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1. Introduction:

The formation of photochemical SMOG in the Lower Fraser Valley (LFV) has been a topic of interest within the research community straddling the British Columbia/Washington border for several years. A research thrust is under way at the University of British Columbia (UBC) to consider modelling the meteorological and photochemical processes in the LFV during ground level ozone episodes. Similar interests have developed within Environment Canada and with the Institute for Environmental Chemistry, National Research Council Canada (NRC). These activities fall under the umbrella of a five year Canadian oxidant research plan prepared by the Canadian Institute for Research in Atmospheric Chemistry (CIRAC)[1].

In 1990, the Canadian Council of Ministers for the Environment (CCME) released the Management Plan for Nitrogen Oxides (NO_x) and Volatile Organic Compounds (VOCs)[2]. This management plan recognized three regions in Canada as Tropospheric Ozone Management Areas (TOMAs). One of the these areas is the LFV in southwestern British Columbia. The strategy introduced in Phase I of the Management Plan comprised of a national prevention program and interim emission reduction targets. To assess the effectiveness of these scenarios, a comprehensive modelling effort was initiated for the LFV.

As a result of the above initiative, a multi-year oxidant study for the LFV was developed. Combining the existing monitoring activities of the Greater Vancouver Regional District (GVRD) and the B.C. Ministry of Environment, Lands and Parks (BC MoELP) with new resources, this multi-year study surpassed the $10.0 million mark.

Activities in this study were centred around the development of a modelling system to describe the meteorology and photochemistry associated with production of elevated ground level ozone concentrations within the LFV. A comprehensive data set was needed that would increase the existing knowledge base and be used to initialize and validate the modelling system. This report describes the development and execution of an intensive field study to provide the comprehensive data set needed to further the research and application of photochemical models to the LFV.

2. Study Design:

The main partners involved with the planning stages of the study where CIRAC, Environment Canada and UBC who provided the necessary expertise to identify the detailed experiments and measurements required to successfully compile the data base. The area to be studied included the entire LFV: east to Hope, B.C.; south the Bellingham, Wash.; and west to the eastern slopes of Vancouver Island. It was realized that the modelling system would require meteorological and chemical data beyond the LFV to describe the boundary conditions for the study area. With this information, a surface and aircraft measurement program was developed.

An assessment of the available data for use in the photochemical modelling of ground level ozone episodes was the first task. A report was prepared (C.G. Voigt, et al., 1991)[3] which identified the existing data, data gaps and a strategy for acquiring the data needed to proceed with the modelling study. This report also reviewed the available literature on present and past field studies highlighting potential problems and identifying the required resource levels. The focus of the report was on the implementation of the Urban Airshed Model (UAM) to the LFV and the specific requirements of this modelling system. The scope of the study was broadened based on the experiences gained from other field studies and not restricted solely to the data needs of UAM.

It was necessary to acquire data that described the physical and chemical processes associated with the development and persistence of elevated concentrations of ground level ozone in the LFV. The modelling system would be expected to describe three situations: an episode with a fully developed sea/land breeze circulation; a day or series of days where ground level ozone concentrations were elevated above 82 ppb; days when the conditions appeared to be conducive for the production of an episode or elevated concentrations and none occurred. The type of data set required for each of these modelling scenarios is basically the same with slightly different spatial and temporal resolution. Awareness of these differences in the required datasets assisted with the field study design.

2.1 Surface Measurement Program:

Careful consideration of the types of meteorological and photochemical scenarios that the modelling system would be expected to replicate, assisted in the development of the field study. Documenting the three dimensional structure of the sea/land breeze, transfer of air in and out of the study area boundaries, and the spatial and temporal variations of the boundary layer depth were among the more important physical process to be considered. The complexity of the photochemical processes required measurements of ozone and precursors which included not only the oxides of nitrogen but also the biogenic and anthropogenic VOCs.

The existing air quality and meteorological networks operated by GVRD and the BC MoELP cover a large portion of the LFV.. These data points provided information on the spatial patterns of ground level ozone concentrations during the September 1988 episode (see Figure 1) and other cases of elevated ground level ozone concentrations (see Figure 2) The analysis of these spatial patterns identified two areas of interest. The first is located just east of Port Moody extending along the base of the north shore mountains. The second, is a broad area encompassing the central valley with concentrations increasing from the Aldergrove to Chilliwack portion of the eastern LFV. These patterns were used to place the surface chemistry sites and assist with the development of an aircraft sampling program.

