PACIFIC NORTHWEST 2001 (PNW2001)
A Field Study of Air Quality in the Seattle/Puget Sound Region

Principal Investigators
Leonard A. Barrie and W. Richard Barchet

Team Members
Michael Alexander, David Covert, James Cowin, Robert Disselkamp, Paul Doskey, Jerome Fast, Tom Jobson, Alex Laskin, Brian Lamb, Yin-Nan Lee, Nels Laulainen, Shutta Shuttahanandan, Chet Spicer, Hal Westberg

1. INTRODUCTION
1.1 Background

There is growing concern about the environmental and health effects of air pollution in the mountain-ringed region of Puget Sound/Georgia Basin in the Pacific Northwest (Figure 1). The population of this region is projected to increase by 50% in the next 10 to 20 years [2000 population is ~6.5 million people: ~3.5 in Puget Sound and 3 in the Georgia Basin]. Oxidants and particulate matter within the region can affect human health and visibility. Recognizing this, the EPA Northwest Center for Particulate Air Pollution and Health (director Prof. J. Koenig) has been established at the University of Washington.

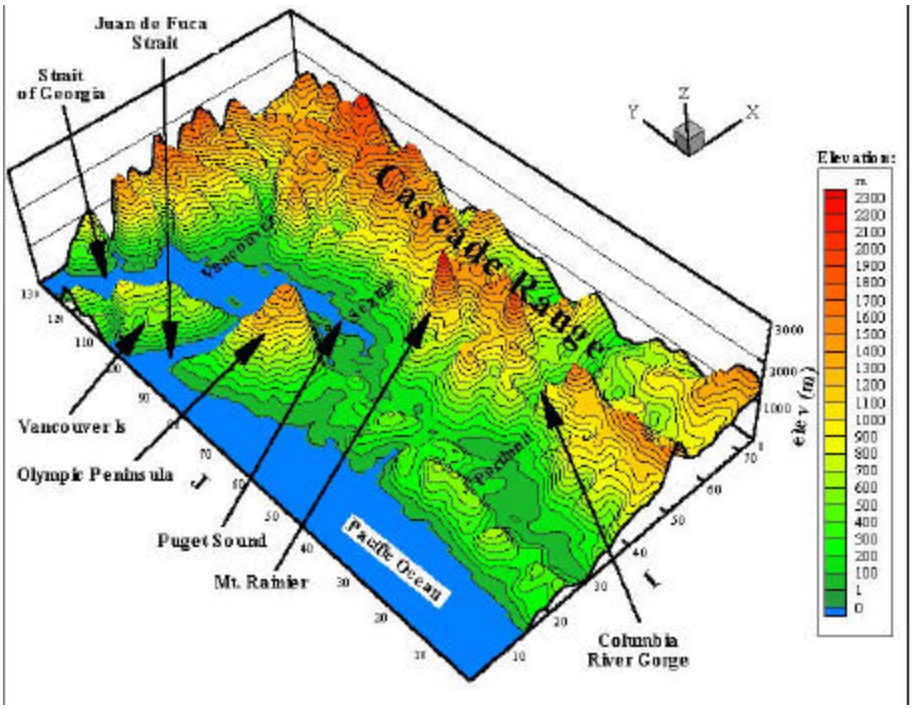

Figure 1 A three dimensional depiction of the mountain-ringed Georgia Basin and Puget Sound region where this study will be undertaken (courtesy of Brian Lamb).

Particulate and ozone air quality problems are present in the Pacific Northwest, as they are in many other large urban/industrial regions of the United States (Special Issue on Pacific 93 oxidants study, Atmospheric Environment, Volume: 31, Issue: 14, July, 1997; Barna et al.,

2000). Exceedances of the ozone NAAQS are periodically recorded in the north-south corridor from Seattle to Portland and annual mean $PM_{2.5}$ levels in Seattle are nearly at the proposed annual mean NAAQS of 15 ìg m^{-3}. Concurrent with elevated ozone is a reduction of visibility in the region. Reductions in visual range are especially noticeable because of the presence of 14,000-ft. Mount Rainier 50 miles to the southeast. Often during the summertime, the view of Mt. Rainier from Seattle is obscured by photochemical haze. Consequently, environmental groups have urged the Washington Department of Ecology to take steps to reduce particulate emissions in western Washington State.

EPA has proposed revised NAAQSs for ozone and particulates. When applied, the new ozone (80 ppbv 8-hr average) and fine particulate matter ($PM_{2.5}$) standards will require state regulatory agencies to reevaluate their existing emissions control plans. In order to ensure that the best decisions are made for controlling these two criteria pollutants, regulators will need to understand relationships between pollutant sources and air quality throughout the region. This will require 1) analysis of spatial and temporal variability in ozone concentrations, 2) investigation of the relationships between the anthropogenic and biogenic precursors (VOCs & NO_x) that produce ozone in the troposphere, 3) analysis of spatial and temporal variability in fine particle mass concentration and its chemical speciation and its relationship to the photochemical processes that produce ozone, and 4) a better understanding of the apportionment between primary and secondary sources of fine particle mass.

