**Environment Canada**

# Meteorological Summary of the Pacific 2001 Air Quality Field Study

*by*

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# Meteorological Summary of the Pacific 2001 Air Quality Field Study


Abstract

A summary of the meteorological conditions that prevailed during the Pacific 2001 Air Quality Field Study (13-31 August 2001) is presented here. The general region of interest is the Georgia Basin with a focus on the Lower Fraser Valley of British Columbia. This report breaks the duration of the field study into three distinct periods (dry, wet and unsettled) and describes the synoptic scale conditions, low-level flow, back-trajectory analyses and stability conditions associated with each. Areas of further research are introduced which have the potential to improve understanding of the local meteorological conditions, which affect air quality over the Lower Fraser Valley.

# Table of Contents

# INTRODUCTION

For past two decades, attention has been focused on southwestern BC because of its sensitivity to episodes of high ozone (O3), particulate matter (PM) and deteriorating visibility in the summer months. The Lower Fraser Valley (LFV) refers to the part of the south coast of British Columbia which includes the city of Vancouver, and the surrounding communities which extend northward to the Coast Mountains, and the Cascade Ranges to the south (Steyn et al, 1997) and eastward to Hope. The proximity of a large water body such as the Strait of Georgia to the west combined with the narrowing LFV provide favourable geographic conditions for the entrainment and build-up of pollutants. The existence of a large metropolitan centre such as Vancouver provides a good source of mobile and stationary emitters of particulate matter. Thus it is not surprising that this area has the potential to experience elevated pollutant episodes.

In the summer of 1993, the Pacific 93 Field Study was undertaken. The objective of this study was to enhance the understanding of meteorology and atmospheric chemistry of tropospheric ozone  pollution in the LFV (Steyn et al, 1997). Numerous papers emerged from this study, shedding light on ozone formation in the this area (Hayden et al; McKendry et al; 1997). As Li (2000) points out, Pacific '93 involved only limited particulate matter (PM) measurements. To this end, Pacific 2001 was set up to "…provide a better understanding of, and reduce the uncertainty of the sources, formation and distribution of PM and ozone in the Lower Fraser Valley. By obtaining detailed data on particulate matter and ozone, it was expected that this information would be used to develop and evaluate air quality models…". Based on climatological information, it was determined that the Pacific2001 Field Study should span from the middle of August through to the middle of September (Li, 2000). Due to logistical problems, this period was reduced to 13-31 August 2001.

It is well established that there is a close relationship between meteorology and air quality. Indeed, knowledge of meteorology is critical in running air quality models. Moreover, an understanding of the local weather was important in guiding the collection of air quality data within the confines of a field study as short as Pacific2001. During the field study, an on-duty meteorologist was employed to provide guidance on the evolution of wind, precipitation, temperatures, etc. during the course of the 3 week period.

In the wake of the field study it is equally important for the principal investigators to have a detailed meteorological description of what transpired in terms of low level flows, stability conditions and other phenomena. Over the spatial scale of this study, there exist considerable variations in wind direction, speed, stability and to a lesser extent, temperature. Many of these variations can be difficult to detect with a coarse observing network. The purpose of this paper is to describe the overall meteorological pattern and describe how the meteorological conditions affected the air quality during Pacific 2001.

The first part of this report provides a summary of some of the data which was available during the field study. Next, a brief overview will be given of the weather during the entire three week period. This will be followed by an in-depth description of the local meteorology and the role it may have played in the observed air quality. Finally, an introduction to possible future areas of research will be given.

# Data and Method

For the Pacific 2001 Field Study, an enhanced surface and upper air program was established to supplement the existing network over the Pacific Northwest. Measurements of various chemical and meteorological parameters were taken during 13-31 August. Three primary surface field sites were set up:

1. Slocan. Located in a typical suburban setting, surrounded by low-rise residential houses with good exposure in all directions and no major point sources within a radius of 3 km. Traffic in the nearby streets is typical of light volume (Li, 2001).

2. Langley. Located in a transition from urban to suburban/rural, enabling examining the impact of agricultural sources on the particulate matter formation and evolution.

3. Sumas. One of the main goals here was to address the issue of PM and visibility. Located at an elevation of 300m, the site provided good exposure and it was expected that it would offer a good monitoring site for changes from light to dark hours.

These sites measured a variety of chemical species and also were equipped with a set of standard surface meteorological instruments (e.g., measuring temperature, moisture, wind speed and direction). With the addition of an existing network of Environment Canada (EC) and Greater Vancouver Regional District (GVRD) reporting sites across the Lower Mainland there were over 35 surface observations of various parameters.

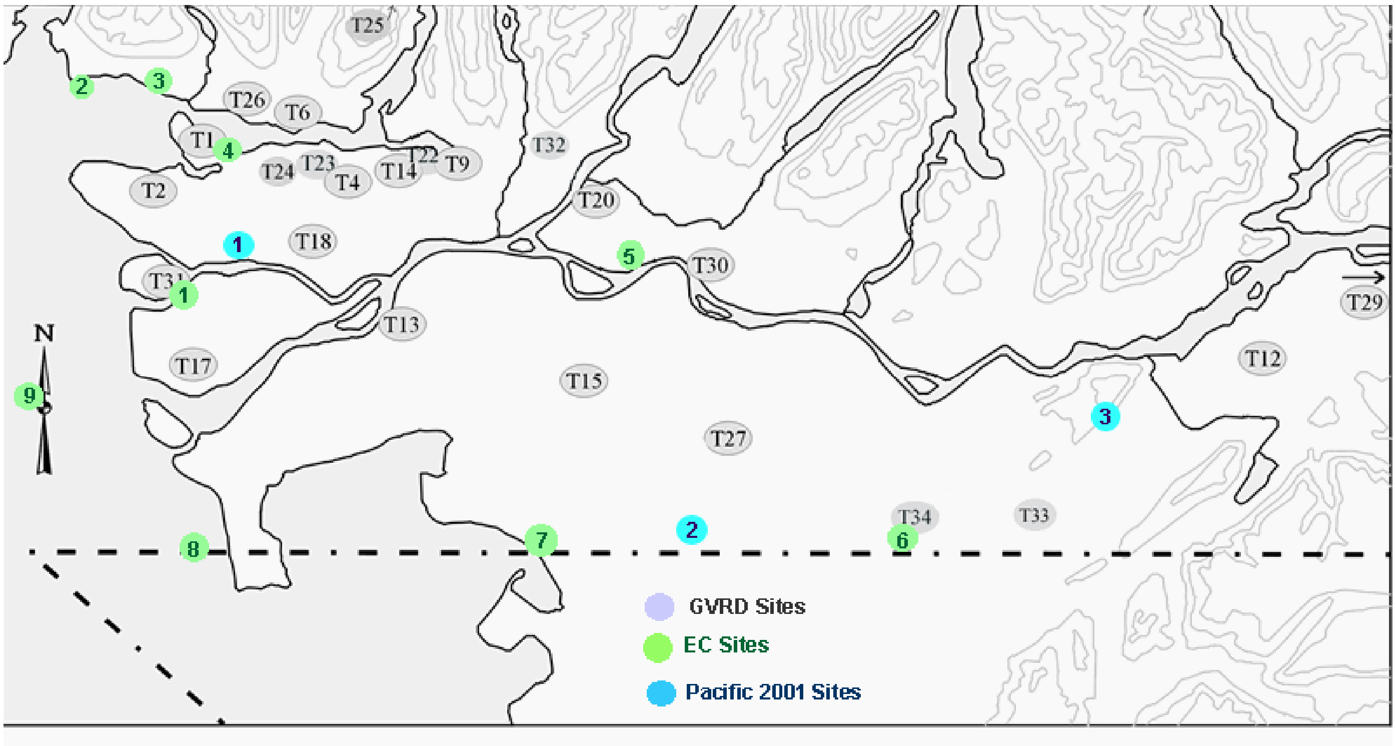


Figure 1. Map showing Pacific 2001 Field Study Sites (blue) along with EC and GVRD stations.

As well as surface observations, 3 radiosonde sites were set up: Esquimalt (southern tip Vancouver Island), Langley, and Chilliwack. In addition to these sites, a tethersonde was set up at Slocan. A ground based Lidar at Langley (Lochiel) and an airborne downward looking lidar was available when weather conditions were favourable.

The radiosondes measured temperature, relative humidity and wind velocity and were launched four times each day (00, 06, 12 and 18 UTC) from 13-31 August. The tethersonde was released on a semi-regular basis from the Slocan site (generally at least twice a day, as close to 00, 12 and sometimes 18 UTC as possible).

These sites represented a dense network of upper air data across the LFV and provided a 3-dimensional picture of the low level flow and stability and in some cases, chemistry across the region. This detailed data made it possible to diagnose mixing heights, stability, prevailing wind direction, etc.

This report utilised surface meteorological data from the EC and GVRD network of observations. Upper air data from the radiosondes (primarily Langley and Chilliwack) and the Slocan tethersonde were also relied on heavily. Surface and airborne lidar measurements were not utilised here but it is expected that future site-specific or event-specific examinations will incorporate this information.

