ concentrations of $2 \mu\text{g}\text{m}^{-3}$ along the west coast of the United States are comprised of approximately 40% organic aerosol, 20% sulfate, and 15–20% mineral dust; the remainder comprises black carbon, nitrates, sea salt, mercury, and other metals. These estimates are supported by modelling studies (USEPA) of trans-Pacific transport using the Community Multiscale Air Quality (CMAQ) regional model. CMAQ suggests that Asia contributes $0.6\text{--}1.6 \mu\text{g}\text{m}^{-3}$ to the monthly average $\text{PM}_{2.5}$ in the West and $0.2\text{--}1.2 \mu\text{g}\text{m}^{-3}$ $\text{PM}_{2.5}$ in the East (see Figure 3). The spatial distribution shown in Figure 3 for April also suggests that the Asian contribution to background levels over B.C. may be lower than further south.

Jaffe et al. (2005) report no trend in CMA since 1988 (despite increased emissions in Asia) but note a decreasing trend in $\text{PM}_{2.5}$ for air trajectories of local/continental origin. This likely reflects documented decreasing emissions of PM_{10} in western regions over the period.

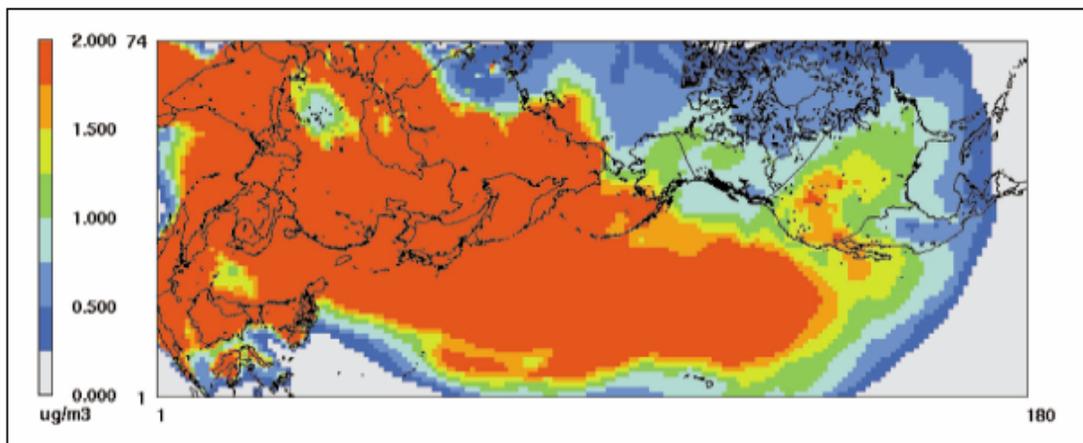


Figure 1. Modeled monthly average concentration of $\text{PM}_{2.5}$ crossing the Pacific Ocean due to anthropogenic Asian emissions in April 2001, calculated using CMAQ as the difference between a base-case simulation and a simulation with anthropogenic Asian emissions removed. Courtesy of Carey Jang, EPA.

Figure 3: from Keating et al. (2005)

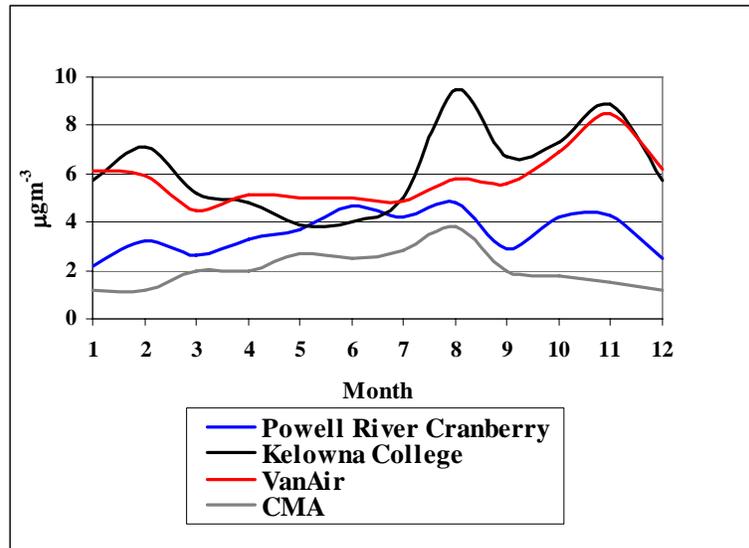


Figure 4: Monthly PM_{2.5} concentrations at selected sites in B.C. and for Combined Marine /Asian air masses (Jaffe et al; 2005)