Information about the depth and extent of the three dimensional flow pattern associated with the sea/land breeze and the exchanging of air in and out of the side valleys was necessary. Therefore, the surface measurements were complemented by two tethersondes, two doppler sodar units, an upper air/ozone sonde release site and a doppler LIDAR.

2.2 Aircraft Measurement Program:

The vertical profiles obtained from the surface sites provide point measurements of the meteorology and chemistry. An aircraft program was developed to measure the temporal and spatial variability of the atmospheric chemistry and meteorology over the entire LFV including variation of the boundary layer depth. Flights at 500 metres and 4000 metres transected the valley with "spirals" flown in the vicinity of the two surface sites. Atmospheric chemistry and meteorology over the eastern coast of Vancouver Island as well as the side valleys of the LFV were also part of the investigation.

3. Field Study - PACIFIC 93:

The climatology of elevated ground level ozone concentrations indicated that the best window for the study would be the last two weeks of July and the first two weeks of August. Study dates were July 15th to August 12th. Many partnerships were developed in order to complete all of the necessary measurement programs. The partners included CIRAC, Environment Canada, University of British Columbia, the National Research Council, B.C. Ministry of Environment, Lands and Parks, Greater Vancouver Regional District, York University, U.S. National Oceanographic and Atmospheric Administration, Unisearch and the University of Victoria. Using the available historical data and the above mentioned field study strategy, the field sites were located as shown in Figure 3.

3.1 Measurement Program:

The "fast chemistry" site was located at the north end of Harris Road (see Figure 3). This site was the main surface chemistry site with the most comprehensive measurement program (see Table 1). Data were collected 24 hours a day for the entire study period. Measurements were continuous in most cases with analyses completed on site for many of the chemicals. An exception were the VOC canister samples where 4 grab samples were taken per day with one being a replicate. The Differential Optical Absorption Spectroscopy (DOAS) instrument operated during the night and was interrupted only by the formation of mist and the occurrence of precipitation. Particulates were measured continuously using a Particle Mass

Selective Sampler (PMS) and an Active Spectrometer Aerosol Sampling Probe (ASASP). Particle light scattering B_{scat} was determined with an Optec nephelometer. A second measurement program was operated at the "mature chemistry" site located at CFB Aldergrove (see Figure 3). Measurements made at the Aldergrove site are summarized in Table 1. As at the Harris Road site, most of the measurements were continuous for the duration of the study. Exceptions were the $RONO_2$ and the VOC grab samples. Both of the sites had a full meteorological station measuring wind speed and direction, temperature and humidity. Rainfall was measured at the Harris Road site.

Profiles of O_3 and NO_2 as well as wind, temperature and humidity were measured with a tethersonde program at the Harris Road site. A similar program acquired O_3 and meteorological data further north over Pitt Lake. The tethersonde program operated daily through the period of elevated ozone.

Three dimensional wind patterns were measured over the LFV and several of the side valleys by a doppler LIDAR. The LIDAR performed both horizontal (RHI) and vertical (CAPPI) scans to provide a three dimensional analysis of the winds at micro to mesoscales.

Meteorological and ozone sonde releases were performed in Langley (T27 on Figure 3). During the earlier part of the study, meteorological sondes were released twice daily. A single ozone sonde was released during this period to acquire an ozone profile for a "clean" day. When the weather conditions became hot and sunny on July 31st, the program increased to 5 releases per day and included both meteorological and ozone sondes. The releases began at 5 am PDT (Pacific Daylight Time) with ascents at 11 am, 2 pm, 5 pm then ended at 8 pm. This program ended on August 6th as the weather again changed and concluded the period of hot weather.

As described earlier, an aircraft program was developed to investigate the entire valley. An on board, downward looking LIDAR measured the depth of the boundary layer and identified particulate plumes. The complete list of chemistry and aerosol instrumentation on the aircraft is given in Table 2. The data acquisition on the aircraft was capable of monitoring 140 channels every second. The flights began on July 19th including areal coverage of the eastern coast of Vancouver Island to the west, eastern end of the LFV as far as Hope, B.C. and as far south as Bellingham, Wash. To accommodate the LIDAR operation, flights were flown at just above 4000 metres with lower flights at 500 metres for the boundary layer chemistry and aerosol measurements (see Figure 4). Aerosol and chemistry data were taken during the 4000 m flights as well. From July 19th to August 10th, 16 flights were completed using over 65 hours of aircraft time.