In this region of complex terrain, the occurrence of high pollution episodes is strongly modulated by synoptic scale atmospheric circulation (McKendry, 1994) and tends to peak in late July, August and September. As studies elsewhere have shown, synoptic conditions that produce clear skies, warm air, light winds and reduced mixing depths promote reduced air quality. What is significant in the Pacific Northwest is that such conditions are *not* associated with a stagnating anticyclone (as in eastern North America), but rather with the development of a low-level thermal trough in combination with an upper level ridge. The position, movement and strength of the thermal trough, the strength and inland penetration of the sea breeze as well as a host of precursor emission factors contribute to significant variations in air quality within particular synoptic types. McKendry (1994) concludes that while recognition of synoptic types and

sequences are useful in air quality prediction, it cannot replace an accurate photochemical model based on a detailed meteorological analysis and emissions inventory. An EPA sponsored attempt to model episodes of ozone in Puget Sound in 1996 (Barna et al., 2000) led to the conclusion that the Puget Sound region is sparse in air quality data needed for comprehensive model evaluation. This is particularly true for measurements above the ground. A combination of ambient measurements and air quality modeling will be required in order to determine the best approaches for remedying existing and preventing further air quality degradation.

The need to better understand the transport, distribution and chemical composition of pollutants that form ozone and particulate matter air pollution in the Seattle/Portland corridor has prompted this proposal to EPA(ORD) and DOE(OBER). The intention is to conduct an air quality measurement research campaign in August 2001 in parallel with a similar effort by a large multi-agency Canadian group led by the Meteorological Service of Canada (Pacific 2001) involving two aircraft. The coordinated national efforts fall under the auspices of the North American Research Strategy for Tropospheric Ozone (NARSTO) and under the Joint Statement of Cooperation on the Georgia Basin and Puget Sound Ecosystem signed in early 2000 by heads of the EPA and Environment Canada.

PNW2001 will involve a coalition of researchers from the Department of Energy, Environmental Protection Agency, Washington State Department of Ecology, and regional universities. The central component of this campaign will be airborne measurements with the Battelle Gulfstream-159 (G-1) aircraft instrumented with atmospheric chemistry and meteorological sensors. The lead scientists will be L. Barrie and W. R. Barchet of Battelle Pacific Northwest National Laboratory. Robert Wilson of EPA Region 10 will assist in coordinating our work with that being done on the development of air quality predictive modeling by the University of Washington (C. Mass) and the Washington State University (B. Lamb, H. Westberg). A regional science team will coordinate our proposed aircraft measurements with ground-based air quality measurements being conducted by other agencies in the study area.

1.2 Objectives and Research Products

The goal of the proposed research is to begin to address the following eight questions by making the first aircraft air chemistry observations in the region coordinated with ongoing regional monitoring and modeling:

1. Is there *transboundary transport of pollutants* aloft between Georgia Basin in Canada and Puget Sound during optimal ozone formation situations?
2. Are the *urban emission of NOy, CO and VOCs* used by predictive air quality models *consistent with observations*?
3. What is the *spatial distribution of O_3 precursors (biogenic and anthropogenic)* before and during ozone episodes?
4. Is there a significant difference in *O_3 production efficiency* in plumes from urban and large point sources of pollution?
5. How is *particulate formation and visibility* related to the photochemical degradation of aromatic and biogenic hydrocarbons?
6. What *chemical components of aerosols* are identifiable by single particle characterization and multi-elemental analysis techniques?
7. Do *polluted layers aloft* contribute to ground level ozone and particulate matter during daytime mixing in the Puget Sound region and to visibility reduction in Class 1 areas?
8. What is *the fate of Puget Sound pollution in late afternoon and early evening* as it moves into the foothills of the Cascades toward Class 1 air quality regions or towards the Portland, OR air shed?

How these questions are to be addressed is discussed in section 3.4. In short, we will make airborne measurements in the Vancouver, BC/Seattle, WA/Portland, OR corridor in conjunction with ground-level studies by universities and other agencies. We will quantify the distribution and transport of pollutants within this area, and together with air quality modelers develop a better understanding of the processes related to the formation of ozone and particulate matter. A highlight of this effort is the deployment on the G-1 of newly developed instruments for real-time VOC measurements, for single particle collection and analysis, and for bulk particle composition measurements. These new instruments are described in detail in section 3.2.1. We will work with regional and Canadian colleagues on the development of a data base that includes airborne and surface observations of chemical and meteorological distributions throughout the region and promote the use of this data base for air quality model evaluation and improvement.

Products of this research will be: (1) a unique air quality/meteorological data base that includes airborne and surface observations of chemical and meteorological distributions throughout the Puget Sound/Georgia Basin region; (2) insight into the distribution, transport and formation of

oxidants, particulate matter and their precursors in air above the ground in Puget Sound; (3) evaluation of inputs to, and performance of, air quality models in the region and (4) peer reviewed journal publications of the results.