One of the objectives of this report is to examine the relationship between the observed meteorology and air quality. Many studies have looked at O3 and offered definitions of an ozone event (Pottier et al, 1997) or station exceedance (Steyn et al 1990). These terms have generally referred to the occurrence of one or more observations of 1-hourly average ozone concentrations reaching or exceeding 82 ppb. Pacific 2001 was an attempt to study not only ozone but also PM. Therefore, it would be useful to incorporate both PM and ozone when making classifications on the severity of an event. Recently, Canada Wide Standards (CWS) were introduced to consider both PM2.5 and ozone:

| | |
|---|---|
| *$PM_{2.5}$* | *30 µg/m3 averaged over 24 hours* |
| *$O_3$* | *65 ppb average over 8 hours* |

By applying these limits we are in a better position to link so-called significant events to meteorological factors. Ozone data is widespread when compared with PM2.5; only three sites from the GVRD network report the latter whereas the majority measure the former. Classification of an event was done by restricting the study to three PM2.5 sites. Two O3 stations -at or near- the PM2.5 site were then selected. The following list of stations was compiled:

| PM2.5 | | O3 | | O3 | |
|---|---|---|---|---|---|
| T12 | Chilliwack | T12 | Chilliwack | T29 | Hope |
| T20 | Pitt Meadows | T20 | Pitt Meadows | T30 | Maple Ridge |
| T31 | Vancouver Airport | T31 | Vancouver Airport | T17 | Richmond South |

We have a reasonably good appreciation of the frequency of O3 exceedances over the last 15 to 20 years; less is known however about PM2.5 in the GVRD. Preliminary work (Anon, 2002) suggests that for stations at Pitt Meadows and Chilliwack, the percentile ranges for PM2.5 concentrations are well below the CWS. Indeed, the 98th percentile for Chilliwack between 1995-2000 lies slightly above 20µg/m3. For purposes of this study, it may be more appropriate to refine the PM2.5 criterion downward to 20.

An event will herein be defined as follows:

1. PM2.5 meets or exceeds 20 µg/m3 in 24 hours and at least one station reports 80% of the O3 criterion.

or,

2. O3 meets or exceeds the CWS of 65 ppb averaged over 8 hours and the PM2.5 is within 80% of the criterion.

Since the end of the Pacific 2001 Field Study, there were numerous requests for back trajectory analyses. These requests from the PI's were made so that they could get an idea of source regions of air pollutants based on air parcel motion. Attempts have been made to address this issue in this report. From the local scale perspective, observed surface winds and upper air data have been used to characterise the low level flow over the LFV. These analyses allow us to understand the prevailing winds in the boundary layer at 6-hour intervals, taking into account topographic and other influences. In effect, the analyses offer a zoomed in snapshot of the observed wind field.

To address a broader scale demand, CMC model back trajectories have been run for most of the field study period. The advantage of this product is that it offers a larger scale perspective of where the air originated from over a 72 hour period. Having said this, there are some caveats that must be kept in mind when using this product. Firstly, the model horizontal resolution is on the order of 80 km and thus may be too crude to adequately represent the orography of the LFV. Moreover, input data can be sparse and when interpolated over a 60-100 km grid, will not have the accuracy of a local scale analysis. Secondly, these back trajectories must be used in conjunction with local scale analyses and can only be considered rough approximations in time and space (e.g., one could say that over a two day period, air parcels originated from the south). In effect, the back trajectories offer us a zoomed *out* time series of the model's interpretation of the parcel horizontal and vertical motion.

# Climatology of the South Coast of BC

When one understands the significance of local weather patterns, one is in a better position to use this knowledge to understand how weather may affect air quality. There are two key factors, which affect the local weather on the south coast: the first is the topography; the second -which can be linked to the first- is differential heating of the land.

Figure 2 offers an illustration of the complex topography, which characterises the south coast of BC. The mountains and valleys have a tremendous influence on the local wind patterns in this region; indeed, the orientation of the inlets ultimately dictates the possible flow directions for wind in the LFV. The presence of the land/water boundary in addition to the topography means that one may experience marked differences in temperature that can ultimately trigger local circulations.


Figure 2. Map of the Georgia Basin and Puget Sound, with shaded relief to highlight the complex orography.

A typical summertime situation in the absence of synoptic forcing (i.e., strong pressure gradients, large scale low pressure systems) will often lead to a diurnal cycle of daytime sea-breeze (inflow) and night time land breeze or drainage flow (referred herein loosely as outflow). To illustrate this bi-modal behaviour, Figure 3 shows the variation in direction for Vancouver in August. In general, during the daytime, inflow conditions advect more stable, cooler air inland; outflow conditions bring warmer often drier air over the area.

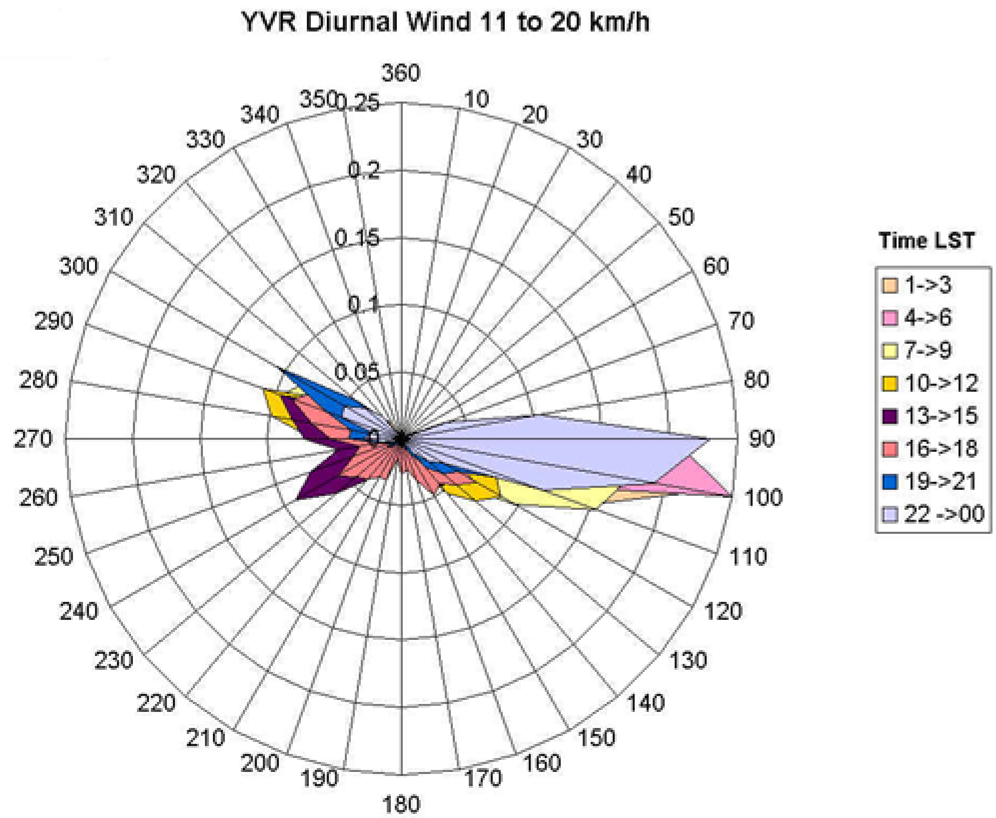


Figure 3. Wind Rose for August at Vancouver International Airport. Colour codes represent 3-hour time periods; the larger the petal, the more prevalent that wind direction during the day.

For Vancouver, the typical directions are westerly in the afternoon and easterly at night. At Abbotsford, wind directions are generally southwesterly in the afternoon and northerly at night. For purposes of this report, we will refer to wind directions ranging (clockwise) from S to NW as constituting Inflow and wind directions ranging from N to SE as constituting outflow.

One can see that a climatological knowledge of the area at the very least helps eliminate unlikely weather scenarios from consideration. If we understand the horizontal direction of flow we are better able to diagnose possible source and sink regions for pollutants. Furthermore, we may be able to assess the degree of mixing in the boundary layer. For example, since inflow conditions are associated with cooler marine air, mixing heights will generally be lower than if there was a warm, dry outflow.

# Meteorological Overview of Pacific 2001

## *Synopsis*

The Pacific 2001 Field Study began at a time when a high amplitude ridge had anchored itself over the Eastern Pacific, resulting in a period of elevated levels of pollutants over the LFV. By 16 August however, marine air invaded the region bringing cloudy and cooler weather and this spelled the end to the relatively poor air quality episode observed until then. Dry conditions still prevailed until 20 August but a well mixed layer had become established helping to better distribute pollutants. By this time the ridge had given way to an intensifying low pressure area moving south across the Gulf of Alaska and toward the Central Coast of BC. The associated frontal system spread rain onto the south coast on Tuesday 21 August and rain continued for three more days. Amounts of between 40 and 100 mm fell across the LFV during a 31/2 day period. Following the wet period, the weather pattern never re-established itself into one in which elevated levels of PM or ozone could be expected. Instead, the remainder of Pacific 2001 saw a more dynamic regime evolve; one where minor impulses (short wave troughs and ridges) moved across the south coast. There was virtually no rain for the remainder of the period; high temperatures managed to climb into the low to mid twenties by 26 August and hovered near this mark through the end of the month.

Effectively, there were three regimes during Pacific 2001: a Dry Period; a Wet Period; and an Unsettled Period. The following is a detailed summary of the meteorology that transpired during these periods. This will include a discussion of the synoptic weather pattern, an analysis of the mixing heights, and a brief description on the observed O3 and PM.

## *Dry Period*

The synoptic pattern during the dry period can be subdivided into two phases: a stagnant phase and a well-mixed phase.

### i) Stagnant Phase

The stagnant phase that evolved just prior to the start of Pacific 2001 could be described as typical of an ozone episode (Taylor 1991). On 10 August, the 500 hPa ridge built northward along the coast, between 120 and 130 W and a thermal trough –axis of warmer surface temperatures- developed along the Washington coast.

The ridge began to weaken somewhat, and a broader axis lay near or just east of 120W by 12 August. Meanwhile the thermal trough also migrated eastward, lying east of the LFV by the $11^{th}$. The ridge sharpened and retrogressed slightly on the afternoon of the $13^{th}$, whereas the thermal trough remained east of the LFV.

