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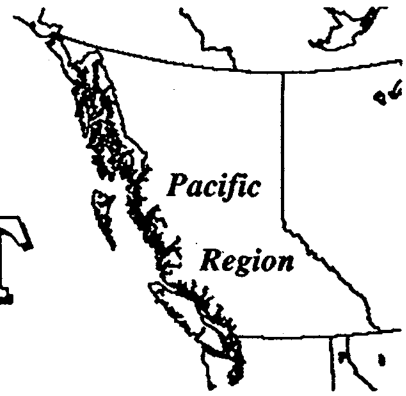
REPORT



The Relationship Between Ground-Level Ozone Concentrations, Surface Pressure Gradients, and 850 mb Temperatures in the Lower Fraser Valley of British Columbia

Bill Taylor
Atmospheric Issues & Services Branch
Atmospheric Environment Service
Pacific Region

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ABSTRACT

During the summer season, the Lower Fraser Valley of British Columbia occasionally experiences very high concentrations of ground-level ozone (photochemical smog). It has been determined that the duration and intensity of these episodes depends solely on meteorological conditions. This paper investigates the relationship between ozone concentrations and certain meteorological variables. A high correlation was found between ozone concentration and the temperature at 850 mb, with higher than average temperatures being observed when levels of ozone are elevated. These high temperatures at 850 mb are generally associated with subsidence inversions and low level stability. The results of the study indicate that ozone events are unlikely to occur below certain temperature thresholds which vary from one month to the next as the summer progresses. It was also found that virtually all occurrences of elevated levels of ozone happen when the west-to-east surface pressure gradient in the valley is negative.

INTRODUCTION:

In the Lower Fraser Valley of British Columbia, certain meteorological conditions combine with the valley geography to produce conditions favourable to high concentrations of ground-level ozone. This paper investigates the relationship between ground-level ozone concentrations and two meteorological variables: the temperature at 850 millibars and the surface pressure gradient across the Lower Fraser Valley. Sufficiently high correlations between levels of ozone and these meteorological factors may provide some statistical basis for forecasting ozone events.

BACKGROUND:

The meteorological conditions necessary for the occurrence of an ozone episode in the Lower Fraser Valley are now reasonably well understood (Taylor, E., 1991; and Steyn, et al., 1990). The synoptic pattern is characterized by an upper ridge of high pressure over British Columbia and an inverted thermal trough extending up from the southwestern United States into the South Coast of British Columbia. The subsidence inversion associated with the upper ridge confines mixing to a thin boundary layer allowing pollutants to accumulate. Horizontal dispersion of this stagnant air is curtailed by the mountains on either side of the Fraser Valley. Warm, dry sub-tropical air transported into the area from the south gives higher than average temperatures at the surface and in the lower atmosphere. Pollutants trapped in the valley on these hot, sunny, summer days react in the presence of sunshine to produce ground-level ozone (photochemical smog) which can remain at elevated levels for several days until the weather pattern changes.

Scire and Chang (1991) identified the relationships between various meteorological variables and ground-level ozone concentrations occurring in southern California around Santa Barbara. The highest correlations were found to be with the 850 mb temperature and surface pressure differences. This is consistent with the findings of Smith (1984), and Moore and Reynolds (1986), cited in the same study, who found the 850 mb temperature to be the most important variable associated with high ozone concentrations. Scire and Chang note that the high temperatures at 850 mb are associated with general subsidence, strong vertical stability, and limited mixing conditions. Scire and Chang found correlation coefficients of 0.4 to 0.7 between temperatures at 850 mb and peak daily ozone concentrations. The lowest correlations occurred during July and August when the variance in temperatures is small. High ozone concentrations were also generally associated with weak surface pressure gradients.

METHODOLOGY:

Following the work of Scire and Chang, a five-year history of upper air temperatures was obtained for the months of May through September to establish monthly means and standard deviations for comparative purposes.