Benefits of this project include: (1) an air quality/meteorological data base that can be used in development and evaluation of EPA air quality models that are key to the design of pollution abatement strategies, (2) a leveraging of resources between DOE and the EPA that will provide data for the first comprehensive testing of EPA air quality forecast models in the region using observations above the ground, and (3) a targeted analysis of model performance under conditions most likely to be important under the proposed revised NAAQS for ozone and PM.

2. PAST RESEARCH AND OBSERVATIONS

2.1 Oxidants

Exceedances of the proposed EPA 8-hour ozone standard occur in the Puget Sound region (Figure 2). With the expected increase of 2 million automobiles in Washington State in the next

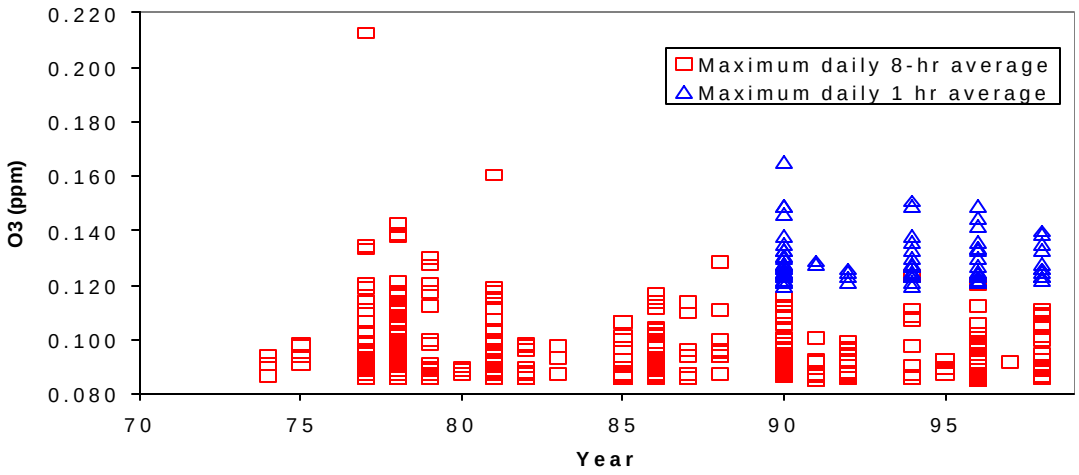

Figure 2. Exceedances of proposed NAAQS ozone standards in the Puget Sound region around Seattle (courtesy of Brian Lamb and the Puget Sound Clean Air Agency).

10 years, it is important to understand the effects of the growth of this pollution source on regional and urban air quality. Understanding the effectiveness of emissions controls on either VOCs or NO_x in reducing O_3 formation in urban areas requires specific knowledge of the area's emissions rates, meteorology, the absolute and relative amounts of VOC's and NO_x, and the regional background levels of both O_3 and precursors. It is generally accepted that the urban VOC/NO_x ratio is such that reductions in VOC emissions would lead to reductions in ozone by further limiting the production of peroxy radicals in the system. VOC emissions in the Puget Sound Region are dominated by mobile and area sources [Barna et al., 2000], source terms that will keep apace with population growth. Verifying emissions estimates with observations and keeping abreast of future changes to these sources in response to changes in the motor vehicle fleet and fossil fuel consumption will be critical for developing effective O_3 abatement strategies and for developing accurate air quality forecast modeling in this region under EPA's EMPACT program (see section 2.2).

A potential complication with urban O_3 control strategies is the dispersion of the urban plume over rural areas where emissions of biogenic hydrocarbons from vegetation can be significant. Biogenic hydrocarbon emissions will mitigate the effectiveness of urban VOC emission controls by supplying reactive organics back into the system [Barna et al., 2000]. Understanding the reactive hydrocarbon emissions from forested areas along the Cascades where the urban plume disperses will be important in assessing the regional effectiveness of VOC control strategies. Regional measurements of NO_x, O_3, and speciated VOC concentrations are therefore required to understand the photochemical evolution of an urban plume from an initially VOC limited system to a NO_x limited system as it disperses over rural areas.

The research community recognizes that ozone accumulation is a multi-scale phenomena involving emissions and chemistry at the urban scale, regional scale, and the large scale effects of long-range transport and mixing. This multi-scale process requires sampling by aircraft to properly assess the regional vertical and horizontal distribution of O_3 and its precursors. However, there have been very few airborne measurements in the Puget Sound region. The last recorded study was from August 23 to September 3, 1988 by a University of Washington student

Figure 3 Aircraft measurements from August 23, 28 and 1-3 September 1988 between 11:00 and 18:00 PST. Left panel - all flight paths. Middle panel - flight paths with ozone >80ppb. Right panel - flight paths with ozone >120ppb (from Basabe et al., 1989; courtesy of T. Larson)

flying a small aircraft instrumented with an ozone monitor in the afternoon boundary layer on the Cascade foothills side of Seattle (Basabe et al., 1989). A summary of his flight track and places where ozone exceeded 80 ppb and 120 ppb respectively are shown in Figure 3.