Based on the assumptions that (a) B.C. is exposed regularly (especially in the non-summer months) to Pacific marine air masses and (b) observations at both Crater Lake and Cheeka Peak are applicable also to B.C., it is revealing to compare the results of Jaffe et al. (2005) with B.C. observations. In Figure 4 the CMA (Combined Marine/Asian Aerosol background) from Jaffe et al (2005) is superimposed on a graph showing monthly mean PM_{2.5} values at selected stations in B.C.. Powell River Cranberry represents a relatively clean coastal site (despite a local point source of anthropogenic PM) with low average PM concentrations while Vancouver Airport and Kelowna represent urbanised coastal and interior sites respectively. Several key points can be made:

- The “clean” Powell River Cranberry location (annual mean 3.6 µgm⁻³) shows the same broad seasonal pattern as CMA at Crater Lake (annual mean 2.1 µgm⁻³). This winter minimum/summer maximum pattern together with low concentrations is indicative of a dominance of natural sources. Based on a comparison with CMA this suggests that the “background” at this site is composed primarily of local natural sources and combined marine/Asian sources in roughly equal proportions.
- The urbanised sites of Kelowna (annual mean 6.2 µgm⁻³) and Vancouver Airport (annual mean 5.8 µgm⁻³) show the reverse pattern in which winter concentrations are generally higher due to increased atmospheric stability (elevating near surface concentrations associated with local emissions) and higher anthropogenic emissions. The elevated concentrations apparent in Kelowna during August are strongly influenced by the significant effect of forest fires in 2003 on seven-year averages. At these sites the comparison with CMA implies that in spring and summer, up to 50% of the monthly average could be attributed to marine and Asian background sources.

In summary, observational and modelling studies suggest that British Columbia is exposed to average annual background concentrations of $PM_{2.5}$ associated with marine and Eurasian sources of the order of $1.5 - 2 \mu\text{gm}^{-3}$. There appears to be no significant trend in this background. Local natural background sources are likely of a similar magnitude. These background levels show a seasonal variation characterised by a summer maximum and a winter minimum. It is likely that there is some spatial variation in these mean background values which is related to the variety and strength of local sources as well as the exposure to marine air masses.

4.3 Episodic Elevated $PM_{2.5}$ Background

From the previous section, it is apparent that exceedances of the CWS are unlikely to arise from mean background values (which for $PM_{2.5}$ are low). However, episodic events that comprise “chemical weather” have the potential to elevate local concentrations beyond the CWS. The major candidate background sources in B.C. are:

- Wind blown local crustal material. The most well known are the winter outflow events in the eastern Lower Fraser Valley when strong winds ($8-10 \text{ ms}^{-1}$) mobilise riverbed materials (McKendry, 2000).
- Local forest fires (predominantly summer) that affect mainly interior regions of B.C. and neighbouring areas (including the USA).
- Trans-Pacific transport of dust (McKendry et al. 2001) arising from severe spring dust storms in Eurasia: Due to the long distance from source, the mean particle diameter for this material is approximately $2.5 \mu\text{m}$ and thus it can contribute significantly to $PM_{2.5}$ (Husar et al. 2001).

In Table 1, an estimate of the maximum short-term background concentrations for these sources is provided on the basis of recent events. Of these, it is clear that forest fires in the local region have the greatest potential to significantly elevate $PM_{2.5}$ concentrations. Forest fires affecting the Kelowna area (Okanagan Valley) in 2003 provide an example of the potential impact of such events on $PM_{2.5}$ concentrations (Figure 5).

