SCIENTIFIC SERVICES DIVISION

REPORT

FORECASTING GROUND-LEVEL OZONE IN VANCOUVER AND THE LOWER FRASER VALLEY OF BRITISH COLUMBIA

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INTRODUCTION

Canada's Green Plan has committed the federal government to becoming involved in the forecasting of ground-level ozone. The Green Plan states:

> *The government will, by 1993, in co-operation with provincial and municipal governments, provide public advisories in major urban areas in BC, Southern Ontario, Quebec and the Maritimes on days when motorists could help reduce unacceptably high ozone concentrations by using public transit*[1].

This report briefly reviews the issue of ground-level ozone and describes some initial work that has been done in British Columbia to develop ground-level ozone advisories for Vancouver and the Lower Fraser Valley.

THE EFFECTS OF EXPOSURE TO GROUND-LEVEL OZONE

Short term exposure to ground level ozone can degrade lung function and cause respiratory symptoms during moderate exercise when concentrations reach 80 ppb. Long term exposure is suspected of playing a role in the development of chronic lung diseases. Many health professionals are more concerned that repeated exposure to ozone over a lifetime may result in permanent impairment of the lung[2].

It has been estimated that the crop losses due to ozone pollution in the Fraser Valley for a "medium" ozone year are $4.4 million[3]. Ground-level ozone is also one of the most important air pollutants affecting United States agriculture. It has been estimated that ozone is responsible for agricultural losses averaging $3 billion annually in the United States[4].

OZONE FORMATION AND ACCUMULATION

Ground level ozone is formed by a photochemical reaction of nitrogen oxides (NO_X) and volatile organic compounds (VOC). The most fundamental reaction[5] is:

$$NO_2 + \hbar\mu \rightarrow NO + O$$
$$O + O_2 + M \rightarrow O_3 + M$$
$$O_3 + NO \rightarrow NO_2 + O_2$$

where O_3 is ozone, O is monatomic oxygen, NO_2 is nitrogen dioxide, NO is nitrogen oxide, M is a molecule that absorbs excess energy in the reaction and $\hbar\mu$ represents solar radiation.

Sunlight is essential for ozone formation. Ozone levels are highest on very warm, sunny days, since the rate of the photochemical reaction is also temperature dependent. The graph in figure 1 shows the hourly concentration of NO_2 and ozone for four days at a site east of Vancouver in the Fraser Valley. This graph also shows the height of the base of the inversion over the Fraser Valley as estimated by using the radiosonde ascent at Quillayute, Washington.