2.2 Oxidant modeling

The proposed field measurements will be leveraged with ongoing photochemical air quality modeling studies to provide a greater understanding of photochemistry in the Pacific Northwest than would be available from either program alone. Specifically, a group of our team members are involved in the development and evaluation of a real-time air quality forecast system for the Puget Sound area. This program is called the Air Indicator Report for Public Awareness and Community Tracking (AIRPACT). It is part of the national EPA EMPACT program designed to provide the public with timely environmental awareness. AIRPACT involves the coupling of the MM5 mesoscale meteorological model daily forecast operation at the University of Washington (UW) with the CALMET/CALGRID photochemical modeling system implemented at

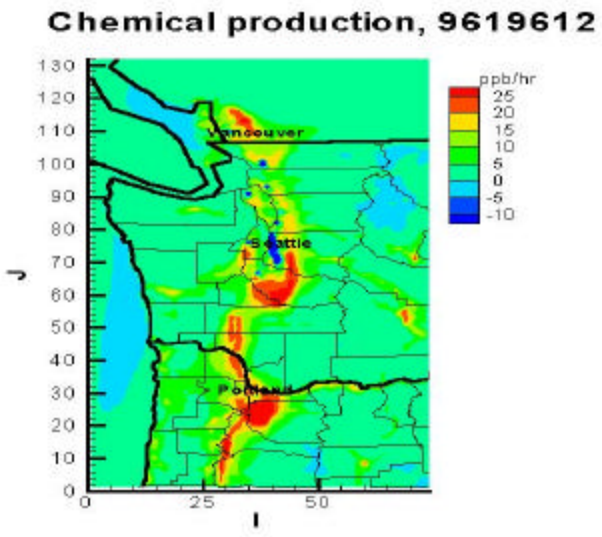

Figure 4 **Large scale map of CALGRID simulation of surface ozone production rates in the Pacific Nothwest at noon for the July 14, 1996 episode. The I and J co-ordinate axes are arbitrary grid point units. (courtesy B. Lamb).**

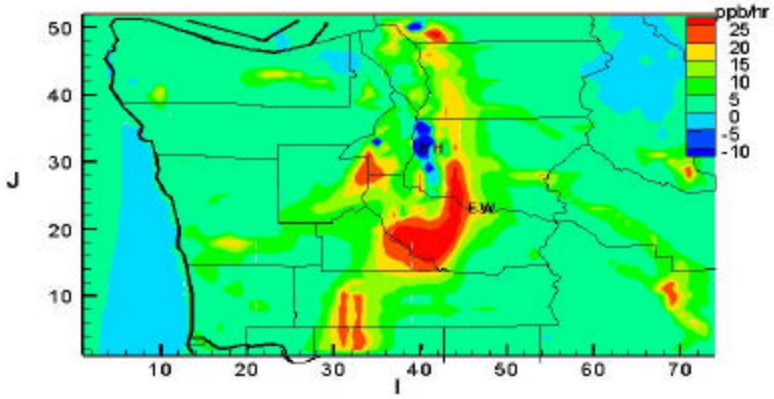

Figure 5 **Small scale map of CALGRID model simulation of surface ozone production rates in the Puget Sound region, the focus of this aircraft campaign, at noon for the July 14, 1996 ozone episode. The I and J co-ordinate axes are arbitrary grid point units. The Seattle urban plume and Centralia power plant plume are shown. (courtesy B. Lamb).**

Washington State University for regional ozone simulations in the Pacific Northwest (Barna et al., 2000; Barna and Lamb, 2000; Barna et al., 2001). The results are daily simulations of detailed air pollutant transport and transformation with 4-km horizontal grid cell resolution. This forecast system has recently been brought online and is currently producing daily forecasts of pollutant concentrations. However, until experience is gained with the system the forecasts are not being made available to the public. We expect that during the proposed field program, the MM5 meteorological forecasts and the corresponding AIRPACT air pollutant forecasts will be an extremely useful tool for designing flight patterns and for determining appropriate flight days.

The basis for AIRPACT is a regional modeling system for the Cascadia area of the northwest which extends from north of Vancouver, BC to south of Portland, OR and from west of the Pacific coastline to east of the crest of the Cascade Mountains. In initial work with this system, simulation of an ozone episode that occurred during July 11-14, 1996, showed that the meteorology in this area of complex terrain is difficult to simulate and that the pollutant spatial patterns are quite sensitive to the simulated wind fields. However, for this episode, observational nudging within MM5 produced a simulation with relatively good agreement between predicted and observed ozone concentrations. Beyond this, a process analysis scheme within CALGRID was implemented so that the model can be used to improve our understanding of ozone processes in this domain. For example, the maps in Figures 4 and 5 show ozone chemical production rates (ppb/hr) for noon on the day of the episode with the highest afternoon ozone concentrations. This map indicates where maximum ozone formation rates are expected to occur during the afternoon. These areas are located along the downwind edges of each major metropolitan area (Figure 4). There is also an interesting feature in the ozone production associated with the single large power plant in the region. Two parallel tracks of high ozone production are predicted along the eastern and western edges of the plume stretching south from the source (approximately grid point 32, 12 in Figure 5). Predicted concentration patterns and the results from this type of process analysis will be used to develop detailed flight plans to allow investigation of ozone formation under a range of different VOC/NO_x regimes within the domain.