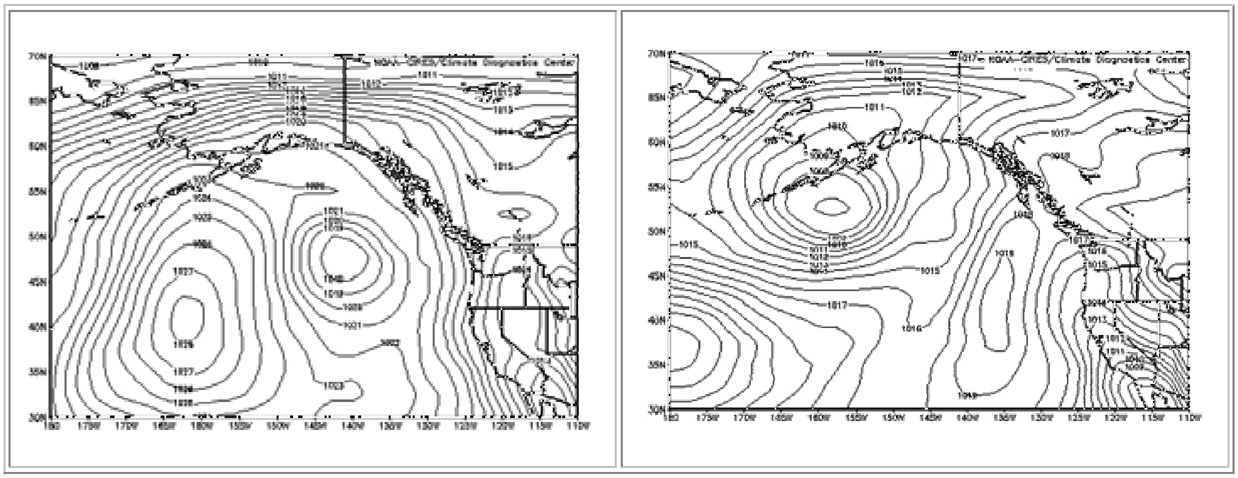

Figure 4a. Mean Surface Pressure field for 9-14 August 2001 (left) and 1-5 September 1988 (right).

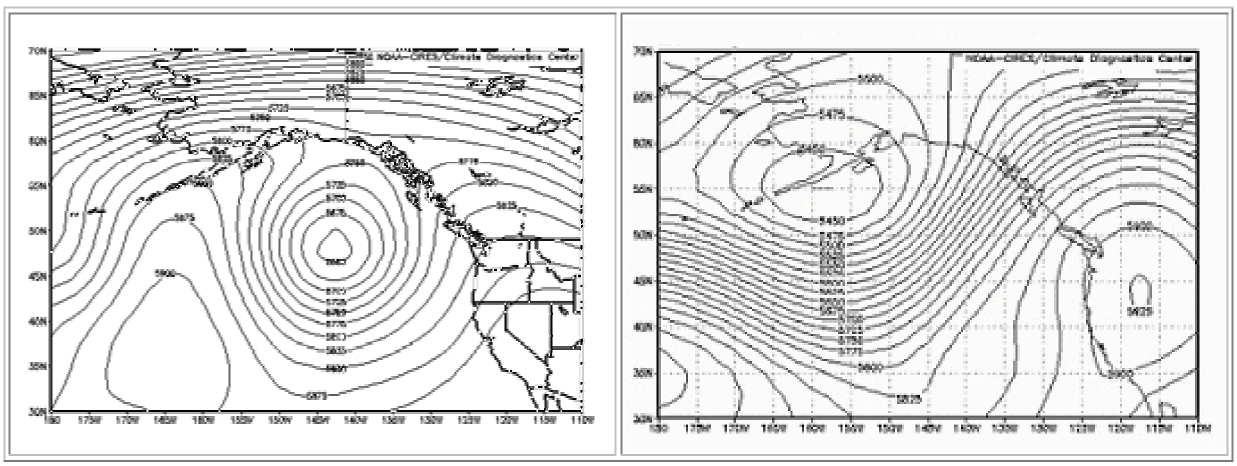

Figure 4b. Mean Upper Level Pressure (500 hPa) charts for 9-14 August 2001 (left) and 1-5 September 1988 (right).

If we compare the synoptic pattern during this period to others characteristic of extreme ozone episodes (e.g., Figures 4a and 4b, for September 1988), it is clear that the 2001 example was not as strong. Nevertheless, it still bears some resemblance to the conceptual model that has been established (Taylor 1991 and Steyn 1990) for ozone. What is interesting is that the thermal trough had moved east of the region before many sites reported their maximum reading of O3. This runs contrary to the findings of McKendry (1994) who postulated that with the thermal trough developing west of the region, this suppressed the sea breeze circulation, hence reducing ventilation and creating favourable conditions for pollutant build up. One could speculate that because this was not as extreme an episode as those described by McKendry, the model does not strictly apply here.

Based on observed GVRD O3 and PM2.5 concentrations, a case can be made for classifying the 10-13 August period an episode (refer back to the guidelines introduced earlier). If one looks at the variation of O3 during the field study, we see relatively high levels of ozone during the first week. While this shows 8-hour running mean values, the hourly data indicate O3 values peaked on 12-13 August at many sites.

The variation of PM10 showed a similar period of relatively high levels through the start of the study and then a decrease after the 15th. The 6-hourly running mean concentrations peaked at a number of sites between 9-10 August (prior to thermal trough passage eastward); secondary maxima were observed on 14-15 August at many sites (post thermal trough passage). It is worth noting that the PM10 data showed considerable diurnal variation and that many of the peaks occurred one or two hours after sunrise. This may be an area for further study. Meanwhile, from the limited data available, PM2.5 values peaked on the 12th.

McKendry (2000) demonstrated that on daily time scales there is at best, a weak correlation between O3 and PM10 during the summertime, suggesting that the meteorological forcings at this time scale are different. Notwithstanding issues at this time scale, the general model of blocking ridge, subsidence inversion, light winds and high temperatures should apply to elevated levels of PM as well.

During this period, mixing heights were suppressed throughout the day (below 1000m) in the midst of a subsidence inversion. The local flow pattern was characterised by inflow (flow from the water to land). Meanwhile, large scale back trajectories suggested 72 hour paths originating from the northwest (i.e., Johnstone Strait to Strait of Georgia).

Piecing these two elements together offers the following picture: air parcels affecting the lower mainland originated from the northwest and travelled through the inner Straits. Local scale forcing steered the air eastward up the valley.

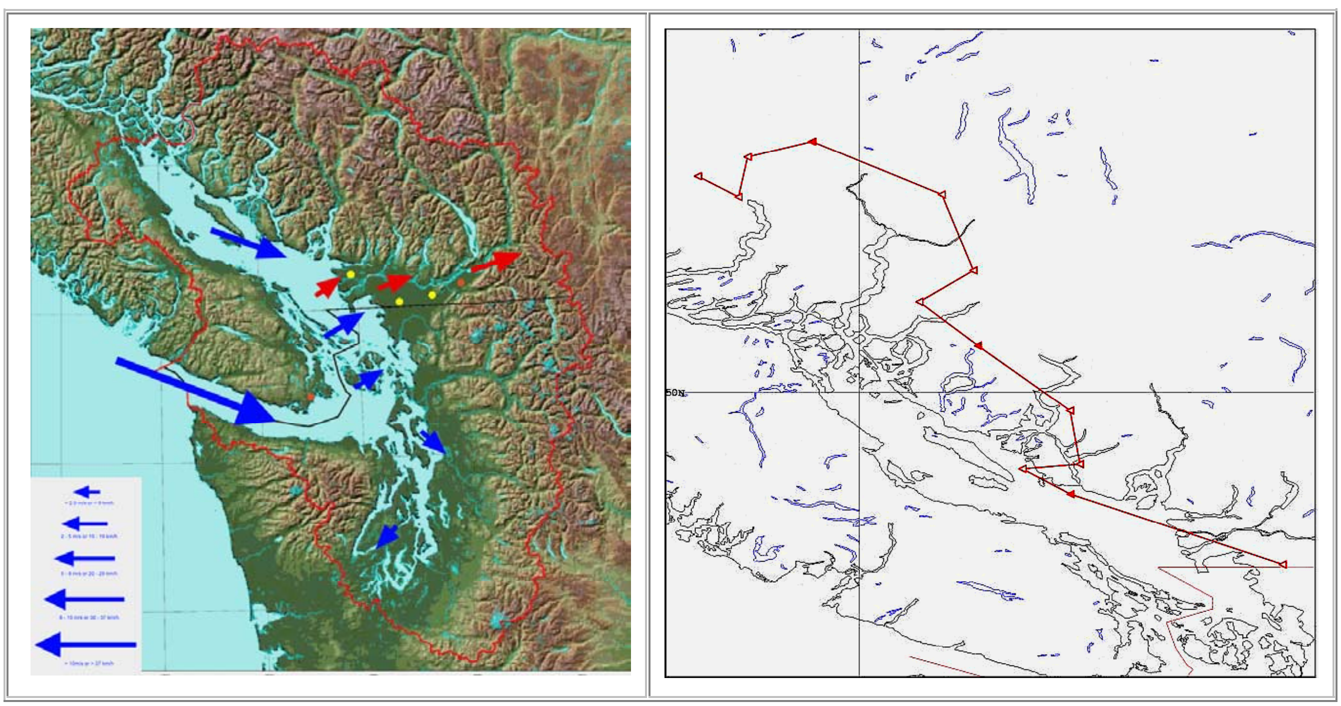

Figure 5. a) Observed Flow Pattern for the afternoon of 14 August 2001; b) Back trajectories valid from the evening of 14 August 2001 for Langley.

## ii) Well-mixed phase.

By 16 August an incursion of marine cloud affected the region – a typical scenario for the end of an ozone episode. This cloud had made its way into many parts of Puget Sound a few days prior to the LFV. In terms of PM and Ozone, concentrations peaked prior to this and showed a steady decline during the remainder of this phase.

Mixing heights rose during this phase. During the afternoon, heights rose above 1500m across most of the LFV. There were two occasions during the field study when the nocturnal inversion did not develop and one of these occurred on the morning of the 17$^{th}$ when the ridge began to weaken.