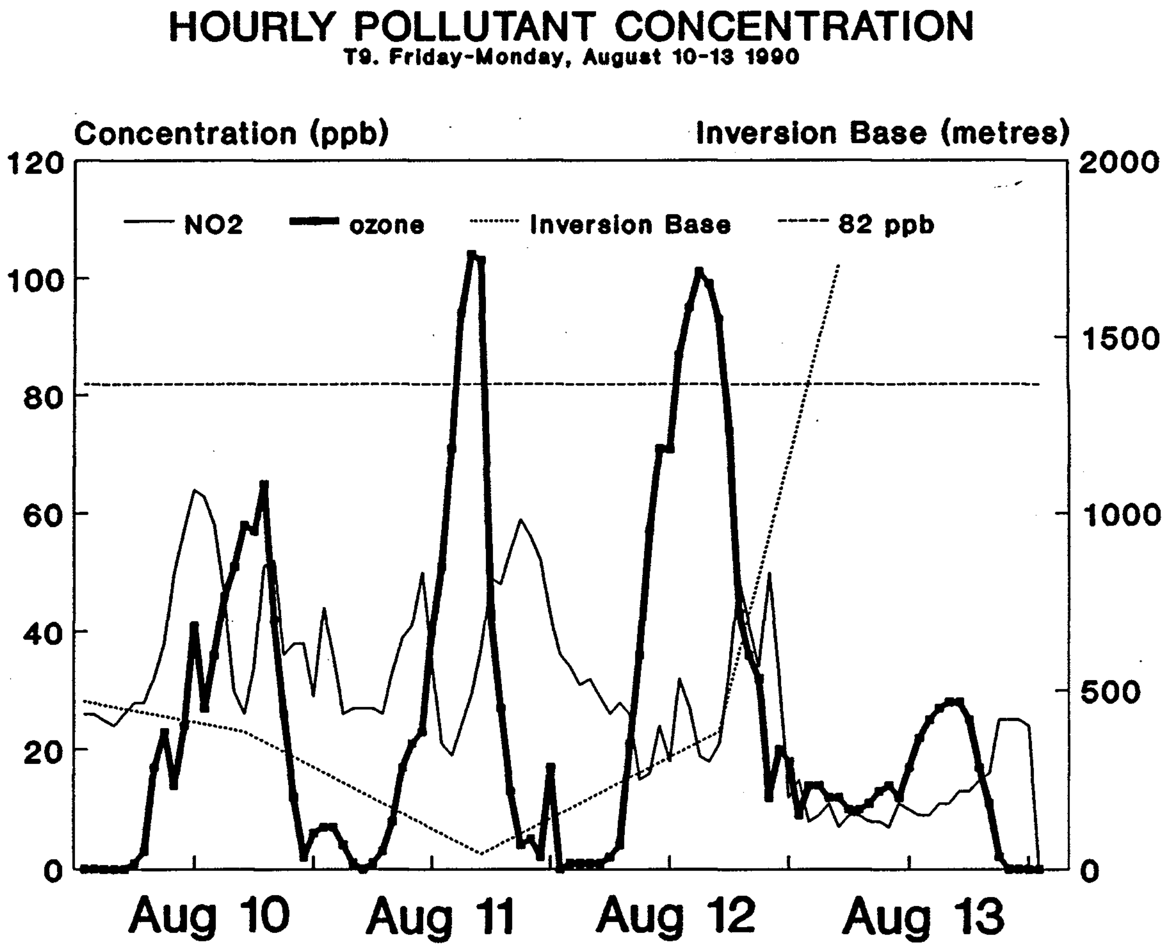

Figure 1. Hourly ozone and nitrogen dioxide concentrations, and the estimated height of the base of the inversion at Port Moody, August 10-13 1990.

Figure 1 shows the typical diurnal nature of ground-level ozone at a low level site. Ozone is photochemically produced during the day and is destroyed by reacting with species such as nitrogen oxide at night. Note that the concentration of nitrogen dioxide falls when the ozone concentration is rising. This is likely due in part to the photochemical conversion of nitrogen dioxide to ozone. Also note that both ozone and nitrogen dioxide concentrations are low when the inversion cap is removed on August 13.

Ninety-five percent of NO_X emissions are from fossil fuel combustion, mostly nitrogen oxide (NO). NO is rapidly converted to NO_2 and other species through oxidation. Volatile organic compounds are released during combustion, from industry, from biogenic sources and from the evaporation of liquid fuels, solvents and organic chemicals.

The mountains surrounding Vancouver and the Lower Fraser Valley form an efficient barrier to the horizontal dispersion of ozone, NO_X and VOCs. The height of this barrier is effectively 500-1000 metres, so that an inversion at or below this height limits the volume of air into which pollutants can diffuse. Ozone and its precursors can accumulate over several days until the inversion lid is removed.

ATMOSPHERIC CONDITIONS ASSOCIATED WITH ELEVATED OZONE CONCENTRATIONS

As air quality and meteorology are so inexorably linked, AES Pacific Region has explored the possibility that high ozone events are associated with particular synoptic events. Ozone concentrations, surface and upper air meteorological charts, as well as upper air profiles from 1990 were examined in order to detect any relationship between Vancouver and Lower Fraser Valley ozone and synoptic meteorological patterns on the west coast. It was found that maximum daily ozone was high when the following occurred:

- a sharp low level inversion over the south coast
- a strong upper ridge over the eastern Pacific and British Columbia and
- a surface thermal trough along the Washington-southern B.C. coast.

Air pollutants, including ozone, increase in concentration when the airmass is stable and winds are light. In the lower Fraser Valley, ozone concentrations appear to increase in summer when a sharp low level inversion (less than 500 metres) persists for several days. Figure 2 shows an example of the strength of an inversion that appears to be needed to produce elevated ozone episodes. Ozone precursors (NO_X and VOCs) accumulate beneath the cap provided by the inversion and form ozone under the influence of strong sunlight and warm temperatures. Inversions of this type are associated with strong upper ridges.