2.3 Particulate Matter

Particulate matter (PM) is increasing in the Puget Sound region. The annual mean $PM_{2.5}$ level in Seattle is 13.5 ìg m^{-3} which is just below the NAAQS standard of 15 ìg m^{-3}. Research by the EPA Northwest Center for Particulate Air Pollution and Health have demonstrated that particulate effects on asthma and incidences of primary cardiac arrest are evident in the Seattle region (Norris et al, 1999; Sheppard et al, 1999; Yu et al. 2000 Levy et al, 2001). There is a lack of data on the chemical composition of ground level aerosols in the region. In an attempt to remedy this, an ad hoc group of researchers meet occasionally in the region to coordinate routine regulatory and university research observations on the chemical composition of particulate matter in this region. Air borne observations are even more scarce.

3. RESEARCH PLAN

3.1 Strategy

The strategy is to focus our research flights on synoptic situations that favor ozone and particle formation in Puget Sound and its surroundings. Pollution episodes in Puget Sound typically involve a ridge of high pressure aloft coupled to an underlying thermal trough along the west coast (McKendry et al., 1997). Northwesterly geostrophic flow aloft, relatively clear skies and transport from Georgia Basin lead to planetary boundary layer winds that are channeled by mountains of Vancouver Island and the Olympic Peninsula southward over Seattle and into the foothills of the Cascades. The decision to fly the G-1 on a particular day will be based on our analysis of predictions of meteorological and air quality conditions obtained from collaborators in the study. Over the course of the three week period, 13 through 31 August, we will conduct ~32 hours of flying involving seven flights including one test flight.

Forecast guidance for the decision to fly will be obtained from several sources. Prof. C. Mass at the University of Washington posts high spatial resolution (4 km) operational meteorological forecasts by the MM5 mesoscale meteorological model on a web site (http://www.atmos.washington.edu/data/). Prof. B. Lamb at Washington State University is developing an ozone forecast for the region using the CARB CALGRID air quality modeling system and expects to post them to a web site starting in May 2001. These research forecast products will be used in conjunction with information obtained from National Weather Service personnel in forecast offices in Seattle and Portland to decide whether to fly the next day. Episodes in which pollution gradually builds over a 2 to 3 day period would be the ideal scenario for G-1 deployment, in which case, three consecutive days of flying would be undertaken.

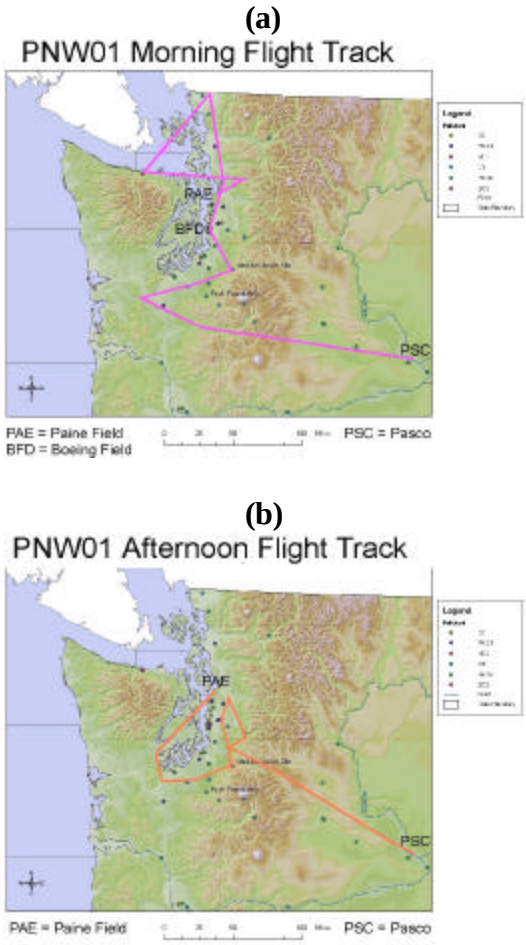

Figure 6 The flight tracks in morning (a) and afternoon (b). The Canadian Convair based in Vancouver, BC will fly the air space north of the border.

An important aspect of the G-1 aircraft deployment will be its coordination with enhanced VOC sampling on the ground by Prof. H. Westberg and the Washington State Dept. of Ecology (see section 3.2.2) and with flights by the Canadian Convair aircraft during Pacific 2001 to the north of the study area (see section 3.2.4).