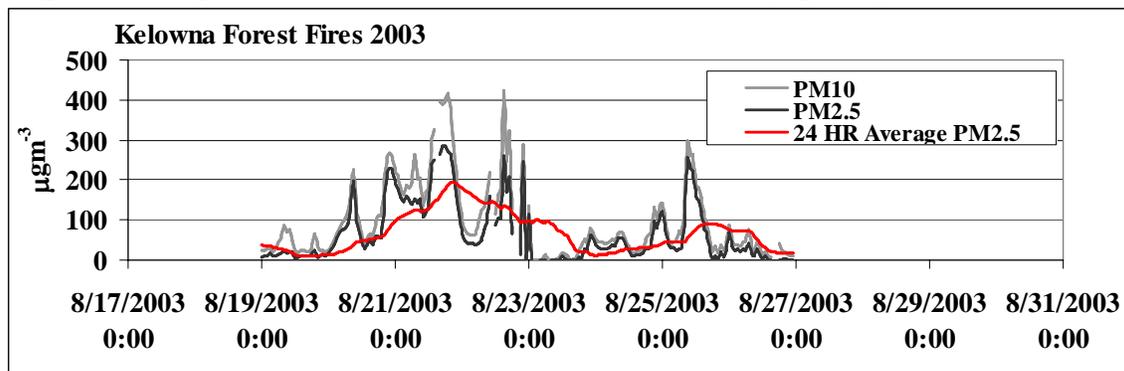


Figure 5: Time series of particulate matter concentrations at Kelowna during August 2003 (data from B.C. Ministry of Environment data archive)

Near the source (i.e. Kelowna), hourly $PM_{2.5}$ concentrations exceeded $250 \mu\text{gm}^{-3}$ while 24 hour averages exceeded the CWS level for several consecutive days. Although Asian dust storms have the potential to add to the local $PM_{2.5}$ burden by approximately $20 \mu\text{gm}^{-3}$ (Hacker et al. 2001, U.S. EPA, 2002), such events appear to be rare due to the unlikely

combination of factors required (i.e. a major dust storm in Asia, favorable transport conditions across the Pacific and down-mixing mechanisms over B.C.).

Conversely, local dust storms, such as those seen in the eastern Lower Fraser Valley during winter, when riverine and soil crustal materials are mobilised, are dominated by coarse materials ($PM_{2.5-10}$) and contribute little to the $PM_{2.5}$ burden. Recent observations of Saharan dust transport to B.C. indicate that such events are likely rare and have only minimal impact on surface $PM_{2.5}$ concentrations (McKendry et al. Submitted).

Table 1: Impact of episodic events on $PM_{2.5}$ background

	Maximum ambient $PM_{2.5}$ Concentration	Duration of Event	Background contribution to ambient	Spatial Extent	Frequency
Kelowna August 2003 Forest Fires	284 μgm^{-3}	7 days	100%	Regional	interannual
April 1998 Asian Dust Event¹	44 μgm^{-3}	days	50% ²	Continental	rare (decadal?)
Chilliwack local dust event (7 Jan 2005)	2-5 μgm^{-3} (PM_{10} 50 μgm^{-3})	days	0-50%	Local	annual

¹ McKendry et al, 2001; Husar et al. 2001

² U.S. EPA (2002) suggest an increase of $8.7 \pm 2.3 \mu\text{gm}^{-3}$ during dust events, with mean maximum dust contributions of $19.7 \pm 8.4 \mu\text{gm}^{-3}$

5. BACKGROUND OZONE

5.1 Sources

Ground-level ozone is a secondary pollutant arising from complex chemical reactions amongst precursor gases, principally NO_x and VOC's in the presence of sunlight. NO_x and VOC's are emitted from a range of both anthropogenic and natural sources. NO_x for example is emitted during combustion processes (e.g. motor vehicles, industry, biomass burning) or soil respiration. Similarly VOC's may be emitted from various tree species (so-called biogenic emissions) or be emitted during combustion and industrial processes. Ozone in the troposphere may also form as a consequence of lightning or originate from the natural intrusion of ozone from the stratosphere (where it exists in relatively high concentrations, the so-called "ozone layer").