As shown in Figure 1(a), the upper air station located nearest to the Lower Fraser Valley is Quillayute (UIL) on the north coast of Washington State. Archival data for the five year period, 1986 to 1990, from May to September inclusive, were obtained from the National Climate Data Center in Asheville, N.C. The data set consists of 765 observations of the 850 mb temperature at 1200 UTC.

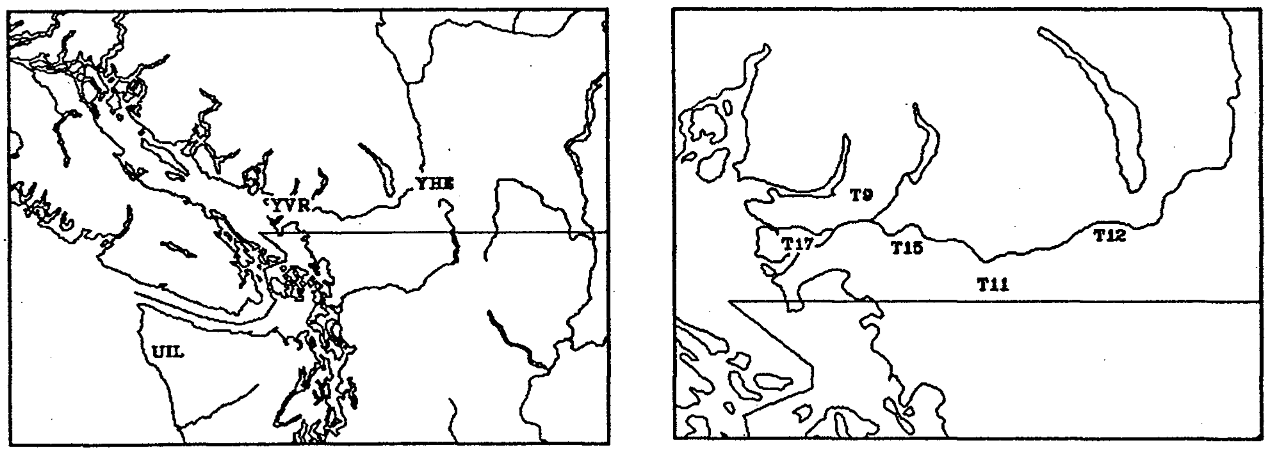

Figure 1: (a) Map of southwestern B.C. showing the relative locations of Quillayute (UIL), Vancouver (YVR) and Hope (YHE) and (b) map of the Lower Fraser Valley indicating locations of five GVRD stations.

Ground-level ozone in the Lower Fraser Valley is measured by the Greater Vancouver Regional District (GVRD) air quality monitoring network. Peak daily ozone concentrations at five GVRD stations shown in Figure 1(b) for the months of May through September for the five-year period have been extracted from a locally maintained database of GVRD data. These maxima are averaged in order to compute a representative peak value for the valley.

The mean daily maximum ozone concentration for the five year period (May through September) was found to be 41.2 ppbv with a standard deviation of 14.4 ppbv. There were 109 cases out of 765 (14%) where the daily average peak concentration of ozone exceeded values greater than one standard deviation above the mean (55.6 ppbv). For the purpose of this study, cases of elevated concentrations are referred to as ozone "events". Of these 109 events, 57 can be classified as "episodes" where the daily maximum ozone concentration at any given station within the valley was found to exceed the threshold value of 82 ppbv.

Average daily peak ozone concentrations exceeding 55.6 ppbv were identified along with the corresponding 850 mb temperatures at 1200 UTC and a correlation coefficient was computed. Also, the mean 850 mb temperature observed during these ozone episodes was compared to the normal mean monthly 850 mb temperature to determine if ozone episodes are associated with significantly higher than average temperatures.

Finally, the existence of a thermal trough extending into the south coastal area should result in lower surface pressures at Vancouver than those found in Hope at the eastern entrance to the Lower Fraser Valley (see Figure 1a). Surface pressure differences between Hope and Vancouver were correlated to average daily peak ozone concentrations greater than 55.6 ppbv to determine the existence of a relationship between these two variables.