One likely scenario of operation will be to fly the G-1 aircraft in the early morning from its home base in Pasco over the Cascades to a location near Chehalis, WA where a transect at ~500 m above ground level would be undertaken across the Seattle/Portland corridor to capture the remnant nocturnal outflow from the Puget Sound basin (see Figure 6a). Then the flight would

proceed northward with a touch-and-go approach at Boeing Field just south of downtown Seattle in order to sample urban emissions in the lower boundary layer. The morning flight leg would continue north to the Canadian border and end with a low level horizontal transect between Bellingham and Port Angeles broken in the middle by a vertical profile spiral up to 15,000 ft. The domains covered by the G-1 and the Canadian Convair aircraft would overlap in the Bellingham area. The flight would end with a low level transect from Port Angeles opposite Victoria BC to Paine Field in Everett, WA north of Seattle.

In the afternoon, after refueling at Bellingham or Everett, WA, the aircraft will be flown (Fig.6b) around the west side of Seattle-Tacoma and Olympia to Mason county, followed by a transect across the southern part of the basin to the foothills of the Cascades and, finally, fly a pattern that will characterize the spatial distribution of pollution in the foothills of the Cascades east and south of Seattle before returning to Pasco over one of the Mountain passes through which pollution leaves the basin. Exact flight paths will be determined by the need to define the nature and distribution of pollution within the boundary layer in the morning, to map the horizontal distribution of pollution upwind and downwind of major sources before and after the influences of vertical mixing and solar radiation, and to be well coordinate with local FAA air traffic control.

3.2 Measurements Campaign and Methodology

3.2.1 Aircraft Observations

Measurements to be made on the G-1 aircraft are listed in Table 1. This study takes advantage of a preceding Department of Energy Atmospheric Chemistry field campaign in June 2001 in Phoenix in which the aircraft will be instrumented with much of the equipment required for this study. This equipment will then be left on board for this study in August. In addition to these

Table 1 Meteorological and chemical measurements on the DOE G-1 aircraft.

Activity	*Instrument Mentors*
Gases	
[1]VOC real time PTR-mass spectrometry	Jobson and Alexander (PNNL)
[2]VOC canister (GC-MS)	Westberg (WSU), Jobson (PNNL) and Doskey (ANL)
HCHO (HPLC)	Lee (BNL) with Jobson (PNNL)
SO_2, NO/NOy, O_3, CO	Spicer (BCO) with Jobson (PNNL)
Aerosols	
Single Particle Analysis (SEM/EDAX/TOF-SIMS)	Cowin, Laskin, Gaspar (PNNL)
Mass, H, Multi-elemental 3 size-segregated	Barrie, Disselkamp, Shuttahanandan(PNNL)
Scattering, absorption, total N, PCASP	Laulainen, Barchet, Barrie (PNNL)
Ultrafine aerosol number 3-sizes	Covert (UW)
Meteorological	
dew point temperature air temperature wind velocity wind component fluctuations	Barchet (PNNL)
Radiation	
UV short-wave-irradiance long-wave irradiance	Laulainen (PNNL)

1. PTR-MS measurement of benzene, toluene, styrene, sum C_8 aromatics, sum C_9 aromatics, isoprene, methylvinylketone+methacrolein, monoterpenes, methanol, acetaldehyde, acetone, acetonitrile, HCN. Target species would be selectable in flight according to experiment objectives.
2. 75 Canister grab samples for C_3-C_{10} hydrocarbons (up to 24 per flight)

instruments, three newly developed aircraft instruments will be deployed. They will measure to measure VOCs in-situ, single particle composition, and bulk particle composition. We emphasize that these instruments will allow collection of new air quality data and will provide key insights with respect to our research objectives. A brief description of these instruments follows.

Proton Transfer Reaction Mass Spectrometer (PTR-MS) for VOCs

PTR-MS represents new technology for the measurement of VOCs in air. The instrument is sensitive enough that preconcentration is not necessary and thus it is capable of continuous *in-situ* measurements of VOCs with detection limits of about 50 pptv for a 10-s integration time. The principle of measurement is chemical ionization of VOCs by H_3O^+ and detection of the ionized VOCs by a quadrapole mass spectrometer. The H_3O^+ ions rapidly perform a non-dissociative proton transfer to many VOCs but do not react with the major constituents of air; O_2, N_2, CO_2, O_3 [Linderger et al., 1998]. The mass spectrometer measures the count rate of the protonated VOC mass and the H_3O^+ ion. The count rates are proportional to ion concentrations and from these values the concentration of the VOC in air is calculated. Because there is no gas chromatographic separation of the various VOC constituents, identification is done by mass alone. The list of uniquely identified species is thus relatively small but includes species that are important in air quality studies (see note in Table 1). The PTR-MS instrument was recently used at a highly instrumented surface site in Houston during the Texas 2000 Air Quality Study, and compared well with coincident VOC measurements made by standard gas chromatographic techniques (both GC/MS and GC/FID instruments). A key investigator in this study (Tom Jobson) was involved in this comparison. Importantly to this proposal, the PTR-MS will measure VOC distributions on much finer spatial and temporal scales than can be obtained with current gas chromatographic or canister sampling techniques and will allow us to better understand the statistical relationships between VOCs and other trace gases typically measured at 1 Hz sampling rates (i.e. CO, NO_y, O_3) and fine particulate matter sampled over at longer intervals.

