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REPORT



Pacific & Yukon Region

Lower Fraser Valley Oxidants Study Pacific 93 - The Meteorology

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November, 1993
Report PAES-93-#8

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INTRODUCTION

The degree of success of the Pacific '93 field measurement program rested on the occurrence of ozone producing conditions between July 15th and August 12th. It was expected that under warm sunny conditions, weather briefings and forecasts would emphasize local conditions and determine the likelihood and duration of ozone episodes. Meteorological support would therefore supplement the planning process. What took place was an unanticipated and strong dependency of all activities on the weather situation. A highly unusual weather pattern brought unstable and rainy conditions to the Lower Fraser Valley during the first two weeks of the study. This complicated the planning process and posed some unforeseen logistic concerns as well as rigorous forecasting demands. This report describes the dependency of the field study on meteorological information.

The synoptic meteorological conditions necessary for ozone episodes were compared with those observed during the first week of August, when ozone concentrations were elevated. The comparison pointed to a 'near' episode during Pacific '93, since synoptic conditions conducive to ozone formation were barely met.

FORECASTING CHALLENGES OF PACIFIC '93

By July 15th, an extensive assortment of surface equipment had been installed at the Harris Road, Aldergrove, and Langley sites and the Convair 580 had arrived in Abbotsford. Start up problems were not uncommon, however, and the poor weather which occurred during the early part of the study was, in retrospect, advantageous. While rain and cloud persisted through the first week, surface and aircraft equipment deficiencies were resolved and the day to day planning process took shape. The field study plan called for evening weather briefings in Abbotsford with short follow-up briefings in the morning as necessary. Principal investigators and flight crew members were to confer then advise others of plans for the following day. No alternate plan was in place for the worst case weather scenario which ensued.

A westerly stream across the Pacific brought a series of frontal systems onto the B.C. coast between July 15th and July 31st. Cloud dynamics became increasingly difficult to assess as frontal systems banked up against the coast and continued to enhance instability. Predicted clear breaks between systems rarely emerged and filled in rapidly due to overrunning airmasses from upstream systems. An anxiously awaited clear break materialized on July 19th when the first test flight was conducted. Low cloud hampered lidar measurements on this flight, and instability in the base of a trough over the valley resulted in rough flight conditions and more cloud than predicted. The situation unfolded similarly to this on several more occasions, with stratus breaking unexpectedly or excessive cloud building up due to persistent instability.

The rapidly changing and unpredictable weather situation caused several altered or cancelled flight plans and complicated the entire planning aspect of the study. First, a shift in emphasis took place from ozone measurements over land to cloud physics studies over offshore marine layers in order to sample 'clean' upstream air. Where this had been regarded as an alternative activity of the

study pending time and conditions, it became the major focus of numerous briefings and planning sessions. It also required more meteorological information and detailed analysis than foreseen, as well as more preparation on the part of the flight crew. Weather conditions were re-assessed nearly hourly on several occasions and included input from several senior meteorologists, with little success at calling the specific conditions sought.

The question is "how bad was it?". The rugged topography and lack of upstream data make west coast forecasting an ongoing challenge, and difficulties with poor weather are not unfamiliar. In July of '93, however, well experienced meteorologists reached forecasting limits in grappling with the unusual behavior of the upper atmosphere. Figure 1 shows the uncharacteristic global pattern of July '93 with an anchoring low in Russia and the Alaska low well southwest of its usual summer position. The more familiar summer pattern of July '92 shows an upper low over the Alaska panhandle with British Columbia under a southwesterly upper flow, which normally diverts frontal systems toward northern B.C. In July of '93, the Alaska low was deeper than commonly observed and held its unusual position south of Alaska through the month. Computer prognosis charts continued to attempt to break down this holding pattern and turned the expected into the unpredictable. The specific conditions required for cloud physics flights were only briefly met and forecasting these became an unsuccessful business.

Forecast accuracy had several logistical consequences. An anticipated flight required several hours of instrument preparation on the part of flight crew members and lead time of up to 18 hours was required to meet NOTAM (Notices to Airmen) deadlines for aircraft and tethered flights. A "go" or "no go" decision became based more on the forecast than on other priorities of the measurement program. The finite number of flying hours required judicious use of flight time, and was an ongoing concern, but especially so when few hours had been utilized three weeks into the study. Crews were at times placed on standby, causing difficult scheduling problems and augmenting overtime costs. Forecast preparation was lengthier than originally planned and required more time at the Pacific Weather Centre, with briefings often delivered in Abbotsford, 60 km away, twice a day. This additional preparation and travel time further escalated budget costs.