RESULTS:

A) 850 MB TEMPERATURE:

The relationship between average daily peak ozone concentrations and the temperature at 850 mb is shown in Figure 2.

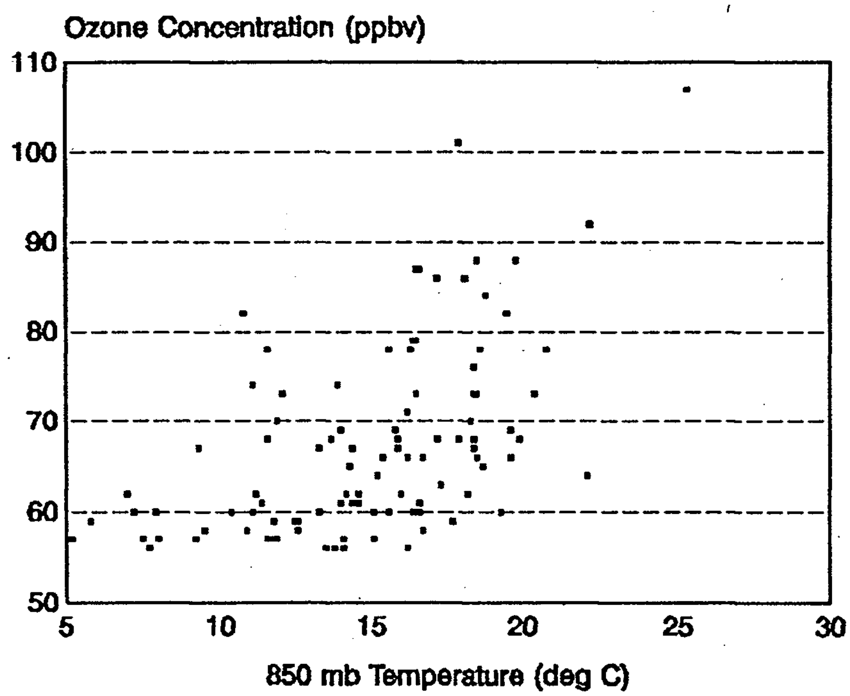

Figure 2: Ozone concentration vs. 850 mb temperature for days when average daily maximum ozone exceeds 55 ppbv.

Of the 109 days identified as ozone events, 8 cases were discarded due to missing data. An overall correlation coefficient of 0.55 was found based on the remaining 101 cases. Individual monthly correlation coefficients (May to September) ranged from 0.47 to 0.83 consistent with the findings of Scire and Chang (1991).

Table 1 is a categorization of ozone events by month including the means and standard deviations for the 850 mb temperature for ozone events. Also shown for comparative purposes are the normal means and standard deviations for the 850 mb temperature for the five year period.

MONTH	Number of ozone events	Mean 850mb temp (°C) (events)	Standard deviation (events)	Mean 850mb temp (°C) (normal)	Standard deviation (normal)
May	10	12.3	5.4	3.0	5.0
June	22	13.1	3.6	6.8	5.4
July	22	14.5	3.6	8.7	4.7
August	32	16.1	3.0	11.2	4.3
September	15	17.2	3.2	10.3	5.6

Table 1: A comparison of monthly temperatures at 850 mb showing normal means and standard deviations based on the five year history and those for ozone events.

The data from Table 1 are summarized below in Figure 3 in graphical form. Figure 3 shows that the mean temperature at 850 mb during elevated levels of ozone is at