Single Particle Composition

A key gap in our knowledge of aerosols is the chemical identity of individual particles in an ensemble of air borne particles. A high time resolution automated sampler (>= 30 s) is used to collected particles between 0.1 and 2.5 ìm and subsequently quantify the size and chemical identity of each particle by using an automated system of scanning electron microscopy (SEM) and single particle composition analysis (elements >= carbon) by electron induced X-ray emission spectroscopy. With 100,000 particles analyzed per day, excellent characterization of particles, particle classes, sources, and particle processing is possible. Measurements in Houston during the Texas 2000 Air Quality Study yielded insights into the time variation of nonvolatile components of the aerosol number size distribution as well as in changes in chemical composition associated with changes in photochemistry and the gaseous composition of the atmosphere. Figure 7 shows how single particle analysis spectra can be combined to follow particle chemistry versus time. These capabilities will be applied on board the G-1 aircraft and at Beacon Hill (see section 3.2.1).

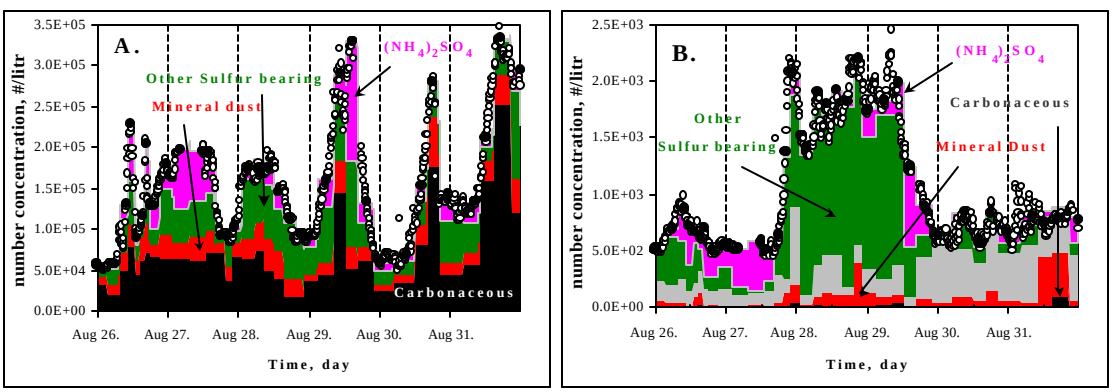

Figure 7 **Time series of the chemical components of A) fine particles (0.1 to 0.7 ìm) and B) coarse particles (0.7 to 2.5 ìm) collected on the roof of a tall office building in downtown Houston during Texas 2000 Air Quality Study in August 2000 by J. Cowin and A. Laskin.**

Bulk Aerosol Composition

High time resolution size-segregated collection of aerosols on board aircraft and *ex post facto* multi-elemental analysis by aerosol size has in the past been limited by the sensitivity of analytical detection techniques. The DELTA group of Prof. T. Cahill in collaboration with PNNL scientists (Barrie, Shuttahanandan, Disselkamp) have developed a 30 L/min, three stage, discrete-stepping, rotating drum cascade impactor sampler for particles below 2.5 ìm. High energy molecular and x-ray beam analytical techniques available at accelerators at PNNL and at the Advanced Light Source facility at Lawrence Berkeley National Laboratory will provide multi-elemental analysis of particulate samples collected at intervals of 5 to 10 minutes on board the aircraft. Elements from Na to Pb as well as particulate mass and H content are measured.

3.2.2 Ground Based Air Chemistry Measurements

Routine regulatory measurements of various gas and aerosol constituents are made at a number of sites in the I-5 traffic corridor by the Washington State Department of Ecology (WADOE) in cooperation with the Puget Sound Clean Air Agency (Figure 6). In addition, the WADOE is funding a routine ground based observational survey of VOCs by Prof. H. Westberg of Washington State University at 6 sites in the Seattle region (The Pilot City Toxic Sampling Program). By May of 2001, a site in Bellingham will be added to the toxics sampling network. Measurements are 24-hour integrated samples every sixth day.

VOC sampling will be enhanced in frequency and temporal resolution at the Beacon Hill site, one other downtown Seattle site to be determined and at Bellingham on days when the G-1 flies. Since determination of VOC concentrations at a surface site downwind of Seattle will be an important component of this study, WSU with help from WADOE will arrange for VOC sample collection at Enumclaw on G-1 flight days. Sampling will be done with Xontech automated canister and carbonyl systems. Three-hour integrated samples will be collected at the urban sites during the peak rush hour period (6-9AM) and in the afternoon (12-3PM & 3-6PM) at the downwind Enumclaw site. Canisters will be analyzed for C3-C12 VOCs in the same manner as the aircraft samples. [Carbonyl samples will be collected on DNPH coated silica cartridges and analyzed by high performance liquid chromatography.] This sampling network will yield

information on the VOC speciation of Seattle urban air and on processed urban emissions that impact the downwind Enumclaw site.