One is left to answer to the significance of weather on an operation of this magnitude. Could there have been better preparation for or management of this worst case scenario? In hindsight, it would have perhaps been more effective and less costly to keep skeletal crews in place until the onset of an episode. In spite of the daily prediction failures, the onset of the warm weather conditions conducive to the production of ozone were successfully forecast with a lead time of 4 days. Under the ridge conditions, the study proceeded as originally planned, with fewer briefings and fewer planning stresses. The focus returned to the measurement of ozone, pollutants, and boundary layer meteorology.

METEOROLOGY REQUIRED FOR OZONE EPISODES

A closer look at the meteorology of ozone events reveals the extent of the summer of '93 weather anomaly. An ozone episode can be defined as the occurrence of one or more hourly average concentration values of greater than 82 ppb within the valley on any two out of three consecutive calendar days.¹ Although ground-level ozone is formed from a photochemical reaction in the presence of warm temperatures and sunlight, the development of the synoptic weather pattern is a crucial element of determination.

The following describes the meteorological parameters which must be in place in order for ozone episodes to occur in the Lower Fraser Valley². While all features must be present, the extent and position of each of these are significant in determining the strength and nature of an episode.

500 hPa Contour Level

The strongest ozone concentrations have been recorded when the 500 hPa ridge axis is directly over or slightly east of southwestern British Columbia. The left and upper right panels of Figures 2 to 5 show typical 500 hPa patterns associated with ozone episodes. The 570 decameter contour height is often used as guidance of the steering flow aloft, shown as a thick solid line. A high amplitude ridge and trough situation normally dominates over western Canada and the eastern Pacific, with the 570 dm contour extending into the Northwest Territories. The Aleutian Low generally troughs and digs southward, helping to build the ridge over B.C. and provides a southwesterly flow of warm air over the area. The thickness pattern is another analysis tool at this level, highlighted as the dotted line. Note the extension of the 576 dm thickness line into southern B.C. during episode conditions. Also note that the contour lines and thickness lines tend to parallel each other, indicating a lack of thickness advection, or cooling or warming within the airmass. This is an indication that conditions are right aloft for stagnation.

700 hPa Contour Level

During an ozone episode, a temperature ridge extends from Arizona and California into southern B.C., with the 10 °C isotherm typically lying over or north of the Lower Fraser Valley. This is shown as a dotted line in the left and upper right panels of Figure 3. This level is still representative of the geostrophic flow and not influenced by the boundary layer. The pattern is thus similar to the 500 hPa level, showing the ridge over B.C., parallel contour heights and isotherms, and a weak southwesterly flow along the west coast. The extension of the 10 °C isotherm into southern B.C. and troughing off the west coast are the guidance features generally used at this level.

850 hPa Contour Level

A temperature ridge normally extends from California into southern B.C., with the 20 °C isotherm lying north of the Lower Fraser Valley. Correlations of 0.4 to 0.7 have been found between temperatures at this level and elevated ozone concentrations. July episodes are generally accompanied by 850 hPa temperatures of 10-15 °C while August events show typical temperatures in the 15-20 °C range.³ Temperatures at this level generally range from 23-28 °C over the California interior during an event. Warming at this level is enhanced by subsidence from increasing thicknesses aloft and works toward suppressing mixing heights at the surface and capping the boundary layer inversions over the valley. Although this level is more likely to be influenced by the mountainous terrain, temperatures provide an indication of the extent of subsidence aloft.

Surface Pressure Level

A surface pressure trough typically extends northward from California into southern B.C. This is often referred to as a thermal trough, being a product of strong land surface heating along the coast and just east of the coast mountains. Surface temperatures can range from 27-33 °C near the shore

to 30-35 °C in the eastern parts of the valley. Surface pressure gradients are generally very slack, with outflow conditions giving warmer than normal temperatures along the coast. Local studies have shown that a weak westerly sea breeze typically sets up during the day with calm or easterly winds at night.¹ The strength of the subsidence aloft helps to determine low level stability and suppression of mixing heights.