5.2 Ozone Background and trends - Relevant Literature

A comprehensive survey of literature pertaining to background ozone concentrations and trends relevant to Canada has been conducted by Vingarzan (2005). This detailed study provides the foundation of this section. The key scientific findings arising from this work are summarised online (http://www.ecoinfo.ec.gc.ca/reports/reports_AS_1_e.cfm) and are reproduced verbatim below:

- *The annual cycle of ozone at background sites in the Northern Hemisphere is characterized by a spring maximum peaking during the month of May. Sites which are affected to some extent by local ozone production exhibit a broad summer maximum. There is no overarching consensus as to the origin of the spring maximum, as evidence supports both enhanced photochemistry in the free troposphere and stratospheric-tropospheric exchange.*
- *Modern day annual average background ozone concentrations over the mid-latitudes of the Northern Hemisphere range between approximately 20-45 ppb, with variability being a function of geographic location, elevation and extent of anthropogenic influence.*
- *Annual average ozone concentrations at Canadian background stations fall between 23-34 ppb, a range similar to low elevation background sites in the US and around the world.*
- *Background ozone levels over the mid-latitudes of the Northern Hemisphere have approximately doubled from those measured over a century ago with the greatest increase having occurred since the 1950s.*
- *Background ozone levels have continued to rise over the past three decades, and this rise has been in the range of approximately 0.5-2% per year. Rising trends have not been uniform, however, as the relatively steep trends of the 1970s and 1980s have given way to more modest trends throughout the 1990s. The slower rate of increase, or in some cases lack of an increase, over the past decade is believed to reflect recent declines in ozone precursor emissions in North America and Europe.*
- *Modelling studies indicate that increases in NO_x emissions since the 1970s account for a 10-20% increase in background ozone over certain areas of the globe. Rising*

methane levels from industry and agriculture are believed to have increased global ozone levels by 3-4%. Countering this, are estimates of declines in the ozone flux from the stratosphere to the troposphere, resulting from stratospheric ozone depletion.

- *Recent global chemical transport model studies indicate that Asian pollution contributes about 3-10 ppb to background ozone levels in the western United States during the spring. A continued rise in anthropogenic emissions from Asia is expected to increase the background level even further.*
- *Using five of the less conservative IPCC emission scenarios, the average global surface ozone concentration is expected to be in the range of 35-48 ppb by 2040, 38-71 ppb by 2060, 41-87 by 2080 and 42-84 ppb by 2100. Such increases would exceed internationally accepted environmental criteria and have negative implications on human health, crops and vegetation.*

Clearly, the relationship between background and CWS is somewhat different for ozone as compared to PM_{2.5}. For PM_{2.5}, mean background levels represent a small fraction of CWS and there are no apparent trends. For ozone, background levels are a significant proportion of the CWS (~50%) and display a significant upward trend.

5. 3 Observed Episodes of Elevated Ozone Background

From the previous section, it is apparent that exceedences of the ozone CWS (65ppb – 8 hour average) potentially may arise from a contribution of both mean background values (20-35 ppb in B.C.) and episodic events that comprise “chemical weather”. The major candidate episodic background sources in B.C. are:

- Intrusions of stratospheric ozone rich air during stratospheric downfolding events (Bovis, 2003)
- Trans-Pacific transport of anthropogenically generated ozone (Jaffe et al. 2004).
- Trans-Pacific transport of ozone generated by bio-mass burning (Jaffe and Keating, 2005).
- Locally generated “natural ozone” from lightning and forest fires.

It should be noted that when considering ozone concentrations in urban settings, background ozone advected over cities may be depleted (titrated/scavenged) by local emissions of nitric oxide (NO). The impact of elevated background concentrations may therefore be greatest in rural or natural settings.

The potential impact of the four sources listed above on ambient ozone concentrations is summarised in Table 2. Bovis (2003) has examined the impact of stratospheric ozone intrusions on surface ozone concentrations in the Lower Fraser Valley by using ⁷Be (a radionuclide measured in Vancouver as part of the Comprehensive Nuclear Test Ban Treaty) as a tracer of stratospheric air. On the basis of this study it is apparent that although stratospheric intrusions contribute to background levels in B.C., the episodic impact on background concentrations at ground level is relatively small. No episodes of significant elevation of concentrations were observed in the period 1996-2002. Jaffe et al. (2003) have documented several cases of trans-Pacific transport of anthropogenic pollutants (1993-2001) based on aircraft and ground observations (Cheeka Peak