Analysis of the local scale flows between 16-17 August suggests a moderate outflow predominating except for weak inflow in the late afternoon hours. This coincided with large scale back trajectory output showing parcels originating from the west, moving through the Strait of Juan de Fuca. At first glance this may appear at odds with a general outflow scenario - a closer inspection indicates otherwise. Effectively, the orography dictates that the flow coming up from the Strait of Juan de Fuca will back from west to southeast or even to the east as it approaches the Vancouver area (Lange 1998). This then is not inconsistent with the outflow signals from observations. It is interesting that the back trajectories indicated a change in flow from the northwest to the west at about the same time as the stratus eventually made its way into the LFV.

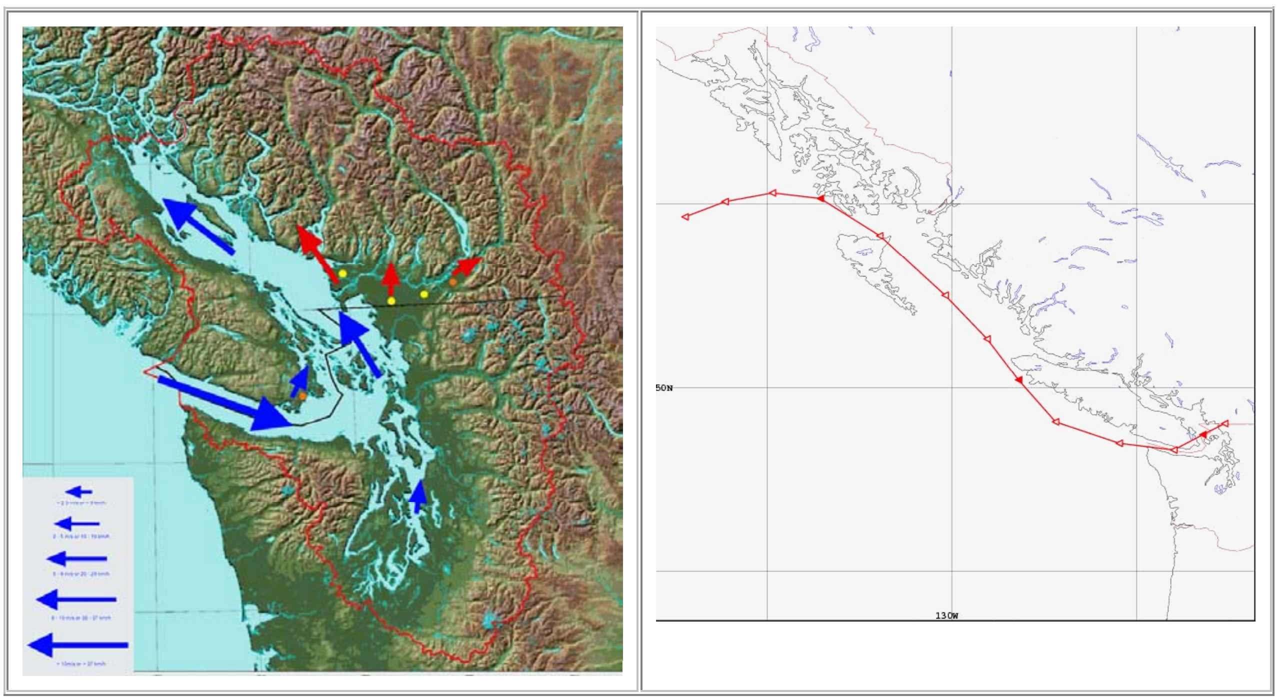


Figure 6. a) Observed Flow Pattern for the afternoon of 16 August 2001; b) Back trajectories valid from the evening of 16 August 2001.

For the remainder of this phase, the local flow pattern showed a light to moderate outflow/inflow cycle. Back trajectories shifted from the southwest to the west; model output showed parcel trajectories further a field by the 19th indicative of a stronger flow from the Pacific.

## *Wet Period.*

The Wet Period spanned 21-24 August. If the stratus intrusion on 16 August did not mark the end to bad air quality, 31/2 days of rain effectively did. Precipitation was widespread throughout the LFV with the bulk falling between 21 and 22 August.

Mixing heights fell off with the commencement of the rain, but began to increase on the 24th in the wake of storm. A moderate to strong outflow prevailed during this time. Large scale back trajectories show parcels originating from the south.

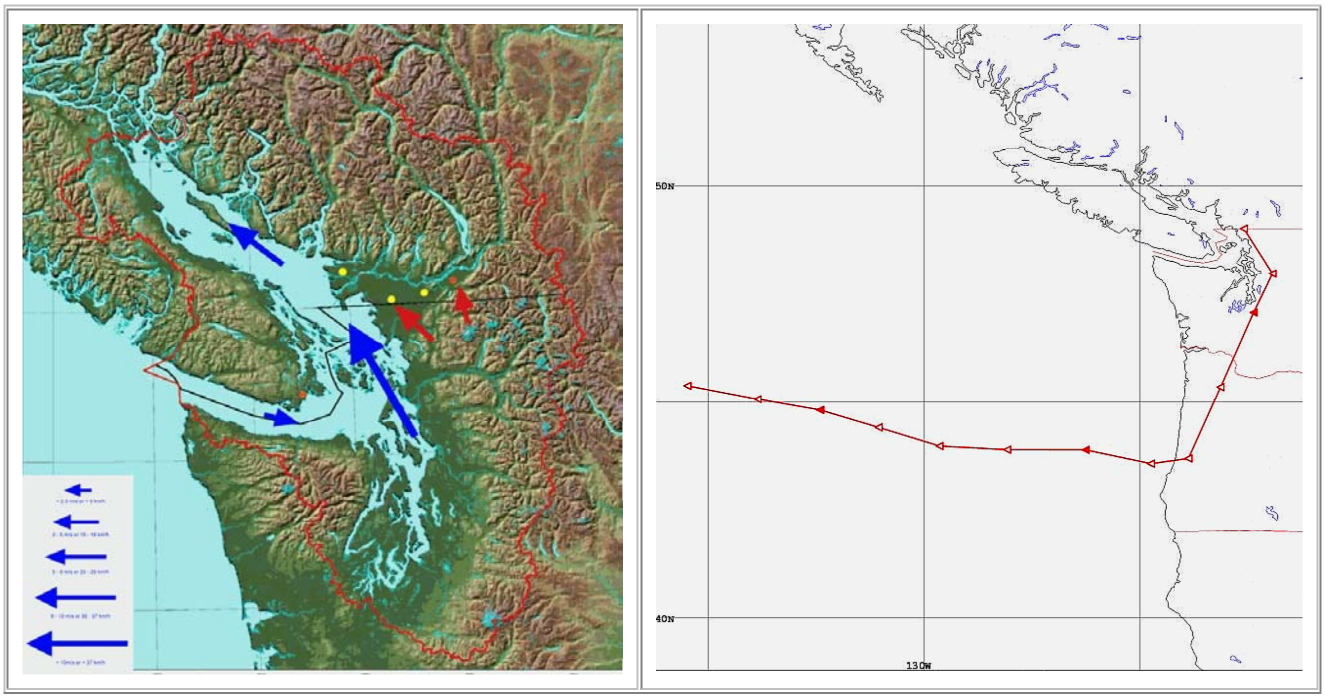


Figure 7. a) Observed Flow Pattern for the morning of 22 August 2001; b) Back trajectories valid from the morning of 22 August 2001.

## *Unsettled Period.*

This period spanned 25-31 August and although relatively dry, did not exhibit the strong blocking pattern conducive to elevated pollutant episodes. Indeed, the pattern was relatively dynamic when compared with the first week of the study. GVRD data indicated PM10 peaks between 25-30 ug/m^^3 on 28 August. Hourly O3 values peaked close to 50 around the same period.

The last week of the month was characterised by the passage of a major trough early in the period and then a second minor trough toward the end. Before and after each trough passage, a ridge tried to establish itself over the region

## i) Major Trough Phase: 25-28 August

Just prior to the start of this period an upper level trough had left a deep, well mixed layer over the LFV. This deep well-mixed layer gradually became suppressed as a ridge of high pressure built. The ridge peaked in amplitude on the afternoon of the 26th.

After a weak upper level impulse moved through on 27 August, a more significant feature crossed the region on the morning of the 28th; the associated surface cold front swept across the valley early in the morning. Cooling in the upper levels, more instability and rising mixing heights accompanied the frontal passage. In fact, there was little if any sign of a nocturnal inversion on the morning of the 28th. Aside from 3 mm of rain being reported at Vancouver Airport, most other stations reported nil precipitation.

In terms of low level flow direction, this phase began with decreasing outflow in the morning. By the afternoon of the 26th, a well pronounced inflow was established. A slightly weaker outflow – inflow cycle repeated itself on the 27th. Flow over the Strait of Georgia was generally northwesterly at the start of the period but by the afternoon of the 26th, a southerly flow prevailed. By 28 August, in the wake of the cold front, a moderate northwesterly flow over the Strait predominated.

Large scale back trajectories showed a gradual shift from the south-southwest to more westerly through the Strait of Juan de Fuca during this time.