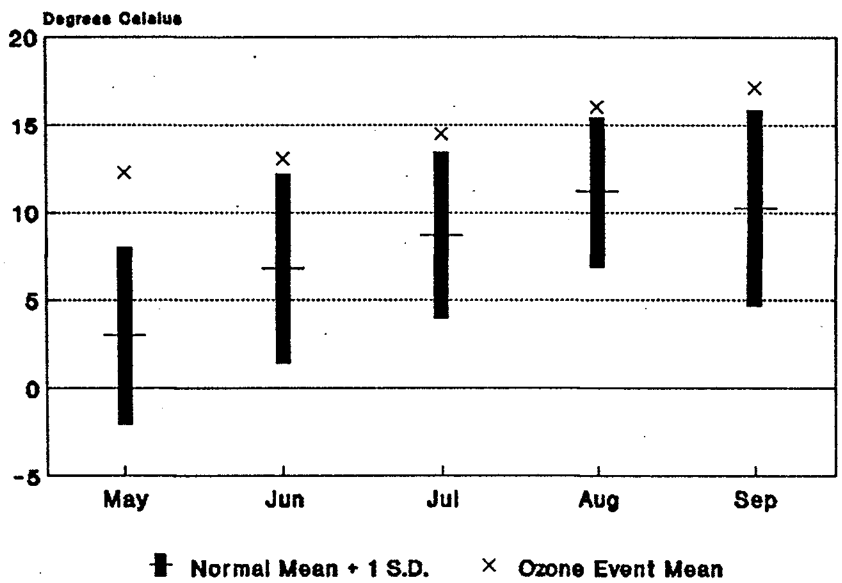

Figure 3: Comparison of normal vs. ozone event monthly mean 850 mb temperatures.

least one standard deviation above the normal mean temperature for each of the months selected.

A monthly frequency distribution indicating the number of ozone event days during the five year period in which the 850 mb temperature falls within specified intervals is shown below in Table 2.

	850 mb Temperature Intervals (°C)					
Month	(0,5]	(5,10]	(10,15]	(15,20]	(20,25]	Total
May	0	4	3	3	0	10
June	0	4	11	6	1	22
July	0	2	11	9	0	22
August	0	1	9	20	2	32
September	0	0	2	11	2	15

Table 2: Monthly frequency distribution (number of days) during 1986-1990 for different intervals of 850 mb temperature (degrees C) when mean daily peak ozone concentration in the Lower Fraser Valley is above 55 ppbv.

The data in Table 2 reveal that elevated concentrations of ozone are almost certainly not to occur below certain 850 mb temperature thresholds. In the month of May, ozone events may occur at relatively low temperatures in the 5 to 10 degree range. During the months of June, July and August, the higher temperatures in the 10 to 15 degree interval are normally required to produce an ozone event. In September, an even higher temperature of 15 to 20 degrees is required before elevated ozone levels are experienced.

B) SURFACE PRESSURE GRADIENT:

The existence of the thermal trough along the western end of the valley should raise temperatures and thereby lower pressures at Vancouver relative to Hope (a distance of 130 km) resulting in a negative pressure gradient along the valley. This phenomenon is evident from Figure 4 which shows negative pressure differences between Vancouver and Hope at 1200 UTC for all but one of the 109 days of elevated ozone levels.

The mean pressure difference at 1200 UTC for ozone events is -1.1 mb. This compares to a normal mean difference at 1200 UTC of -0.6 mb for the five year period (May to September) and a standard deviation of 0.8 mb. This difference is not large, but it is significant that virtually all ozone events occur when the surface pressure is lower at Vancouver than Hope. A correlation coefficient of -0.32 was found between ozone concentration and pressure differences for the 109 ozone events. The overall correlation coefficient for the five year period is -0.34, suggesting that a negative pressure gradient alone is insufficient for predicting ozone events. An approaching cold front, for example, could result in a negative gradient and no ozone would be expected to be present. High levels of ozone are only observed when the low pressure at Vancouver relative to Hope is due to the existence of a thermal trough.