The end of an episode is typically characterized by a stratus surge through Juan de Fuca and Georgia Straits. The marine layer can usually be traced northward along the California, Oregon and Washington coasts for a few days before the surge penetrates through Juan de Fuca Strait. This event is best documented in the September, 1988 episode and is attributable to a mesoscale coastal high pressure ridge along the coast. The northward propagation can be fairly accurately timed except when interrupted by large gaps in the coastal topography.⁴ The breakdown of an episode is also accompanied by a shift or collapse of the 500 hPa ridge and an eastward shift in the thermal trough.

METEOROLOGY OBSERVED DURING PACIFIC '93

It is possible to obtain an impression of the nature of the Pacific '93 episode without probing too deeply into dynamic meteorology. The bottom right panels of Figures 2 to 5 show the patterns observed during peak ozone concentrations on August 5th, and contrast sharply with those of the other three panels.

500 hPa Contour Level

Figure 2 shows the contrast at the 500 hPa level, with a cut-off low at 40 ° North, 160° West longitude replacing the typical long wave trough normally found at this position. Since a digging trough is needed to amplify the downstream ridge, the upper ridge over B.C. is very weak to non-existent. Ridging is evident along 145 °West, about 20 ° farther west than normally observed. The 576 dm thickness contour extends into northern Oregon, well south of its usual central B.C. position. A northwesterly flow dominates over B.C. instead of the typical southwesterly flow, with cold thickness advection evident from the northwest.

700 hPa Contour Level

The ridge/trough situation is more evident at the 700 hPa level (Figure 3, bottom right) and lies nearly 20° West of its usual 'episode' position. B.C. is actually under the eastern extremity of the ridge, a condition not normally conducive to ozone formation. The 10° C isotherm lies in central Oregon in contrast to the usual position in southern or central B.C.

850 hPa Contour Level

The 850 hPa temperature ridge (Figure 4, bottom right) shows a narrow tongue protruding into eastern B.C. rather than its usual broad coverage over the southern half of the province. While temperatures in California reached typical 'episode' values of 24-28 °C, the northwesterly flow over B.C. inhibited warming aloft and weakened subsidence conditions.

Surface Pressure Level

Strong surface heating produced the typical thermal trough along the California - B.C. corridor (Figure 5, bottom right panel) with temperatures reaching near record values under sunny skies. It appears this contributed largely to ozone formation, and produced the weak event, since dynamics aloft were weak and not indicative of episode concentrations. While data records from the study are yet being quality assured, the peak reading on the Greater Vancouver Regional District monitoring network was 81 ppb at Langley on the afternoon of August 5th. Under conditions described above as typical ozone episode patterns, it is possible to reach 213 ppb, the peak concentration recorded in 1988.

The position of the Lower Fraser Valley under the eastern portion of the upper ridge was a significant variation from the normal episode position, and the accompanying northwesterly flow precluded the subsidence necessary for a strong event. Of equal significance is the arrival of a vorticity centre over the valley on August 4th. This produced instability and led to isolated evening thundershowers, which washed out some pollutants and further weakened the event. A short wave ridge followed the vorticity centre on the 5th and provided a return to clear and stable conditions, when peak ozone concentrations were observed. Stable conditions were unusually short lived during the August '93 event.

The summer of 1993 was a very atypical summer, not only in the Lower Fraser Valley, but globally. The lows south of Alaska and over Russia which held through July and caused normal flow patterns to divert, resulted in the Mississippi floods and the east coast heat wave. The Pacific high pressure ridge which normally moves over B.C. in a typical summer did not arrive until early September. While the ridge approached the coast on several occasions, it retrogressed westward in response to these holding patterns and subsequent long wave readjustments. The following climate data for the month of July indicate the extent of cloudy weather:

	July	
	Normal	1993
Sunshine Hours	295.9	200.9
(19% less than normal)		
Mean Rainfall (mm)	36.1	34.3
Days with Measurable Rainfall	7	12
Mean Temperature (°C)	17.2	16.4

(Source: AES Records)

CONCLUSION

Meteorology played a dual role in Pacific '93, with boundary layer measurements forming part of the study and synoptic forecasting forming part of field support. Interpretation of the results should incorporate both scales. While the significance of synoptic features is shown here, the weakness of the episode may not be fully attributable to the lack of appropriate synoptic conditions aloft. One could consider the possibility that the '88 episode is as unusual a pattern as the '93 case, and that the odds of all features occurring to a similar extent may be highly unlikely. What is important is the case that presents itself most typically, for this is the one crucial to model. The representativeness of the Pacific '93 intensive study must be considered when modeling the event as

typical. Lack of attention to this concern could lead to deceptive interpretation of the field study results.