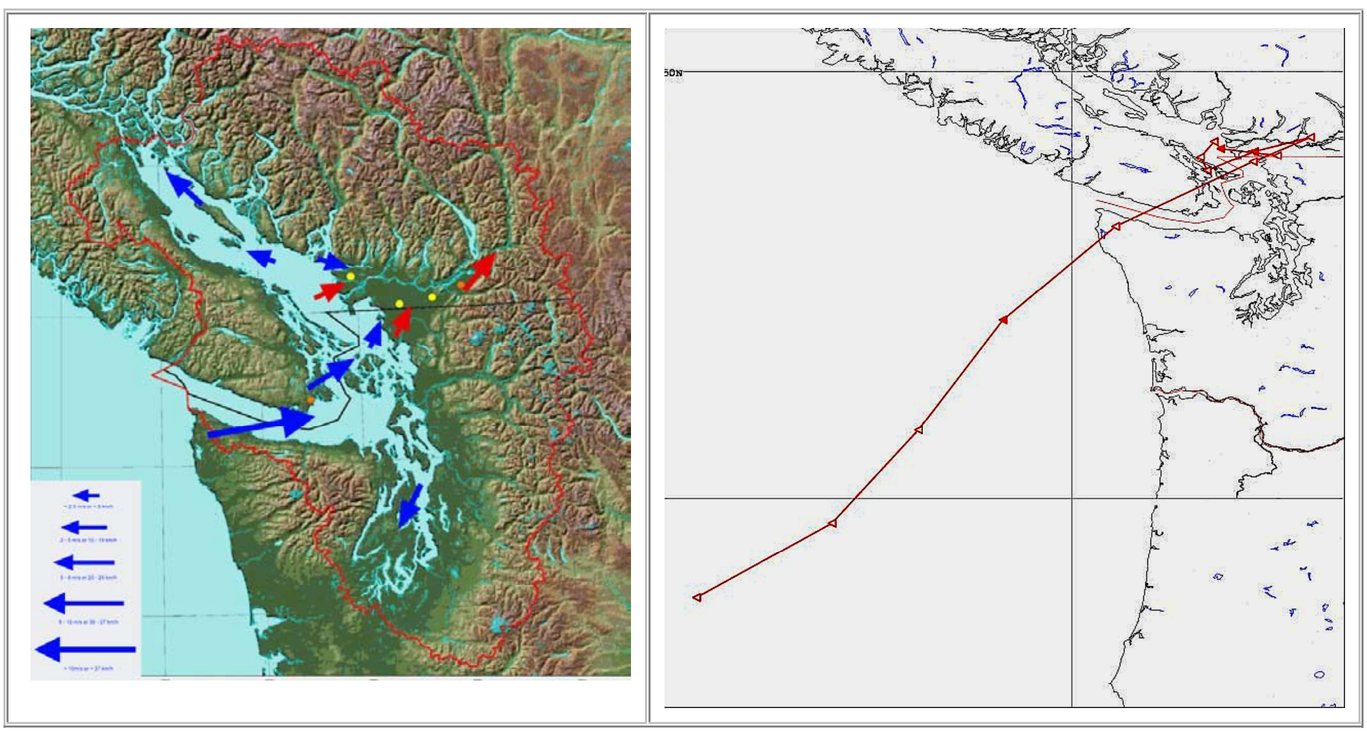

Figure 8. a) Observed Flow Pattern for the afternoon of 26 August 2001; b) Back trajectories valid from the evening of 26 August 2001.

## ii) Minor Trough Phase: 29 August – 01 September

The final phase - transient still - was again characterised by trough-ridge couplets. The passage of the cold front was followed by a weak ridge rebuilding on the 28th and falling mixing heights by the 29th. The ridge broke down on 31 August leading once again to higher mixing heights.

The local flow pattern was characterised by a moderate to strong sea breeze signal on 29 August. By 30 August, a weak outflow signal developed and continued on the 31st. Back trajectories showed parcel origin shifting from the west to the northwest.

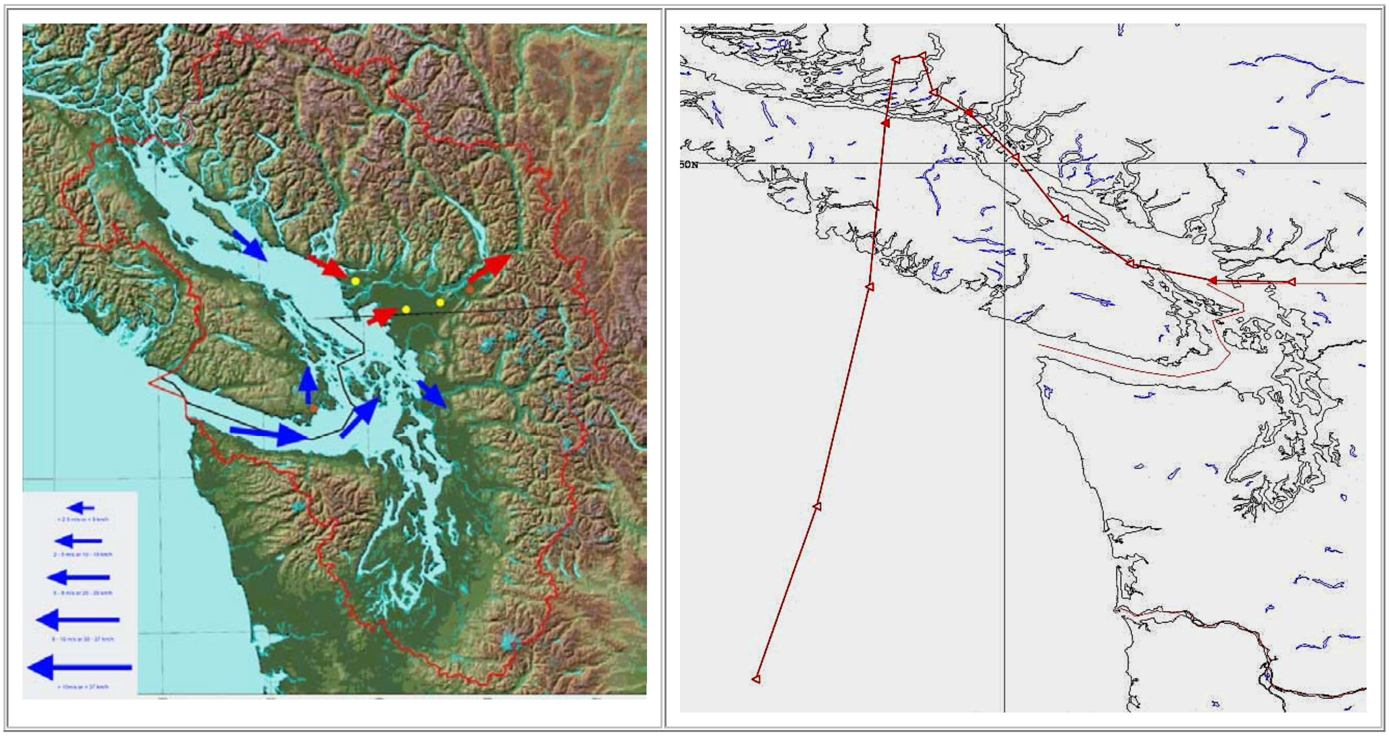

Figure 9. a) Observed Flow Pattern for the afternoon of 29 August 2001; b) Back trajectories valid from the evening of 29 August 2001.

## *Meteorological Summary*

A detailed examination of the low level flows has been prepared for participants of Pacific 2001 (internal document). A shortened version of this has been produced below, which incorporates the key elements discussed in the previous sections.

Table 1. Summary of Observed Flow pattern and Mixing Height Data for Pacific 2001 Field Study Period.

| Day | General description of significant meteorology |
|---|---|
| 13 | Moderate to strong daytime sea breeze signal. Mixing heights between 500 and 1000m. |
| 14 | Same scenario |
| 15 | Same scenario |
| 16 | Marine cloud invades; more outflow in the morning. Weak afternoon sea breeze. Mixing heights rising. |
| 17 | Same flow scenario; mixing heights non-zero in the morning, rising above 1000m in the afternoon. |
| 18 | Marine cloud dissipates. Slightly weaker outflow in the morning; light to moderate sea breeze in the afternoon. Mixing heights > 1500m |
| 19 | Moderate sea breeze in the afternoon. Mixing heights > 1500m. |
| 20 | Light to moderate outflow morning; light to moderate inflow afternoon. Mixing heights higher. |
| 21 | Moderate to strong outflow signal throughout the day; mixing heights 1000 to 1500m |
| 22 | Same flow scenario. Wet. |
| 23 | Same flow scenario. Wet. |
| 24 | Moderate outflow becoming light inflow in the afternoon. Clearing late. Mixing heights > 1500m. |
| 25 | Light to moderate outflow becoming moderate inflow. Ridge building, mixing heights falling. |
| 26 | Strong sea breeze signal. Mixing heights less than 1000m. |
| 27 | Less sea breeze signal. Short wave trough moves through in the evening. Mixing heights rise to above 1500m. |
| 28 | Return to stronger sea breeze signal; cold frontal passage early in the morning. |
| 29 | Slightly weaker sea breeze. Mixing heights near or below 1000m. |
| 30 | Light outflow > light inflow. Mixing heights above 1500m. |
| 31 | Light outflow. High mixing heights. |

## Graphical Summary of Boundary Layer Winds

The following summarises the low level winds (average winds within the mixed layer) from the Langley and Chilliwack upper air sites during the Dry Period and the Unsettled Period. (These can be interpreted as follows: the total length of each 'petal' is indicative of the relative frequency of that direction; for a given wind direction, each colour represents the relative proportion of wind speed ranges. Wind speeds are in 2-knot ranges with the maximum range greater than 11 for all cases.)