Observatory). Although episodic enhancements of mid-tropospheric O₃ concentrations to 80-90ppb were observed there was little evidence of significant episodic enhancement at ground level. Weiss-Penzias (2004) confirm that the enhancement of ozone due to Asian sources at Cheeka Peak, Washington is of the order of 5 ppb and is at a maximum in spring. Although the enhancement of ozone due to anthropogenic Asian sources of precursor species appears relatively small, the impact of biomass burning plumes originating in Eurasia seems to have the potential to significantly enhance background levels and contribute to exceedances of the CWS. Jaffe et al. (2004) show that the extensive wildfires in Siberia during summer of 2003 (the largest in a decade) likely had a significant impact on O₃ concentrations in the Washington/B.C. region. At Enumclaw, Washington State, 8-hour average ozone concentrations reached 96 ppb on 6 June 2003, of which 15 ppb was attributed to the Siberian fire plume (Figure 6). In the LFV O₃ concentrations reached approximately 80 ppb during this event and were likely enhanced to a similar extent.

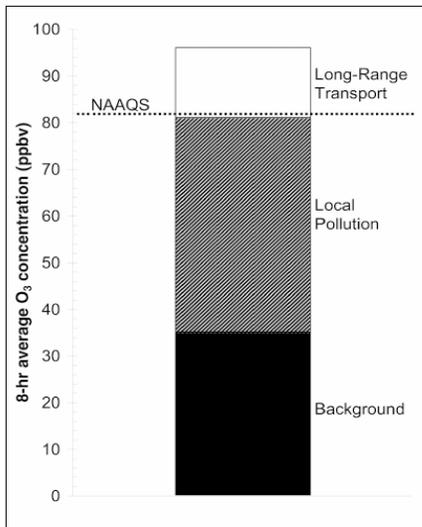


Figure 2. A plume from a Siberian forest fire contributed 15 ppb to an observed 8-hr average O₃ concentration of 96 ppb in Washington State on June 6, 2003.⁹

Figure 6: From Keating et al. (2005)

The extensive Kelowna forest fires of 2003 provide an indication of the potential O₃ enhancements associated with local biomass burning (Figure 7). At sites within the Okanagan region (and recognising that O₃ enhancements likely increase with distance from source) during the peak of the event (21-23 August) concentrations decreased from hourly maximum values of approximately 60 ppb to “background” values of 30-40ppb. On this basis, it might be argued that at least locally, the forest fires were not responsible for significant O₃ enhancements and may have in fact reduced ambient concentrations. Further research is required to assess the exact impact of the fires on local atmospheric chemistry.

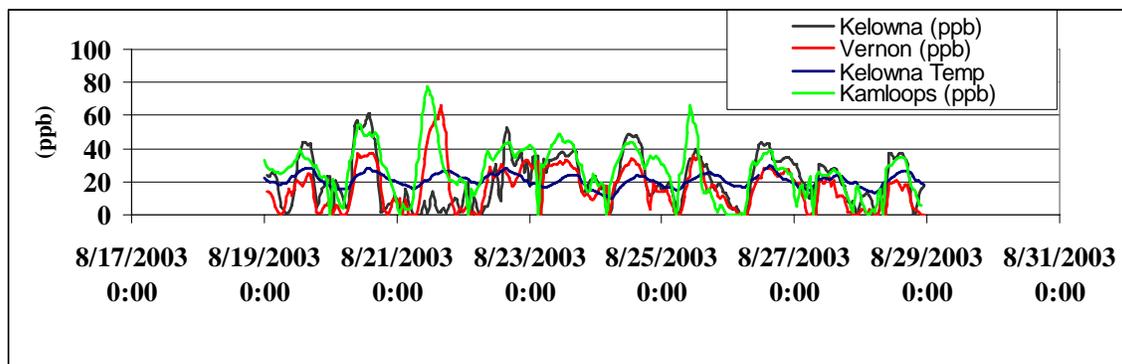


Figure 7: Time series of O₃ concentrations at interior stations during forest fires of August 2003 (data from the B.C. Ministry of Environment data archive)

Table 2: Impact of episodic events from different background sources on the O₃ background

Background sources	Maximum Ambient O ₃ Concentration	Duration of Event	Background Contribution to Ambient	Spatial Extent	Frequency
Stratospheric Intrusion¹	30-40 ppb	days	50-100% (20-40 ppb)	regional	Several times per year
Trans-Pacific Anthropogenic Ozone²	>80 ppb mid-troposphere 40 ppb Ground	Hours - days	50% at mid-troposphere 0-10% Ground (5 ppb)	regional	spring – 4-6 cases/decade
Trans-Pacific Biomass Burning Plumes³	96 ppb	hours	Siberian plume 15% (15 ppb) 50% “normal” background	regional	rare
Local Forest Fires⁴	60 ppb	days	Uncertain but fire effect likely small	local	inter-annual