Most interesting is the fact that in spite of the non-episode patterns observed during Pacific '93, ozone concentrations reached threshold values. This attests to the significance of mesoscale dynamics and these are complex, being a collection of micro-climates imposed on an overall weak mesoscale flow. Future studies will further examine the role of meteorology in suppressing mixing heights and contributing to ozone production.

In spite of the unforeseen weather, the successes of Pacific '93 were many. The extensive and cross-referenced measurements taken during the last week of the study are unparalleled in the Lower Fraser Valley and will play a strong part in enhancing the understanding of the complex interaction of chemistry and meteorology of the area. Many measurements were taken on clean air days when instability produced good mixing and this showed some interesting 'hot spots' of pollutant activity, such as Port Moody. This may serve to guide the analysis process and future studies. Upstream measurements were more numerous than expected, and these will provide further insight into the chemical reactions and meteorological mechanisms in near shore areas. What initially appeared as a non-episode may go far towards providing valuable information and more comprehensive results.

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3. B. Taylor, The Relationship Between Ground-Level Ozone Concentrations, Surface Pressure Gradients, and 850 mb Temperatures in the Lower Fraser Valley of British Columbia, Atmospheric Issues and Services Branch, Atmospheric Environment Service, Pacific Region, Report PAES-92-3.
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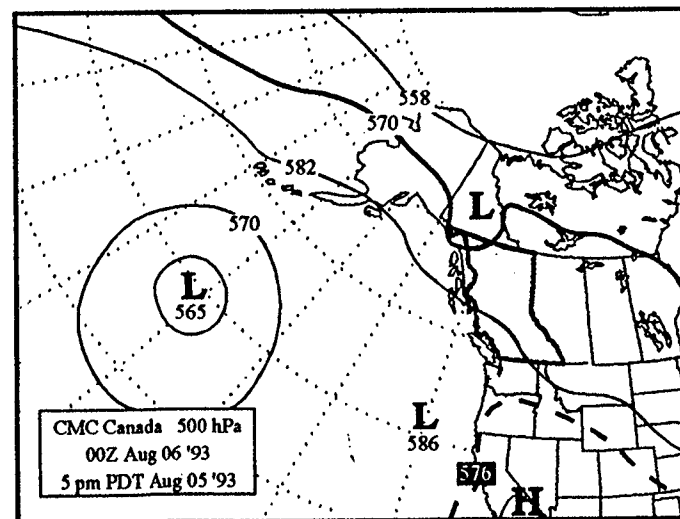
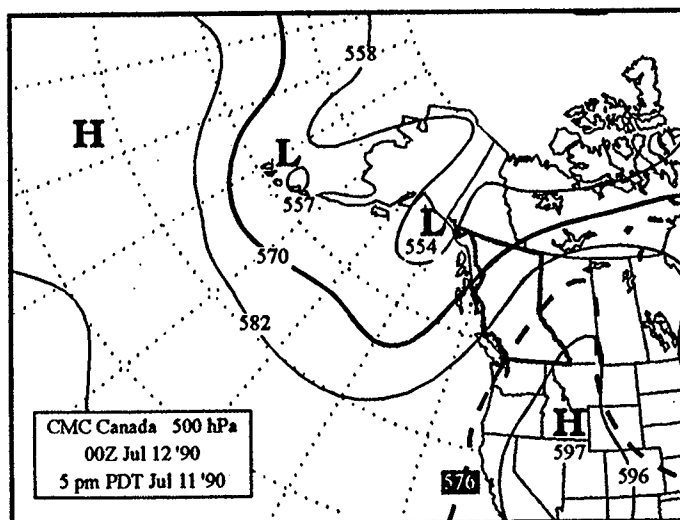
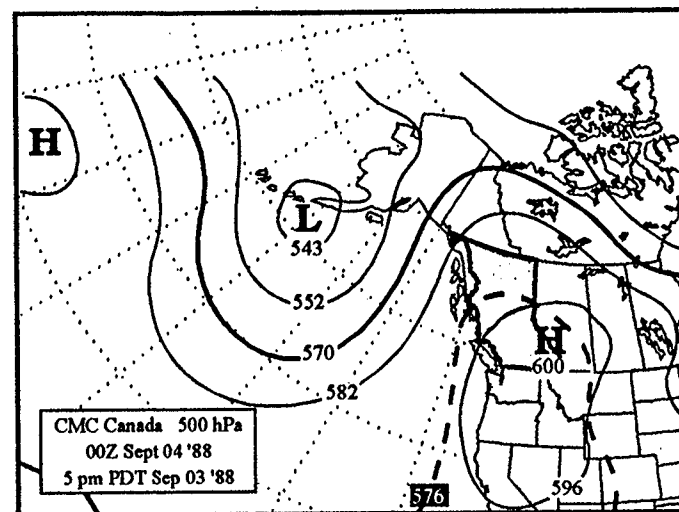
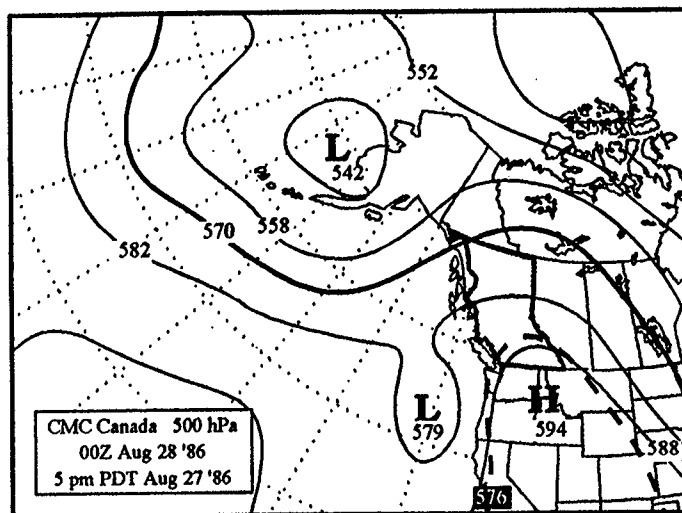