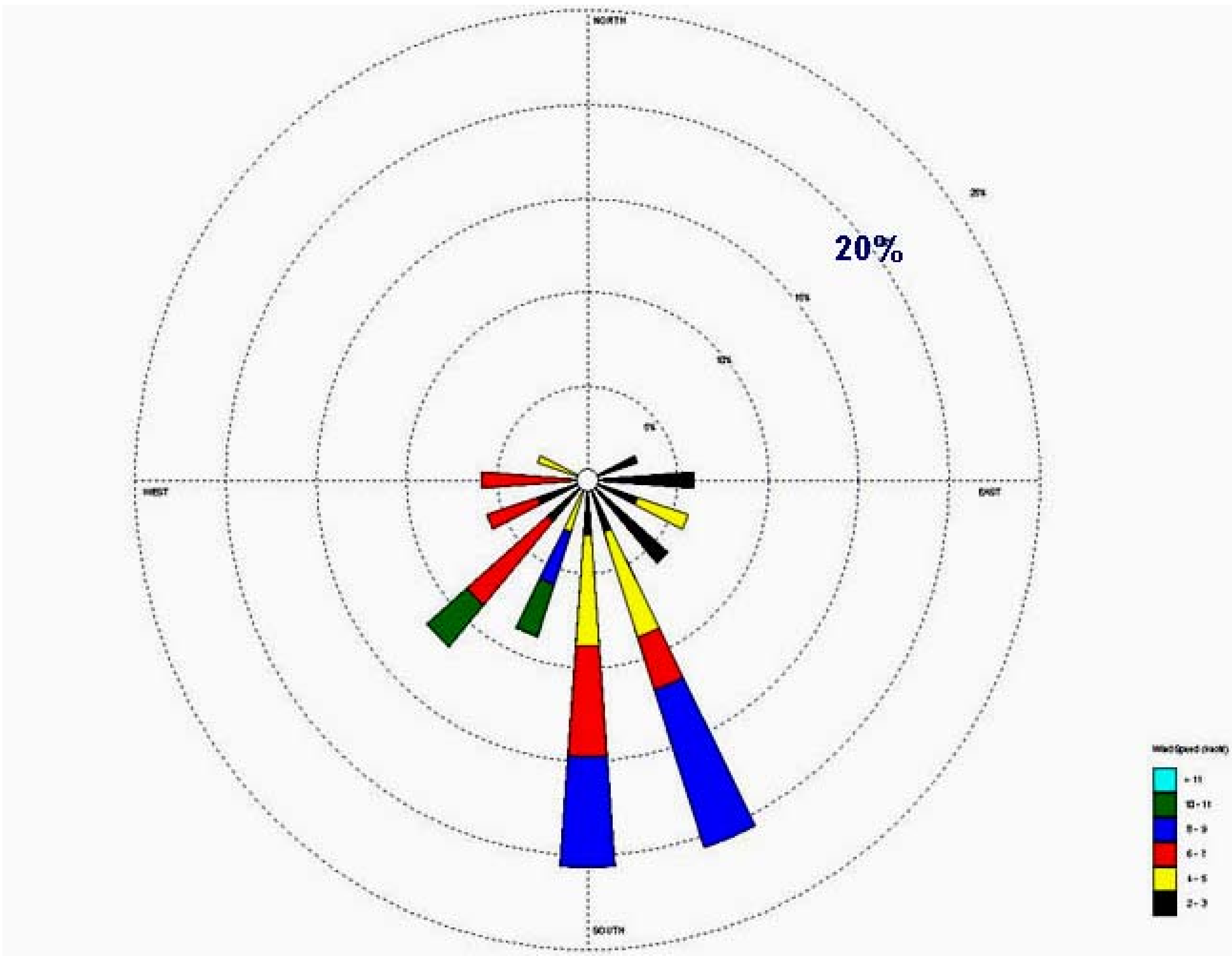


Figure 10 a). Wind rose plot for Langley during Dry Period.