3.2 Weather During Pacific 93:

The key to the development of ozone episodes in the LFV are the local meteorological conditions. An upper ridge creating a strong subsidence inversion that caps the Valley is critical to the development of the sea/land breeze circulation and subsequent building of pollution levels.

For the first half of the study period the LFV was dominated by unusually cool, unstable weather. Pollution levels were near background concentrations. Particulate and aerosol concentrations were elevated in some areas but generally conditions were very clean. The upper flow pattern changed slightly on July 31st with the ridge moving eastward clearing skies over the LFV and capping the valley with a weak inversion. These conditions lasted until August 6th when a push of moist Pacific air flushed the Valley of the air pollutants that developed over the preceding 6 days. Ozone concentrations ranged from high 80s (ppb) to low 90s (ppb) during the height of the period with aerosols and particulates creating poor visibility conditions in all areas of the Valley, particularly in the eastern sections between Chilliwack and Hope.

3.3 Results:

Tremendous quantities of data were generated through the many measurement programs active during the field study. The first report from Pacific 93 is the "meta-data" report which describes in detail the data and the sites. The datasets will be available to the principal investigators by the end of January 1994 with a data analysis workshop planned for early April.

4. Other Related Studies:

Prior to Pacific 93, flux studies of biogenic VOCs from an indigenous forest canopy were completed at a site on Vancouver Island. These measurements were taken to determine the contribution of biogenic VOC emissions to the overall inventory. An identified difficulty with existing biogenic inventories is the use of emission factors determined from studies performed in other areas of North America. This study will provide information on emissions from forest canopies characteristic of this region of B.C.

Except for the aircraft program, all of the measurements mentioned have been on the Canadian side of the LFV. Through the cooperation of the Northwest Air Pollution Control Association and the University of Western Washington, O_3, NO_x and meteorological parameters were measured at a number of locations in Whatcom County, Wash.

In the Canadian portion of the Valley, impacts of ground level ozone on health and vegetation were being monitored during the field study. A program to measure sensible and latent heat fluxes, radiation and UV flux density was also carried out in the Valley. The BC MoELP completed an extensive visibility measurement study, REVEAL, through the same time period as Pacific 93. An Interagency Monitoring of Protected Visual Environments (IMPROVE) sampler was located at the Harris Road site. Other IMPROVE samplers, transmissometer and nephelometer were sited in the eastern portion of the Valley.

5. Summary:

The field study, Pacific 93, which is part of major oxidant study in the Lower Fraser Valley, reached a successful conclusion. Elevated ground level ozone concentrations, precursors and aerosols were measured in considerable detail both temporally and spatially. Meteorological conditions were such that two of the required ozone scenarios were investigated. Conditions of complete capping of the Valley with a strong subsidence inversion and the development of a well established sea/land breeze circulation were not observed during the field study. Exchange of air between the LFV and adjacent regions was documented. The examination of the data is ongoing with a comprehensive analysis workshop expected in the spring of 1994.

References:

1. The Canadian Oxidants Research Program, Report prepared by the Canadian Institute for Research in Atmospheric Chemistry, 1991.

2. Management Plan for Nitrogen Oxides (NO_x) and Volatile Organic Compounds (VOCs): Phase I, Report prepared by the Federal-Provincial Long-Range Transport of Air Pollutants Steering Committee for the Canadian Council of Ministers of the Environment, 1990.

3. Voigt, C.G., D.G. Steyn and D.A. Faulkner, A Report on the Data Requirements for Atmospheric Modelling to Support the NO_x/VOC Program for the Lower Fraser River Valley. Prepared for Science & Professional Services, Department of Supply and Services and Atmospheric Environment Services, Pacific Region, Environment Canada, 1991.