Figure 2

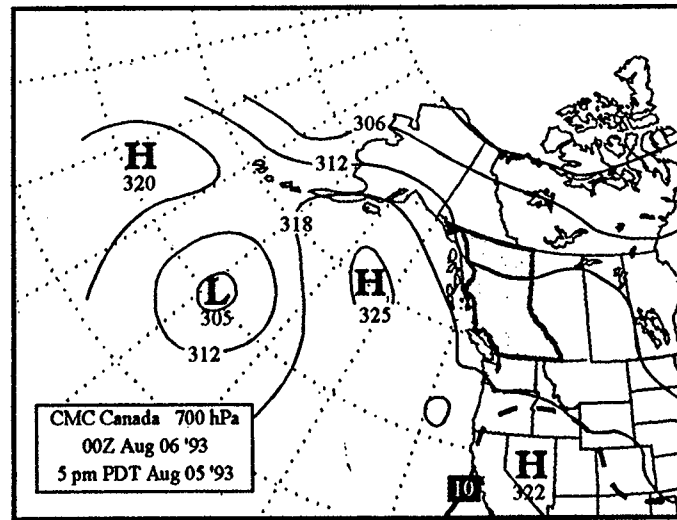
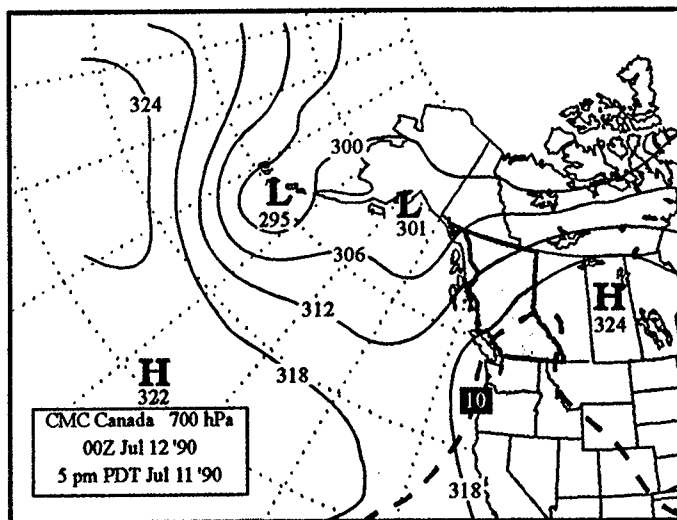
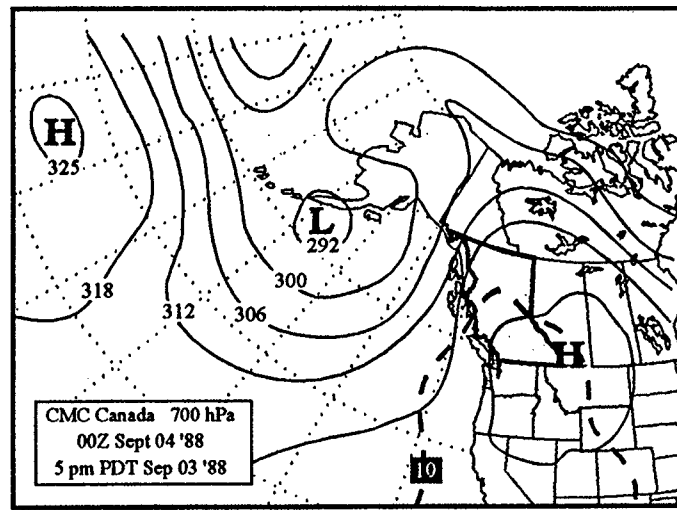
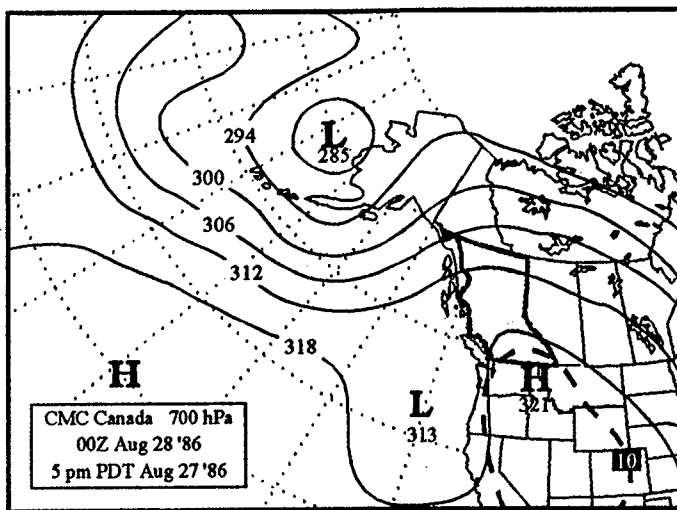