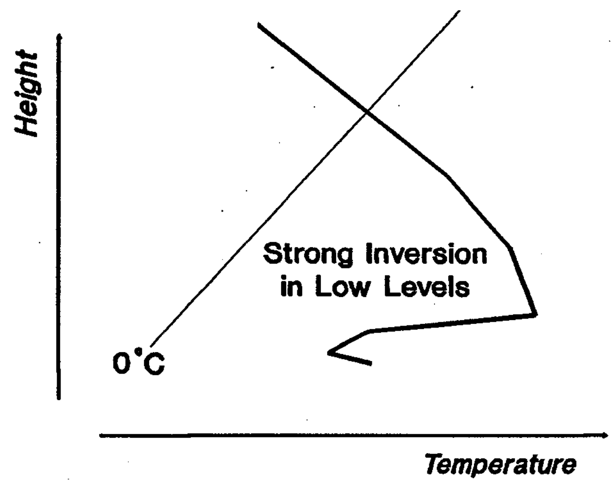

Figure 2. Typical atmospheric profile associated with elevated ozone concentrations in the Lower Fraser Valley.

Another necessary condition for elevated ozone concentrations in the Lower Fraser Valley is an inverted thermal trough along the coast and sometimes even a small, weak thermal low centre near southern Georgia Strait.

Figure 3 shows this thermal trough digging north from a strong thermal low centre in the southwestern United States. Thermal troughs of this type are associated with the western part of a strong upper ridge that drives very warm, dry sub-tropical air northward along the west coast. The lowered sea-level pressure on the coast produced by these thermal troughs apparently restricts the normal flushing of Pacific air inland. This pressure pattern presumably also interferes with and restricts the mesoscale sea breeze that typically develops each afternoon on sunny and warm days. Combined with the trapping effect of the mountains surrounding the Fraser Valley, the inversion and the thermal trough produce very stagnant conditions and allow ozone and ozone precursors to accumulate rapidly.

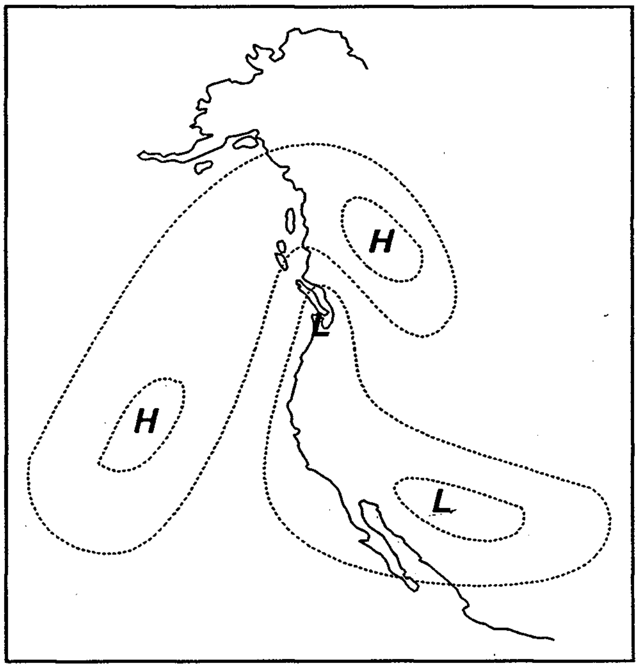

Figure 3. Typical synoptic situation associated with high ozone levels in the Fraser Valley.

This synoptic situation generally only occurs about 4-8 times per summer in the Fraser Valley.

Ozone episode conditions quickly end when the thermal trough dissipates or moves inland or mid level cloud invades area. The thermal trough usually moves inland in advance of a cold front moving eastwards from the Pacific. The timing of the movement of the thermal trough inland is critical. It appears that if the trough lingers over Vancouver at least until midday, an ozone peak will occur. If it moves eastward up the Fraser Valley much before that, the ozone and other pollutants are adequately dispersed. Work needs to be done to learn more of this relationship and to improve the forecasting of the movement of the thermal trough.

Ozone episodes never occur when an offshore Pacific high pressure ridge is creating inflow conditions on the south coast, even under sunny and warm conditions. Ozone episodes also never occur under cloudy or convective conditions.

The graph in figure 4 shows the maximum daily ozone at the Rocky Point Park ozone monitoring site in Port Moody, just east of Vancouver, in the summer of 1990. The bar graph marks those days when an inverted thermal trough was present along the Oregon-Washington-southern B.C. coast. Longer bars signify days when a small weak thermal low was located in the thermal trough near southern Georgia Strait.