Table I: Measurements and Instruments

Harris Road (fast chemistry) Site

Measurement	Instrument
O_3	TECO 49
NO/NO_2	Ecophysics
$HNO_3/NO_3^-/NH_3$	filterpack
NO/NO_y	Monitor Labs 8440 modified
SO_2	TECO 43S
RO_2H	HPLC
H_2O_2	Kok
NO_2 actinometer	Monitor Labs
CO	TECO 48
PAN	GC/ECD
VOCs	Chrompack
$RONO_2$	Cartridge
HONO	denuder
$HONO/NO_3^-/CH_2O$	TDL
particle size	PMS/ASASP
precipitation	sequential sampler
RO_2	radical-detector
profiles	tethersonde

Aldergrove (mature chemistry) Site

Measurement	Instrument
O_3	TECO 49
NO/NO_y	TECO 42S
NO_2	LMA-3
$HNO_3/NO_3^-/NH_3$	filterpack
PAN	GC/ECD
$RONO_2$	cartridge
CO	TECO 48
VOCs	canisters

Table II: Aircraft Measurement Program

Measurement	Instrument
Droplet Liquid Water Content	PMS King Probe
Droplet Liquid Water	Johnson Williams
Aerosol Spectrum (0.1-3)	PMS PCASP 100X Probe
Aerosol/droplet spectrum (0.3-20)	PMS FSSP 300 Probe
NO, NO_2	Unisearch LMA-3 NO/NO_2 Monitor
NO	ECO-PHYSICS
NO_y	Monitor Labs
O_3	TECO 49 Analyzer
O_3	Unisearch LMA-3 O_3 Analyzer
SO_2	TECO 43S
CO	TECO 48 (mod)
H_2O_2	Kok
Aerosol filtering system	3 stage;H^+,Na^+,NH_4^+,K^+,Ca^{++},Mg^{++},Cl^-,NO_3^-,SO_4^-,HNO_3,SO_2,NH_3
VOC	Canisters
PAN	GC
Aldehydes	Liquid Scrubbers
Aerosol Carbon	Aetholometer
Cloud and Precip Collectors	AES designed
Upwelling Solar Radiation	Eppley
Downwelling Solar Radiation	Eppley
Surface Brightness	Barnes PRT-5
Temperature	Rosemount (de-iced)
Temperature	Rosemount (non de-iced)
Temperature	NCAR
Dewpoint	Cambridge Hygrometer
Horizontal Winds; 3 axis gusts	IRS; Rosemount 858; TAS

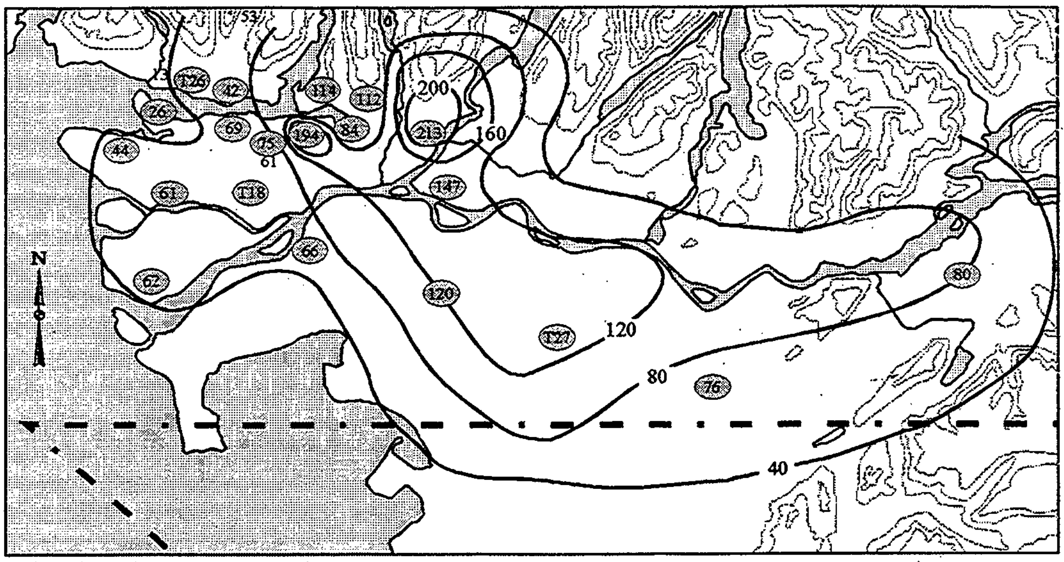

Figure 1. Surface ozone concentrations September 3, 1988 (5 p.m. PDT).