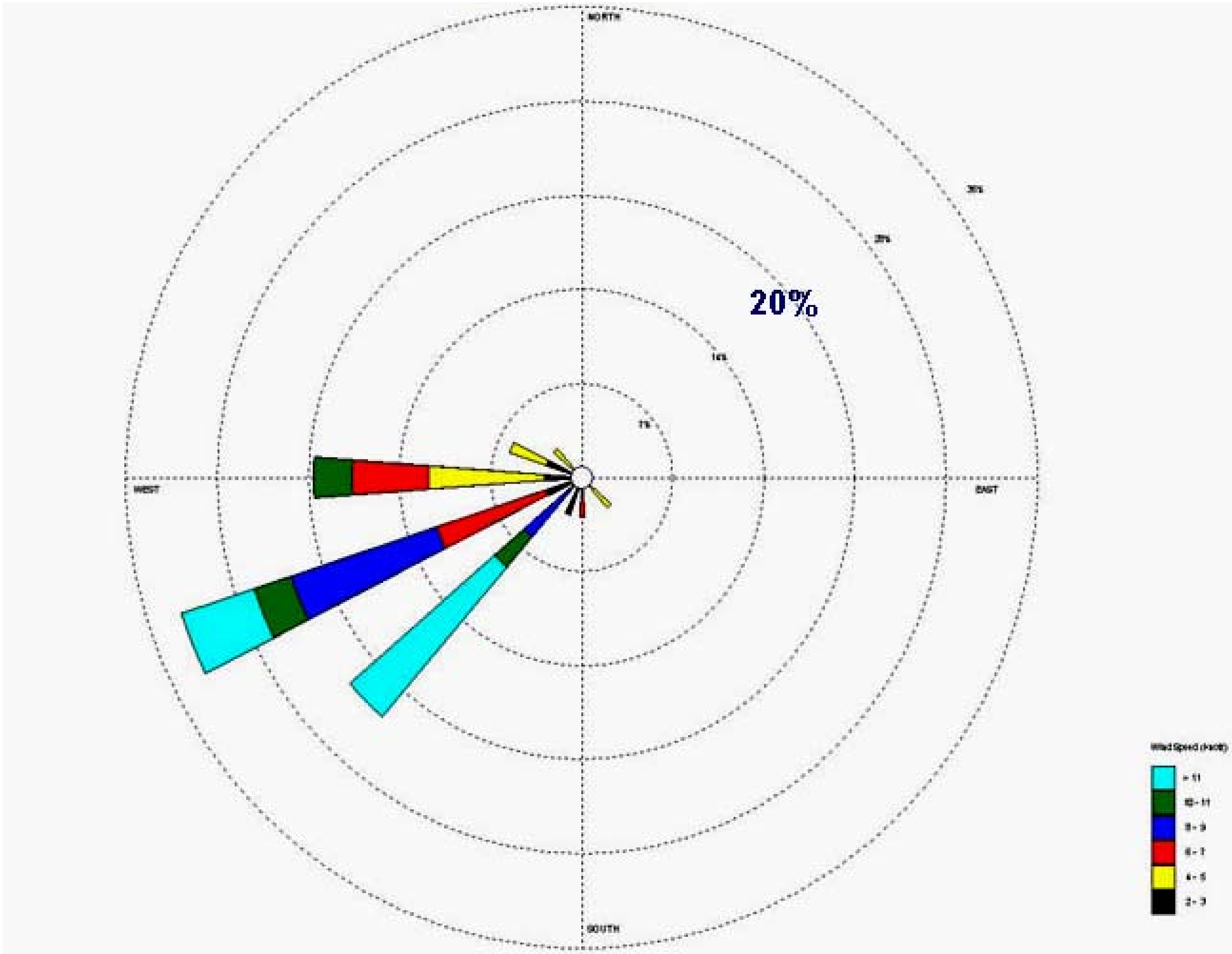


Figure 10 b) Wind rose plot for Chilliwack during Dry Period

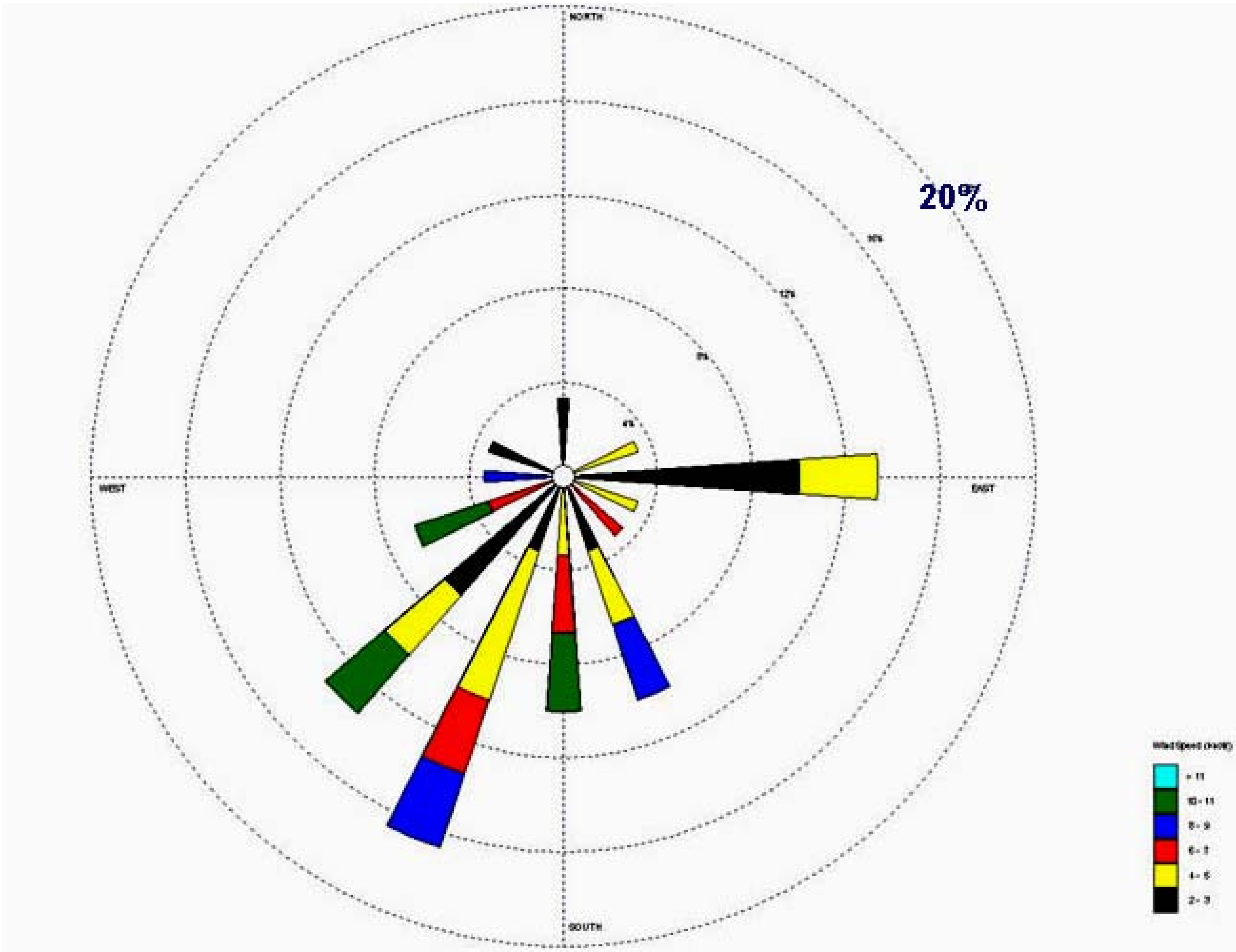


Figure 11 a). Wind rose plot for Langley during Unsettled Period

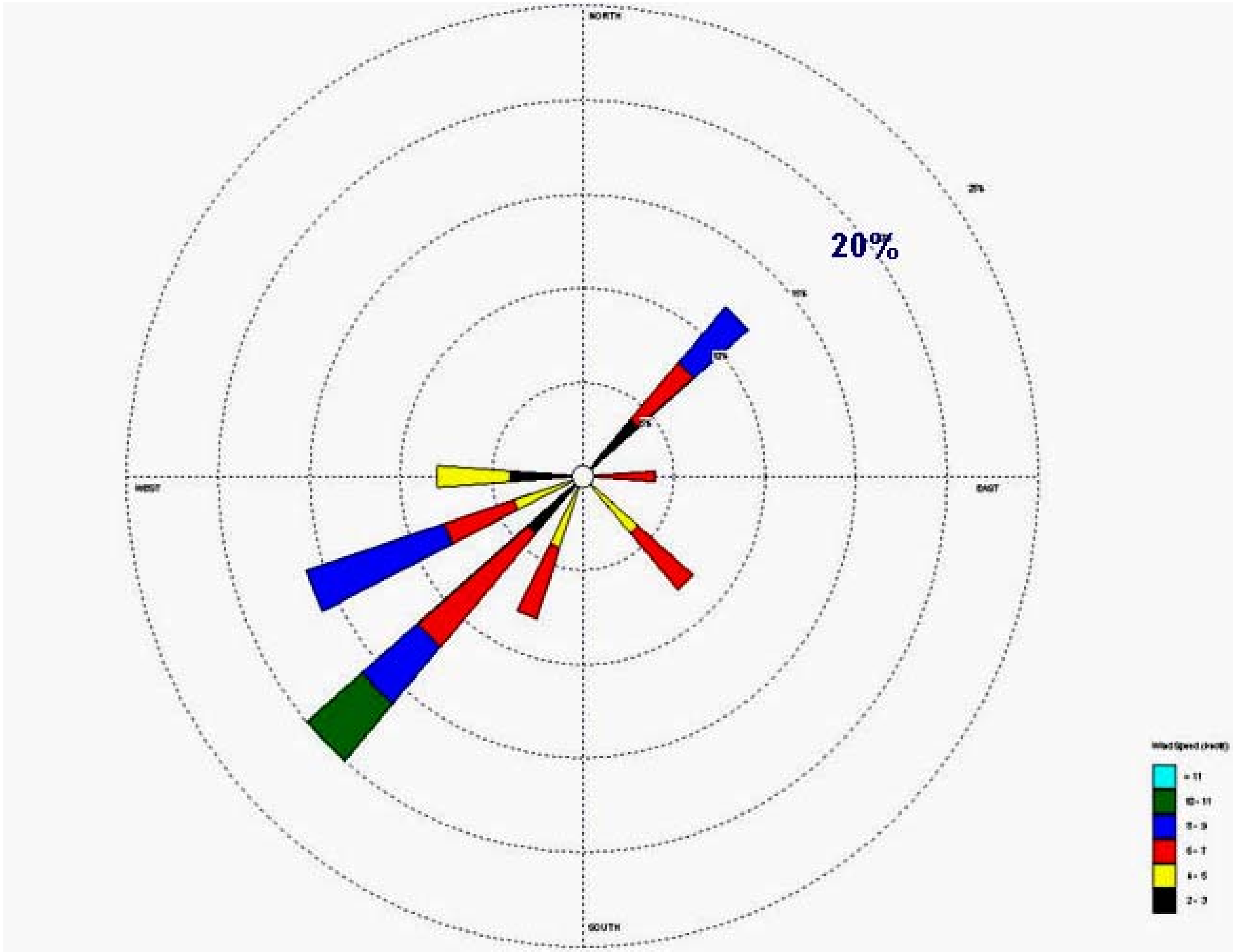


Figure 11 b). Wind rose plot for Chilliwack during Unsettled Period

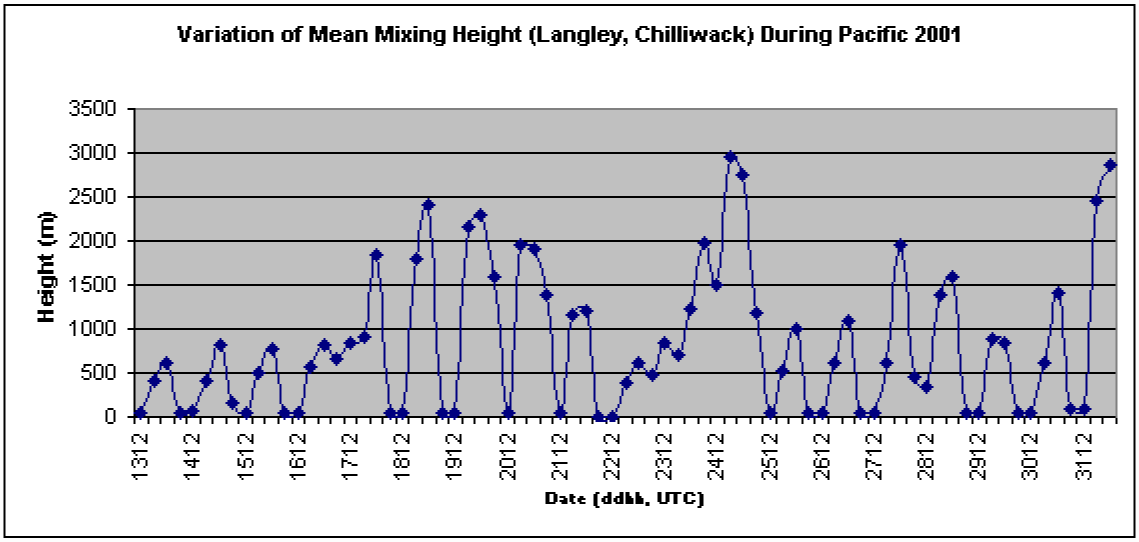


Figure 12. Summary of average of mixing height from Langley and Chilliwack at 6 hour intervals.

# AREAS FOR FURTHER RESEARCH

The detailed data from the Pacific 2001 field study has allowed for a comprehensive summary of the prevailing meteorological conditions to be prepared. Furthermore, it has highlighted areas which would benefit from more detailed investigation. The following introduces a few such areas which may be worthy of more research.

## *The Role Strait of Georgia – Gulf Islands as a Pollutant Reservoir*

Since the early 1990s there has been some discussion regarding the role that the Strait of Georgia – Gulf Islands (SGGI) area plays as a ‘reservoir’ or holding area for pollutants. One hypothesis is that a sea breeze return circulation transports pollutants aloft back over the water.

Lu and Turco (1994) described how local factors play a role in creating elevated pollutant layers over southern coastal California. Following this work, McKendry and Steyn (1997) described how pollutants can be trapped aloft over the LFV. In the absence of synoptic forcing, and given strong surface heating, favourable inflow conditions will develop in the afternoon. The unstable boundary layer can then lead to pollutants being vented aloft into the entrainment layer (e.g., elevated inversion layer). This is further enhanced by the presence of mountains surrounding the Fraser Valley. The authors describe how these pollutants can be mixed downward the next day as the mixed layer redevelops, leading to an early morning spike in (for example) ozone.

It is also possible that these pollutants may be entrained in the return circulation of the sea breeze, thus transporting material sea-ward (Figure 13a). Given the geography of southwest BC, one might see such a scenario taking place not only over the LFV but also Vancouver Island. Perhaps an even more common scenario is that of (night-time) drainage acting to transport pollutants trapped below the inversion layer, sea-ward (Figure 13b).

A second hypothesis for a build-up of pollutants over the SGGI is that of low level convergence. As we have alluded to earlier, it is quite common to have northwest winds through the Strait of Georgia and southeast winds coming up from the San Juan Islands. Ultimately, these two flows converge and/or weaken (Figure 13c). This line of convergence will translate northward and southward depending on the strength of the respective flows through the Straits but has been found to lie across the Gulf Islands in a northeast-southwest orientation. Given source regions of pollutants from the south or from the north, the low level flow converging over the Strait could contribute to elevated concentrations here.

It is unlikely that these mechanisms would be coincident in time and space. Certainly the occurrence of strong low level convergence and a sea breeze circulation would tend to counteract one another. Diagnosing one of these mechanisms at work though, does raise the possibility of the SGGI acting as a reservoir for pollutants. Indeed, during the field study one could observe a relatively thick haze layer over the Strait on 26 August. If this area can be a holding area for pollutants, it may subsequently act as a 'source' region for the LFV given favourable inflow conditions.