Figure 4 indicates the correlation between ozone peaks and thermal troughs or thermal lows in this area. It also suggests that ozone peaks are higher if the thermal trough persisted for more than one day. It is proposed that a persisting thermal trough would allow ozone, ozone precursors, and other pollutants to accumulate over time, thus increasing the maximum daily ozone concentration.

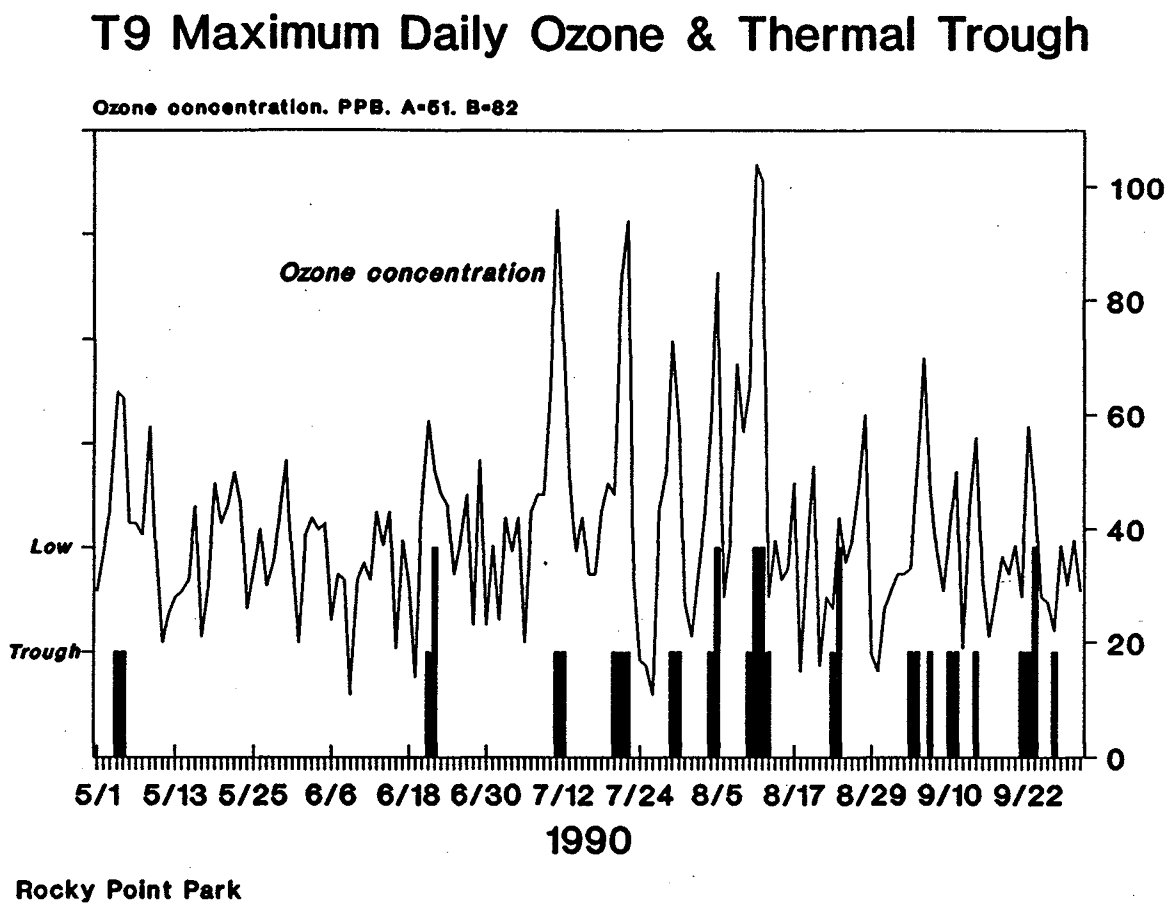

Figure 4. The maximum daily ozone concentration (line graph) at Port Moody and days when an inverted thermal trough or low centre (bar graph) was present. Longer bars indicate a low centre.

SUMMER 1991 OZONE FORECAST EXPERIMENT

In order to meet the Green Plan commitment of providing ozone advisories for the lower Fraser Valley, AES Pacific Region conducted an experimental ozone forecast during the summer of 1991. Maximum and mean daily ozone concentrations were forecast for days one, two and three at six monitoring sites.

The methodology used was that ozone concentrations will increase under warm, sunny conditions when a strong upper ridge persists over the eastern Pacific and B.C., a surface thermal trough is present along the west coast and a sharp inversion based below 1000 metres is present. The aim of the experiment was to forecast the presence and severity of ozone peaks for days one, two and three. Less emphasis was put on trying to accurately predict ozone concentration if they were expected to fall below 50 ppb.