Figure 3

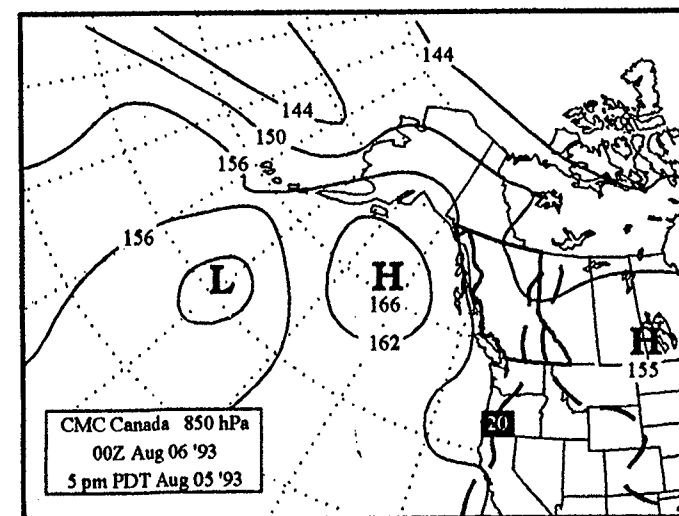
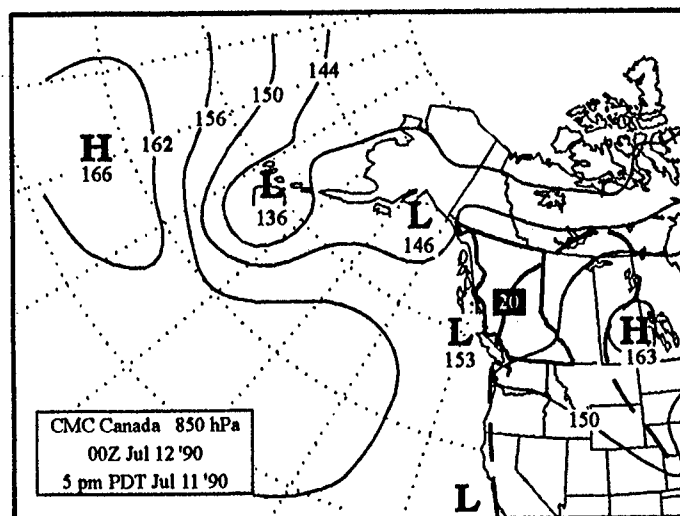
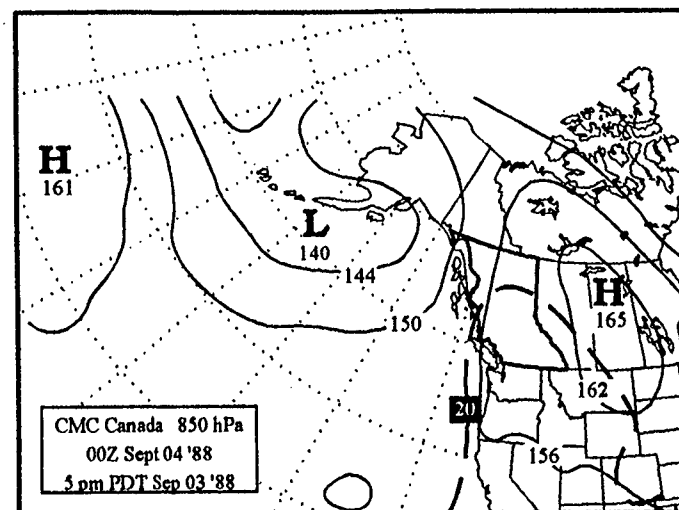
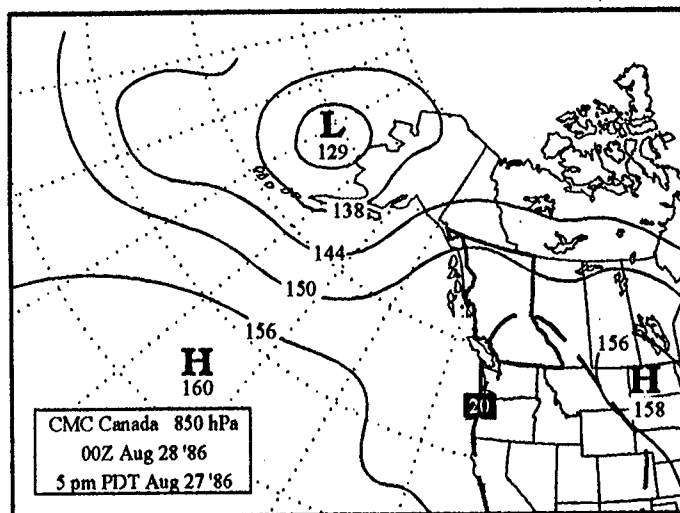