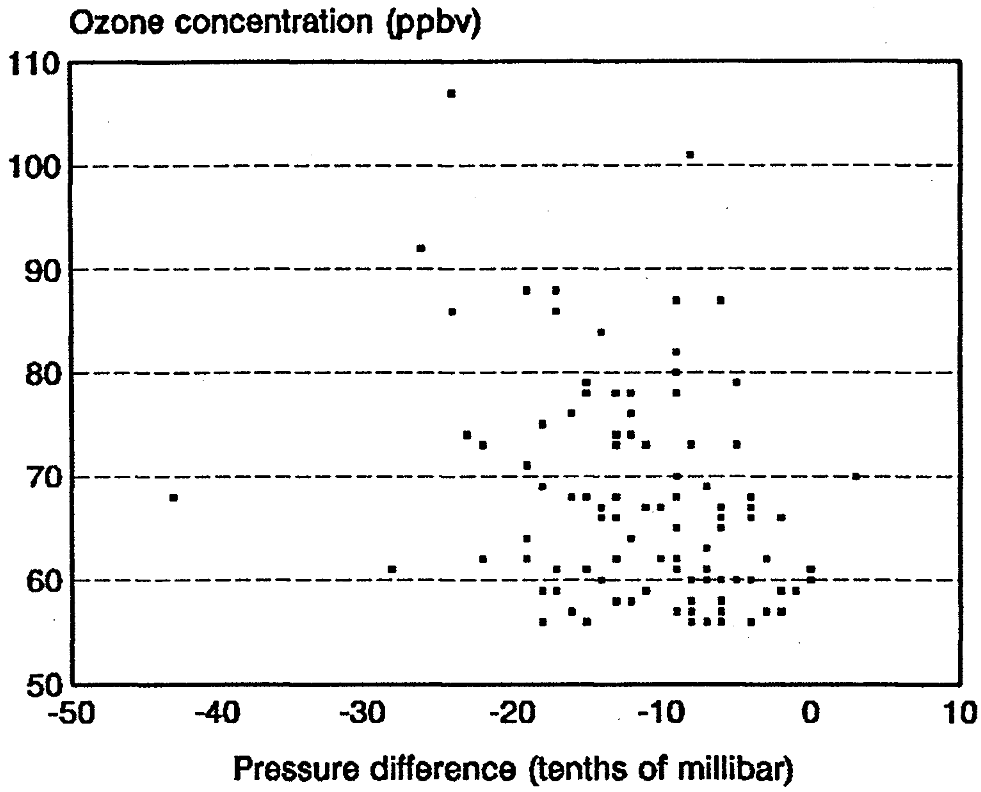

Figure 4: Ozone concentration vs. surface pressure differences between Vancouver and Hope for days when the average daily maximum ozone exceeds 55 ppbv.

CONCLUSION:

An analysis of the five year period, from 1986 to 1990, for the months of May to September (765 days) shows that the month of August has the highest frequency (31%) of elevated levels of ozone followed by June (22%) and July (22%). The lowest incidence of ozone events is found in May (10%) and September (15%).

A strong correlation between high ozone concentration and the temperature at 850 mb was found (r = 0.55). This suggests that forecast 850 mb temperatures have some predictive value with respect to ground-level ozone concentrations. Also, 850 mb temperatures during ozone events were found to be, on average, at least one standard deviation above monthly mean values. For the months of May through August, an 850 mb temperature of at least 5 degrees Celsius is required to produce an ozone event, but elevated levels are more likely once the 850 mb temperature reaches 10 degrees Celsius. In September, the threshold temperature is higher yet at approximately 15 degrees Celsius. Higher than average 850 mb temperatures are consistent with conditions of subsidence inversion and low level stability associated with elevated ozone levels.

The correlation between ground-level ozone concentration and the surface pressure gradient in the valley is not strong ($r = -0.32$), however, it is noteworthy that virtually all cases of elevated ozone occur when the surface pressure is lower at Vancouver than Hope. While the five year history for these months indicates that the pressure pattern is typically negative (-0.6 mb), the surface pressure gradient is slightly more negative during ozone events (-1.1 mb) due to the existence of the thermal trough which lies along the western end of the valley.

Given these findings, elevated levels of ozone may be expected when a higher than average temperature at 850 mb at Quillayute is forecast and the pressure difference between Vancouver and Hope is negative.

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