Maximum and mean daily ozone concentrations were forecast on most weekdays by 8:00 AM from May 1 through to early September. Also included was a forecast probability that ozone concentrations would exceed level B (82 parts per billion) at any site in the Lower Fraser Valley on each day. The forecasts were faxed to the Greater Vancouver Regional District (GVRD) daily at their request and for their use. Box 1 shows a typical forecast.

In support of this experiment, hourly ozone data was retrieved automatically from the GVRD database each morning. Additional data normally available to meteorologists in the Pacific Weather Centre was also accessible by the ozone forecaster.

1991 OZONE FORECAST VERIFICATION

A graph of the observed and day-one forecast maximum daily ozone concentrations at Port Moody in 1991 is shown in figure 5. Gaps in forecast data occur because forecasts were only issued on weekdays when the forecaster was available.

1991 was not a "good" year for ozone as there were relatively few high ozone days. No objective analysis has been done to assess forecast skill. However, the graph in figure 5 shows that the forecaster generally predicted the correct trend to ozone concentrations, particularly later in the summer when he had attained some experience. The errors in ozone prediction were mainly due to inaccuracies in forecasting:

August 12, 1991
FACSIMILE TRANSMISSION
ATMOSPHERIC ENVIRONMENT SERVICE
PACIFIC REGION

TO: KEN STUBBS GVRD FAX 436-6707 PHONE 436-6747
FROM: ERIC TAYLOR AES FAX 664-9195 PHONE 664-9123

Experimental ozone concentration forecast for Greater Vancouver and the Lower Fraser Valley issued by Environment Canada at 07:38 PDT Monday, August 12 1991 for Today, Tuesday and Wednesday.

All ozone concentrations are in parts per billion.
Forecasts are the MAXIMUM one-hourly concentration expected, followed by the MEAN hourly concentration for the day. EG. 90/50 means: the expected maximum one-hourly concentration will be 90 PPB while the mean for the 24 hour period is expected to be 50 PPB.

PROBABILITY>LVL B is the probability of reaching or exceeding the level B ozone concentration (82 PPB) at ANY ONE of the 20 ozone monitoring stations in Greater Vancouver or the Lower Fraser Valley.

Station	Today Aug 12	Tuesday Aug 13	Wednesday Aug 14
T1 ROBSON SQ	15/5	20/10	20/10
T9 ROCKY PT	30/15	35/15	35/15
T15 SURREY EAST	30/15	35/15	35/15
T17 RICHMOND S	30/15	35/15	35/15
T11 ABBOTSFORD	30/15	35/15	35/15
T12 CHILLIWACK	30/12	35/15	35/15
PROBABILITY>LVL B:	0%	0%	0%
Forecast max temps			
VANCOUVER	21	23	23
ABBOTSFORD	22	25	25

Forecaster: Eric Taylor

Box 1. Typical experimental ozone forecast transmitted to the Greater Vancouver Regional District by AES.

- the location, movement and dissipation of the thermal trough.
- the strength and speed of incoming cold front (which pushes the thermal trough inland).
- the height and sharpness of the inversion.

STATISTICAL TOOLS FOR FORECASTING GROUND-LEVEL OZONE

Statistical approaches have been used with some success in linking meteorological variables to ozone concentrations in the Fraser Valley. Robeson[5] reported that maximum daily ozone concentrations were best correlated with observed maximum temperatures. Maximum temperatures are indeed highest in summer when a strong upper ridge, coastal thermal trough and low level inversion are present.

AES Pacific Region has developed a preliminary set of multiple linear regression equations linking maximum daily ozone to temperature, yesterday's ozone, precipitation and MSL pressure differences between the coast and the interior. The latter were included in an attempt to detect the thermal trough occurrence on the southern B.C. coast. This met with only limited success, since similar pressure differentials are associated with totally different synoptic situations. Figure 6 shows the observed and statistically forecast maximum daily ozone concentrations at Port Moody for 1990.