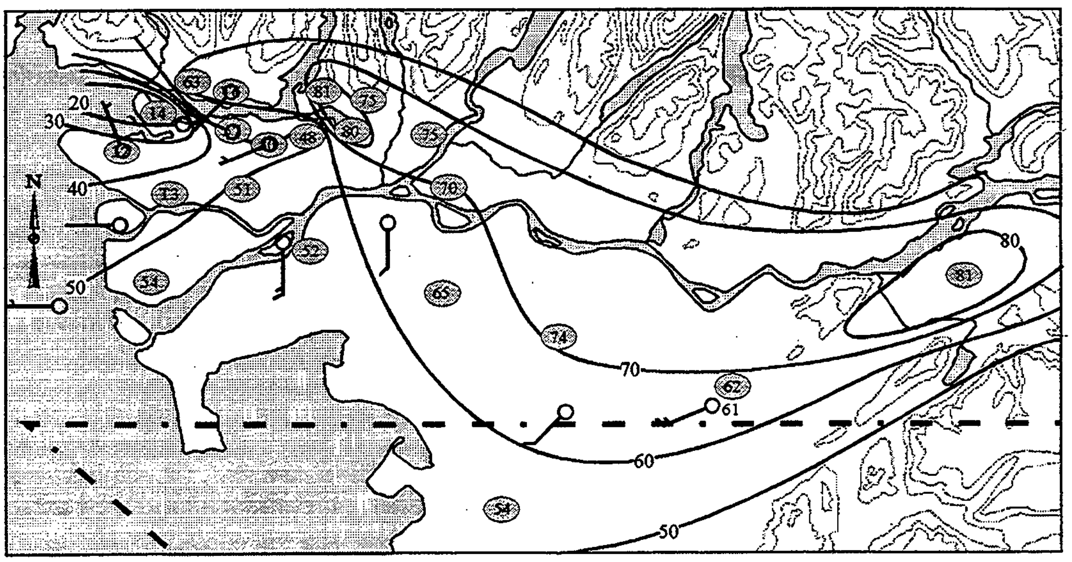

Figure 2. Surface ozone concentrations August 13, 1992 (5 p.m. PDT).

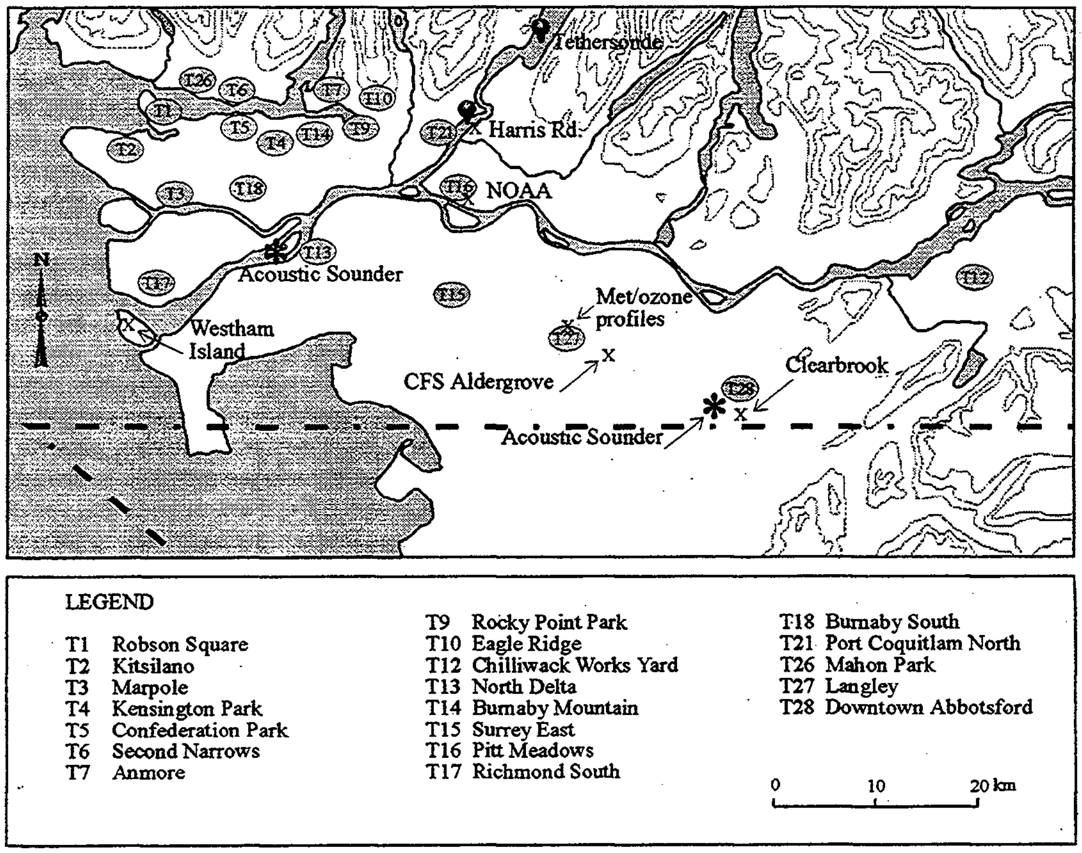

Figure 3. Field study sites in the Lower Fraser Valley during Pacific 93.