¹ Bovis 2001

² Jaffe et al. 2003

³ Keating and Jaffe, 2005; Bertschi and Jaffe 2005, Bertschi et al. 2004, Jaffe et al. 2004

⁴ based on analysis of Kelowna 2003 event

6. RECOMMENDATIONS FOR MONITORING IN B.C.

Currently, monitoring in B.C. is largely restricted to urban settings or close to significant anthropogenic point sources. In some cases (eg. Powell River Cranberry), monitoring stations provide a reasonable estimate of concentrations experienced in “pristine” settings. However, based on the findings described above, there is good justification for the expansion of O₃ and PM_{2.5} monitoring in B.C. to a limited number of “clean” sites in order to:

- (1) more accurately define the exact background concentrations which may affect the application of CWS
- (2) monitor trends in background concentrations that appear significant in light of burgeoning emission sources (particularly in Eurasia).

The analysis above suggests that different monitoring strategies and priorities are appropriate for O₃ and PM_{2.5}. For PM_{2.5}, given that (a) concentrations are generally low in B.C., (b) background concentrations are small (1-2µgm⁻³) compared to the CWS (c) spatial variations in background appear to be negligible with respect to the CWS and (d) there appears to be no discernible long term trend, there appears to be no urgent need for monitoring at numerous “clean” sites across the Province. However, a good case can be made for baseline monitoring stations spanning different physiographic regions (e.g. West Coast, Interior plateau, Northeast) where the magnitude and variability of “background” is not well-known. The highly variable location of forest fires makes it difficult to site monitors specifically to address this aspect of the “background”.

For O₃, mean background concentrations represent a significant proportion of the CWS and there is an increasing trend. Furthermore O₃ concentrations show significant altitudinal variability. These factors imply a slightly different monitoring strategy than for PM_{2.5}. A top priority is the need to establish a long-term baseline pristine site (perhaps a west coast Vancouver Island site analogous to Cheeka Peak) that would permit short-term variations (chemical weather) and long term trends in “background” concentrations to be identified, particularly in air masses with a trans-Pacific trajectory. The dependence of ozone concentration on elevation and the importance of mid-tropospheric trans-Pacific ozone transport suggest the need to also maintain a high altitude site (Environment Canada already conducts chemical monitoring at Whistler Peak). Finally, strategically located ozone monitors in two or three “clean” sites around the province (again perhaps in major physiographic regions) would assist in determining the spatial impact of local and long-range biomass burning plumes, Eurasian anthropogenic sources and stratospheric intrusions.

Recommended priorities (in order) are:

- (1) Establishment of a long-term pristine west coast baseline site (O₃ and PM_{2.5}, and other atmospheric constituents if possible). West coast Vancouver Island would be an ideal candidate.

- (2) Collaborate with Environment Canada to continue and enhance high-altitude measurements at Whistler Peak, particularly ozone (but other atmospheric constituents as well).
- (3) Establishment of at least two other “clean” interior sites for O₃ and PM_{2.5} (perhaps Interior Plateau, and Northeast).

In addition to the establishment of new monitoring sites, careful data analysis (including stratification of data) from “non-pristine” existing monitoring sites may provide valuable information on the magnitude, variability and source of background concentrations in specific airsheds. By utilising trajectory analyses together with local wind data, it may be possible to identify conditions when background (as opposed to local anthropogenic) sources dominate. The impacts of forest fires on PM_{2.5} and O₃ at the regional scale might also be better defined.

7. SUMMARY AND CONCLUSIONS

In the absence of “pristine” monitoring sites for PM_{2.5} and O₃ in British Columbia, survey of the current literature, together with cursory analysis of available monitoring data, provides an estimation of the likely magnitude, and spatial and temporal variability of background concentrations across the region. In addition, it is possible to identify the likely major sources of short-term variations in background concentrations. These results are summarised in Table 3.

Table 3: Summary of background PM_{2.5} and O₃ concentrations in B.C.