The forecast values were calculated from four different regression equations for each site. These regression equations were derived from, and used, in a "perfect prog" forecast mode

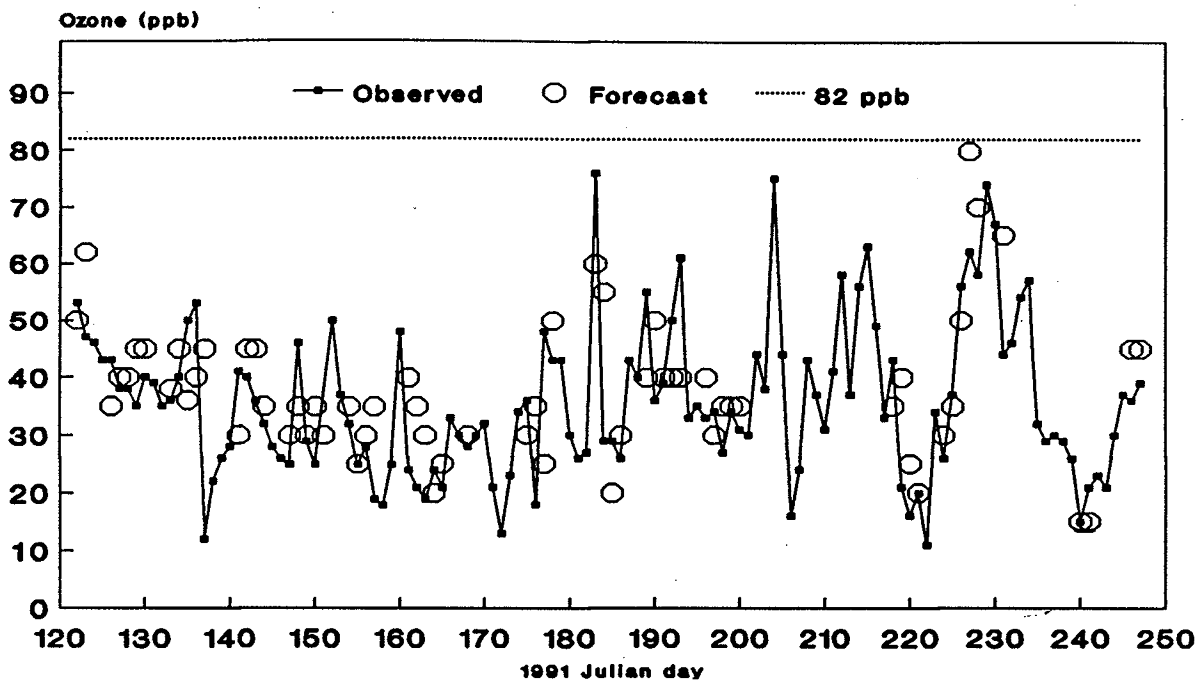

Figure 5. Graph of observed and day 1 forecast of maximum daily ozone concentration at Port Moody in 1991.