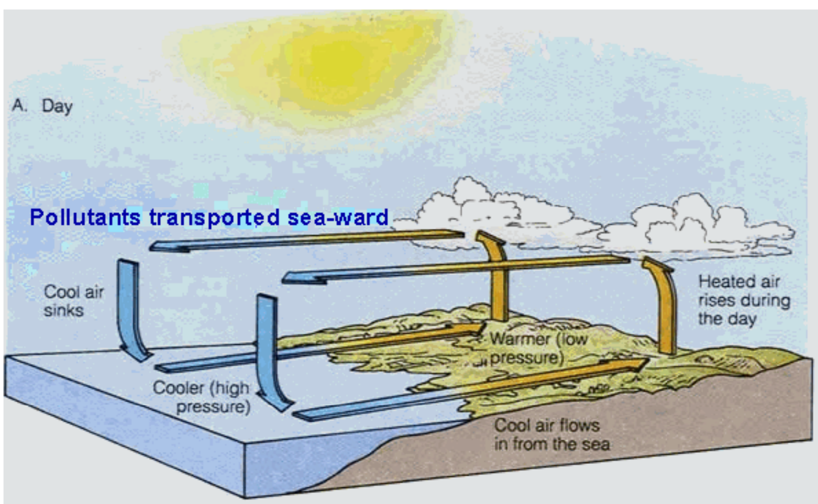


Figure 13a. Schematic representation of daytime Sea-Breeze circulation showing how air ascends over land and subsequently moves sea-ward.

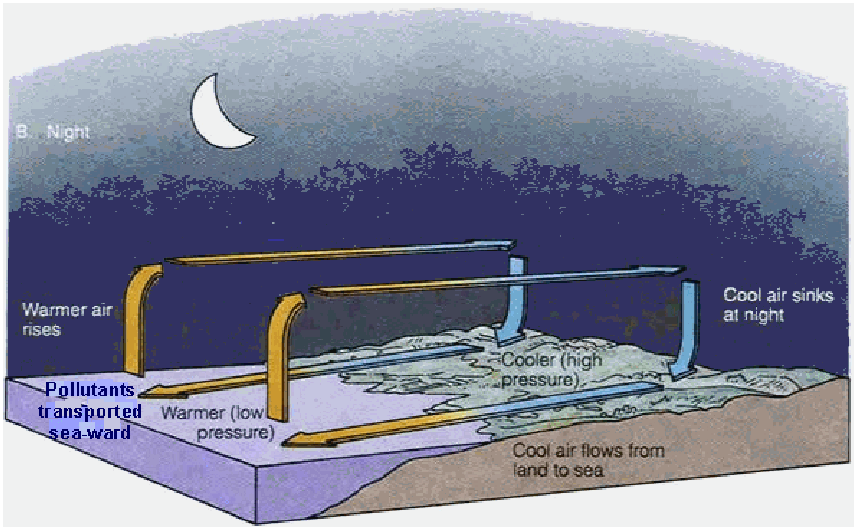


Figure 13b. Schematic representation of night time Land-Breeze circulation showing how air descends over land and subsequently moves sea-ward.

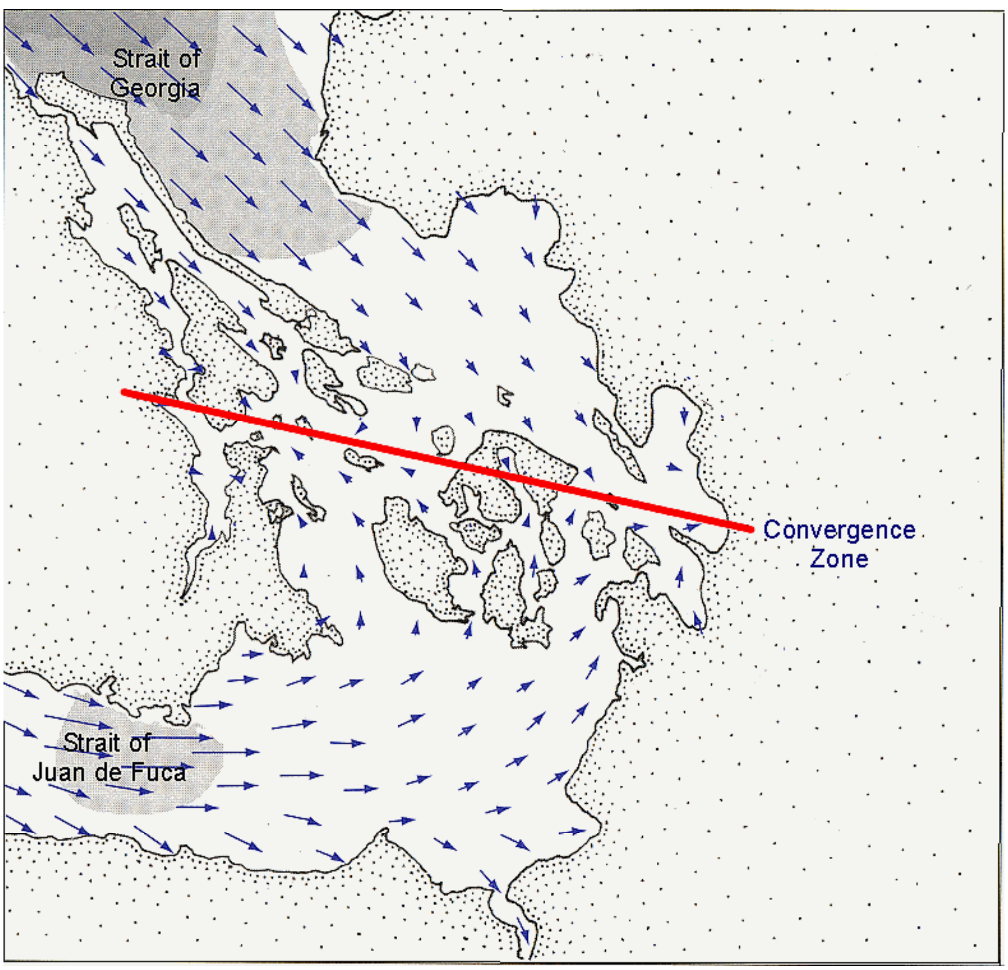


Figure 13c. Schematic representation of Low Level Convergence over SGGI.

Many of the principal investigators discovered curious spatial and temporal patterns in the chemistry data during the last week of the field study. One such development was observation of a lag in peaks of SO4 concentrations at Saturna and inland stations. There has been some speculation that the SGGI may have played a role as a 'source' for pollutants inland. An in-depth investigation into this period would prove worthwhile if only to examine the relationship between meteorology and air quality under these common, more 'benign' conditions

### *Mixing Heights and the Sea Breeze*

It is generally understood that a well developed sea breeze will have the effect of reducing mixing heights on affected inland areas. Meanwhile, lower mixing heights can lead to increased pollutant concentrations. However, it does not necessarily follow that the stronger the sea breeze signal, the more likely one is to observe higher pollution. Indeed, the sea breeze may have the opposite effect by increasing dispersion and by entraining potentially cleaner air from the water.

The presence of the sea breeze is an indication that there is strong surface heating taking place as well as weak synoptic scale forcing. These conditions are consistent with the presence of a large scale ridge of high pressure which is responsible for subsidence and lowering mixing heights.

As alluded to earlier, many studies have related the presence and location of a thermal trough to ozone episodes. It has been shown that a weak or flat thermal trough near or west of the LFV is conducive to moderating the sea breeze while conditions still remain favourable for suppressed mixing heights. Thus, a balance between a weak sea breeze signal and low mixing heights are key ingredients for ozone (and potentially other pollutant) build-up. In terms of a predictive tool, it may be difficult to objectively locate or assign a strength to the thermal trough. The strength of the sea breeze on the other hand more explicitly describes the flow and would prove to be a more useful measure.

The relatively high resolution upper air sounding network along with surface and airborne lidar offer us an opportunity to investigate the interaction between the mixed layer and the sea breeze. From this we may be able to gain a better understanding of the role the sea breeze plays in the air pollution problem over the LFV. Moreover, the field study data will allow us to compare mixing heights derived from soundings with those derived from lidar. From this, we may also evaluate mesoscale model derived mixing heights.

## CONCLUSIONS

Pacific 2001 has provided an opportunity for scientists to better understand the formation and distribution of PM and ozone in the Lower Fraser Valley. Because of the close linkage between meteorology and air quality, an understanding of the former is an important step in understanding the latter. To that end, this report has presented the following meteorological information:

- Description of the prevailing synoptic scale weather pattern and its relationship with existing conceptual models for O3 and PM.
- Characterisation of the low level flow, including both local scale winds (e.g., inflow, outflow) and back trajectory output.
- Description of vertical mixing and wind speed for dispersion potential.

The first week of the study revealed a similar pattern to the conceptual model formulated for ozone episodes. This general model (multi-day time scales) may be applied for to PM as well. The breakdown of the stagnant phase and rising mixing heights resulted in lower concentrations of Ozone and PM. However it was noted that the timing of the end of the episode vis a vis the strength and movement of the thermal trough did not necessarily correspond with classical patterns. Given the sometimes vague identification of a thermal trough, we believe that more emphasis should be placed instead on the strength of the sea breeze or inflow/outflow within the conceptual model.

After three days of wet weather, the last week of the field study brought with it a transient weather pattern – something more common to the west coast than a high amplitude blocking pattern. During this time, we saw a good deal of variability in mixing heights and low level flow conditions. This led to interesting spatial and temporal variations in air chemistry over the LFV which has begged the need for further investigation.

The observed flow patterns highlight the subtle but important role that the Straits play in influencing pollutant concentrations in the Georgia Basin. The Strait of Georgia typically sees northwest winds in the summer; the Strait of Juan de Fuca, typically westerly winds which back to southeasterly over Haro Strait and the San Juan Islands. The predominance of one flow over the other at any particular time may give clues as to the 'cleanliness' of the incoming air for the LFV

With the detailed data on particulate matter and ozone, it is expected that this information will be used in the development of air quality models. At first glance, the weather during Pacific 2001 was not ideal for a prolonged pollution episode; in retrospect, it may well have proved to be fortuitous for air quality research. In the three weeks of the field study, we observed all the variability one comes to expect during the course of an entire summer in the Lower Mainland. Thus, air quality modellers have a more realistic cross section of meteorological conditions from which to use as input.

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