	Estimated Mean Background	Seasonal Range	Short-term Peak Background	Average Contribution to ambient	Trend
PM_{2.5}	2 µgm ⁻³	1-4 µgm ⁻³ Summer Peak	250 µgm ⁻³ Local Forest Fire	25%	little evidence (Jaffe)
Ozone	20-35 ppb ¹	20-35 ppb Spring Peak	40-50 ppb + Trans-Pacific fire plume (15 ppb)	variable (up to 100%)	0.5-2%/year

¹ Vingarzan, 2004a, based on nearby clean sites Olympic Peninsula and Mount Rainier; GVRD 2005

For PM_{2.5}:

- Mean annual background concentrations of approximately 2 µgm⁻³ are low compared to the CWS. They vary seasonally with a summer peak and winter minimum. It is likely that precipitation variability is a major control on background concentrations across the Province. Lower values are likely in wet coastal areas while slightly higher values might be expected in drier regions.
- Local forest fires represent the major and most frequent source contributing to short-term peak background concentrations. (Forest fires in Kelowna during

2003 had peak hourly PM_{2.5} concentrations of 250 µgm⁻³). Episodic trans-Pacific dust transport is rare but has the potential to elevate concentrations by approximately 20 µgm⁻³).

- Mean background concentrations in air masses arriving in B.C. with north Pacific trajectories are of the order of 1.5 - 2 µgm⁻³. This represents a significant proportion of the overall background concentration in B.C..
- There is little evidence of an upward trend in background concentrations. It is likely that background concentrations associated with regional or continental scale transport are decreasing due to abatement strategies in urbanised areas.

For O₃:

- The mean background is estimated to be in the range 20-35 ppb and varies seasonally with a spring maximum. This level represents approximately 50% of the CWS and given short-term variability in background sources, it is likely that the CWS will occasionally be exceeded by either background sources alone, or the additive effect of local anthropogenically generated ozone and background levels.
- There is little evidence that stratospheric intrusions of O₃ rich air contribute to exceedances of the CWS at ground level in B.C. (Bovis, 2001). However this source may contribute 20-40 ppb to short-term peak concentrations (but generally in meteorological conditions not conducive to elevated concentrations associated with local anthropogenic activities).
- Episodic trans-Pacific ozone transport (arising from either biomass burning or the anthropogenic combustion sources in Eurasia) may episodically increase short-term ground level concentrations by 5-15 ppb. In one case this has been shown to lead to exceedance of an 82 ppb 8- hour standard.
- Mean background concentrations show an upward trend of 0.5 -2.0%/year.

Based on these results it is recommended that priorities for monitoring in B.C. should include:

- establishment of a long-term pristine west coast baseline site (O₃ and PM_{2.5}, and other atmospheric constituents if possible).
- collaborate with Environment Canada to continue and enhance high-altitude measurements at Whistler Peak, particularly O₃ (but other atmospheric constituents as well).
- Establishment of at least two other “clean” interior sites for O₃ and PM_{2.5} (perhaps Interior Plateau, and Northeast).

Further information on background concentrations across B.C. may also be gleaned from analysis of existing data (see Appendix for proposed methodologies) and modelling studies.

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APPENDIX – PROPOSED METHODOLOGIES FOR ESTIMATING REGIONAL BACKGROUND FROM EXISTING MONITORING SITES

Atmospheric pollutant monitoring in British Columbia has traditionally focussed on local communities and pollutant exposures arising from the sum of background concentrations and predominantly local sources associated with human activities (e.g. resource industries, transportation). Consequently, the determination of regional background concentrations from monitoring data is usually confounded by local pollutant sources. Although, this report has provided reliable estimates of the likely magnitude of mean background concentrations of $PM_{2.5}$ and O_3 in B.C., it is likely that regional variations in background concentrations exist due to:

- For the case of $PM_{2.5}$: variations in aridity/precipitation, vegetation cover, proximity to oceanic air masses, differing wind climates (that may mobilise and transport fine PM).
- For the case of O_3 : variations in elevation, latitude, biogenic factors, upwind sources. It should be noted that in the regional context in B.C., and away from the primary urbanised areas of the LFV, CRD, and Okanagan Valley, local anthropogenic sources of ozone precursors are less critical in determination of background concentrations. Given that mean background concentrations are reasonably well known, the major issue is the likely impact of stratospheric intrusions on chemical weather long range transport.