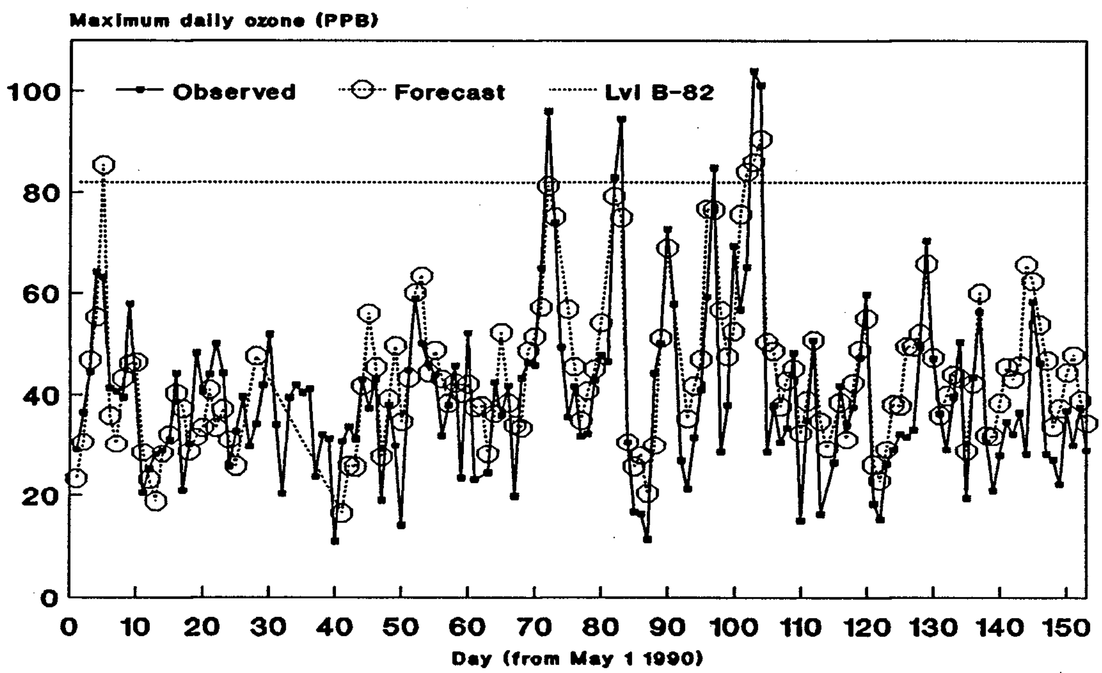

Figure 6. Observed and statistically forecast maximum daily ozone concentrations at Port Moody for the summer of 1990. Statistical forecasts were derived from four separate regression equations.

for:

i) days when precipitation occurred and yesterday's ozone was below 60 ppb (LOW1).
ii) days when precipitation occurred and yesterday's ozone was above 60 ppb (HIGH1).
iii) days when precipitation did not occur and yesterday's ozone was below 60 ppb (LOW0).
iv) days when precipitation did not occur and yesterday's ozone was above 60 ppb (HIGH0).

Figure 6 shows that this statistical forecasting approach proved very successful in forecasting the trend of ozone concentrations. If the meteorological variables could be accurately predicted, statistical forecasting of ozone shows great promise.

Figure 7 shows a scatter diagram of observed and statistically predicted values for the same site in 1990. As is typical of these linear regression approaches, extremely high values of ozone are underforecast.

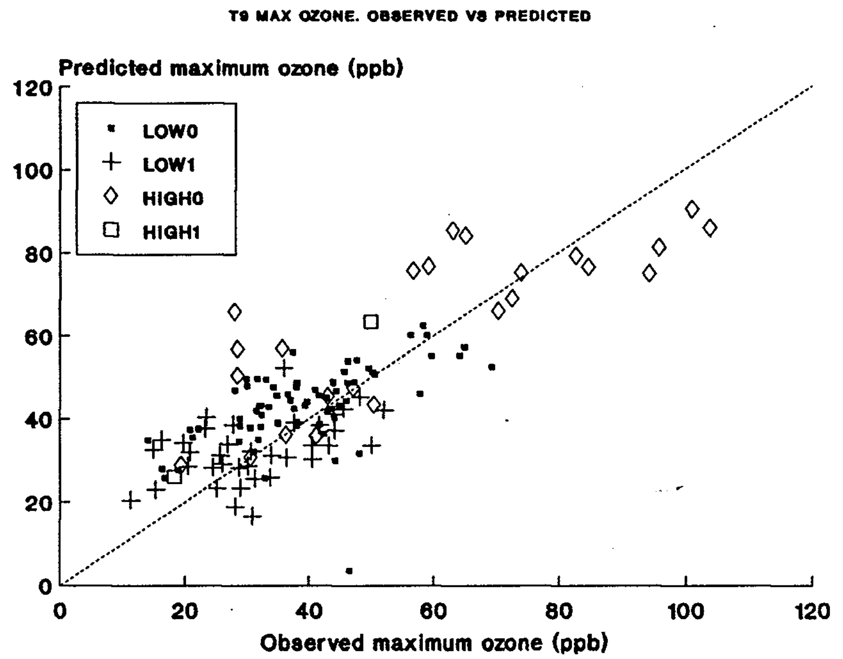

Figure 7. Observed and statistically forecast maximum daily ozone values. Four regression equations were used (see text).

A more sophisticated set of statistical procedures is now being sought by contract. It is hoped that the contractor can develop a statistically-based system to provide the probability that the maximum daily ozone at any individual monitoring site or in the entire Fraser Valley will exceed 82 ppb.

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1. Government of Canada. *Canada's Green Plan.* 53.

2. Canadian Council of Ministers of the Environment. *Management Plan for Nitrogen Oxides and Volatile Organic Compounds. Phase I. November 1990.* 6-7.

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4. S.V. Krupa, W.J. Manning, "Atmospheric ozone: formation and effects on vegetation," *Environmental Pollution.* **50:** 101 (1988)

5. Robeson, Scott M. Time Series Analysis of Surface Layer Ozone in the Lower Fraser Valley of British Columbia. University of British Columbia masters thesis.