Figure 4

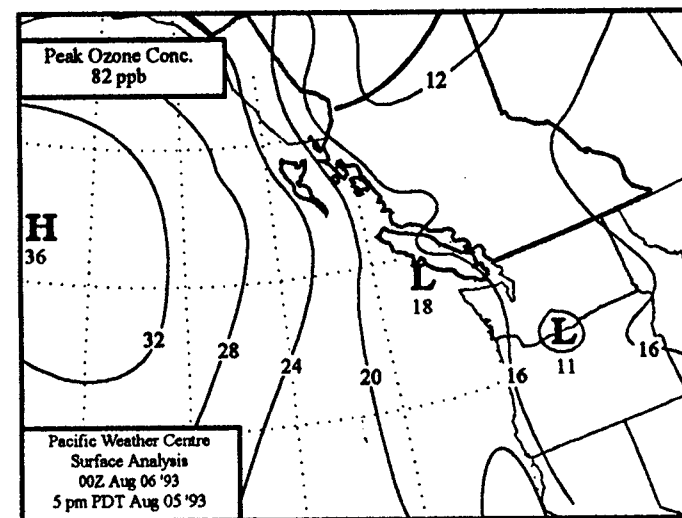
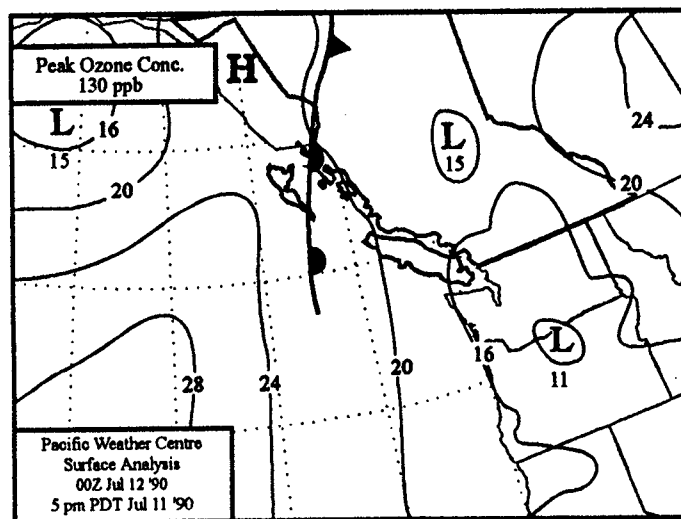
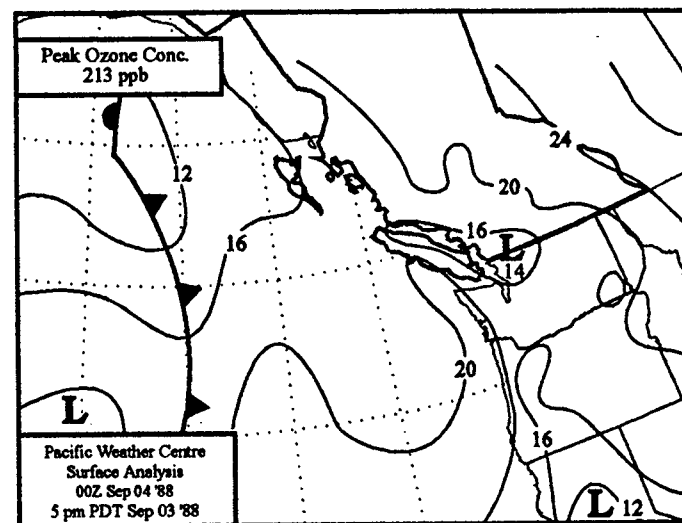
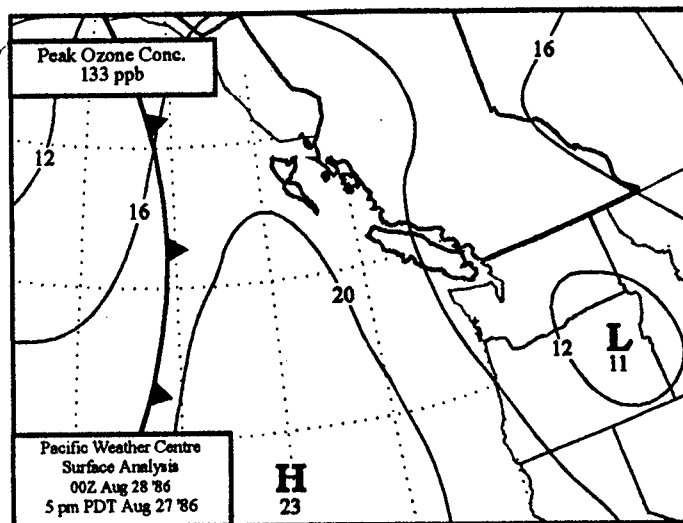


Figure 5