Despite the inherent difficulties in extracting estimates of background concentrations from existing monitoring stations, several approaches are proposed that share the common goal of effectively removing the influence of local sources of pollutants. Such methods invariably rely upon the use of other data sources, and in their most sophisticated form include the use of modelling products (some of which may be accessed online) to determine the impact of long range transport.

Proposed Methods

- (1) Surface wind data to remove the influence of local anthropogenic sources:
In locations where monitors are occasionally influenced by a large point or line sources (e.g. a pulp mill or major highway) it is possible to stratify pollutant data by wind speed and direction. Pollutant concentrations from sectors with known upwind anthropogenic sources may be removed from consideration when estimating background values. Standard approaches in order of increasing sophistication include :
 - (a) contingency tables (mean values of pollutants calculated for cells in a grid of wind direction classes by speed classes). Such tables can be represented graphically in a three-dimensional contour plot to illustrate mean concentrations (of say $PM_{2.5}$ or O_3) and to identify concentrations associated with sectors deemed to be relatively “clean”.
 - (b) Pollution wind roses: this widely used approached is a graphical means of representing the data described in (a) and is a variant of the standard wind rose.

Note: in both the approaches described above stability data may also be exploited.

Table 2 Frequency table for post-monsoon Peelamedu

SPM D	0-250 µg/m ³	250-500 µg/m ³	500-750 µg/m ³	50-1000 µg/m ³	>1000 µg/m ³
N	0	0	0	0	0
N-E	0	0	0	5.88	0
E	0	0	0	0	0
S-E	0	20	0	5.88	5.88
S	0	0	0	0	0
S-W	5.88	11.76	5.88	29.41	11.76
W	0	0	0	0	0
N-W	0	5.88	5.88	6.67	5.88

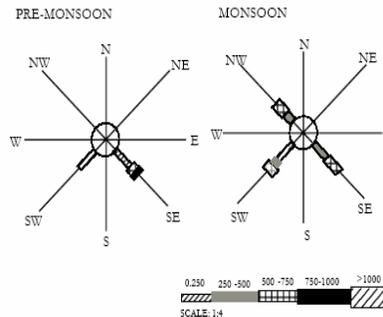


Figure: example of pollutant wind roses from India. Note that instead of the tradition wind speeds plotted on the arms of the rose, frequencies of pollutant concentration classes are plotted.

- (2) Ancillary monitoring data: It may be useful in some cases to use other monitored species (where available) to identify times when local anthropogenic sources (combustion) are active (and thereby exclude such times from estimation of background concentrations) – routinely monitored candidate species include carbon monoxide (CO), NO, NO₂ and SO₂. If such species are all low when PM_{2.5} or O₃ are high, it may indicate natural sources of PM_{2.5} and O₃.
- (3) Time of day/stability may also be used to stratify data into periods when local sources are known to be weak (industry not operating or traffic light) – e.g. early morning but neutral stability.
- (4) Statistical techniques: a variety of multi-variate statistical techniques are available that may exploit all data in 1-3 above in order to identify clusters of data when monitoring data best reflects “background” values. Discriminant analysis, Principal Component Analysis (PCA), and cluster analysis are potential candidate methods.
- (5) Trajectory analysis: at larger scales than implied in (1) backward trajectories using CMC products or Hysplit (<http://www.arl.noaa.gov/ready/hysplit4.html>) may be calculated in order to investigate long range contributions to local pollution burdens. This may also form part of investigation of cases of stratospheric intrusions of O₃. The latter may also involve detailed synoptic (and upper air) analyses.
- (6) Chemistry modelling available online from GEOS-CHEM Near Real Time (NRT) products (http://coco.atmos.washington.edu/cgi-bin/ion-p?page=geos_nrt.ion) or NAAPS aerosol model (<http://www.nrlmry.navy.mil/aerosol/>). These products may be used to identify cases of long-range transport of aerosol and ozone that contribute to chemical weather.

Given that each monitoring station considered in such an analysis represents a unique set of circumstances with respect to its exact location in relation to local and distant sources, the geographic setting, the nature and distribution of sources etc., it is apparent that methodologies adopted will vary from monitoring site to site. Furthermore, to a large degree, the availability of wind and ancillary pollutant data will dictate the methods used and in large part determine the accuracy of the background concentration estimates.