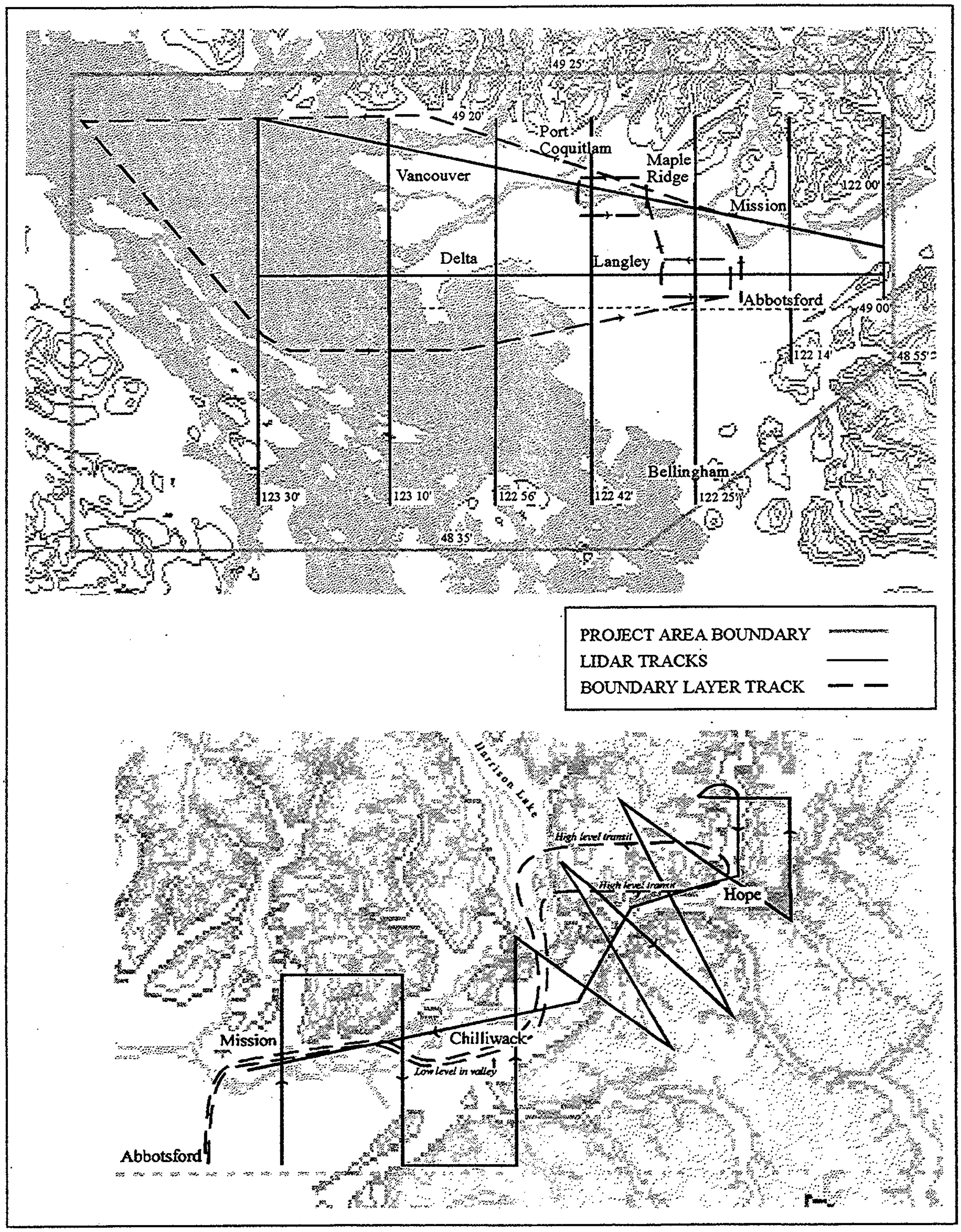

Figure 4. Flight patterns for aircraft measurement program during Pacific 93.