An intensive air chemistry and aerosol ground monitoring site is operated by the Washington Department of Ecology at Beacon Hill in the heart of Seattle. Measurements there by a consortium of government and university researchers are summarized in Table 2.

Table 2 A summary of ongoing and prospective measurements at Beacon Hill (courtesy of J. Frost).

Constituent Measured	*Investigator(s)*
Criteria Gases(continuous): CO, SO_2, NO_x, O_3	Dept. of Ecology
*VOC Canisters 1 hour integrated	H. Westberg
Carbonyls (DNPH integrated cartridge)	H. Westberg
$PM_{2.5}$ daily	Dept. of Ecology
Speciation of daily aerosol URG sampler	EPA (RTP)
New IMPROVE sampler	EPA and Cahill et al.
Aerosol Scattering (nephelometer)	Dept. of Ecology and U. of Washington
Aerosol Absorption Photometer(PSAP)	Dept. of Ecology and U. of Washington
Continuous Particle Number Size Distribution from 3 nm to 3000 nm, 5 min mean	D. Covert, U. of Washington

*** to be added during field campaign**

On each flight day, ozone vertical profiles will be measured at Enumclaw at 13:00 and 16:00 LST by Jerome Fast of PNNL in collaboration with EPA region 10, the Department of ecology and Washington State University.

In addition, Dan Jaffe of the University of Washington under EPA (OIA) will be measuring CO, O_3, aerosol chemistry and Hg(0) at Cheeka Peak on the west coast of the Olympic Peninsula during this study. These continuous surface measurements will provide additional information on inflow conditions to the Puget Sound region. D. Jaffe also has NSF funding to conduct vertical profiles of selected air chemistry constituents using a light aircraft in collaboration with I. McKendry of the University of British Columbia. Some of these flights may be undertaken during the PNW2001 period. Finally, measurements of NO_y in the basin are lacking and D. Jaffe has proposed to regional sponsors to do this at a selected ground level site. Enumclaw,

downwind of Seattle during ozone episodes, would be a prime candidate for such a site. This would complement ozone measured at the site and match aircraft NO_y measurements (see section 3.2.1)

3.2.3 Ancillary Meteorological Cooperation

We are working closely with Prof C. Mass, University of Washington, who is running and evaluating the MM5 meteorological driver of the air quality predictive system and with the meteorological community at the Pacific Northwest National Laboratory to optimize meteorological information during this campaign.

3.2.4 Coordination With The Pacific 2001 Study

Pacific 2001 involves a large contingent of Canadian provincial and federal scientists mounting an air quality study of particulate matter and ozone formation in the Vancouver and Georgia Basin region. Led by the Air Quality Research Branch (S.M. Li Chief scientist; D. McKay Director) and B. Thomson of the Pacific/Yukon Region of the Meteorological Service of Canada, a study involving three major ground-based supersites and two aircraft will be mounted (see Appendix B for the Tables listing instrumentation at each of these sites and in the aircraft). One aircraft, the Convair, will carry an upward and downward looking aerosol lidar measuring vertical profiles of aerosol scattering and a total column FTIR instrument as well as *in-situ* ozone and aerosol size distribution measurement equipment. The flight plan will involve much flying at 5-km altitude and deep vertical profiles in the border area near Bellingham. A small Cessna aircraft will also be used to obtain vertical profiles of a limited set of gases and aerosols above the intensive ground sites in the Fraser Valley.

At least two air quality models will be run for the Vancouver district. The EPA CMAQ model will be exercised by D. Singleton's group at the National Research Council of Canada. This work is closely related to that by the Washington State University group led by Prof. B. Lamb that is implementing CMAQ for EPA Region 10. The second air quality model is the AURAMS high resolution unified air chemistry and sectional air quality model of the Air Quality Research Branch of the Meteorological Service of Canada (M. Moran, P. Makar, W. Gong, S.L. Gong).

The comprehensive aerosol data set generated by Pacific 2001 will be very useful in testing the accuracy of CMAQ aerosol model in the region and therefore is of relevance to producing better ozone and particulate matter predictions in the US Pacific Northwest.

3.3 Air Quality Modeling For PNW2001

As indicated previously, our collaborators at Washington State University will run the AIRPACT forecast modeling system (MM5/CALGRID) during the study period. Forecast results will be automatically archived so that detailed comparison of model predictions and PNW2001 observations can be conducted after the field study phase. Because the initial version of AIRPACT is aimed at gas phase pollutants, their emphasis in the evaluation of AIRPACT will be on ozone precursors and products.

To extend the AIRPACT evaluations, they also anticipate using results from the field program to evaluate simulations obtained using the MM5/CMAQ modeling system. They are currently involved in applying this system to a regional haze episode in the Pacific Northwest. In the first phase of this work, they are comparing CALGRID and CMAQ results for a July 11-14, 1996 ozone episode. In the second phase, they will be simulating a July, 1996 haze period for a three state domain covering ID, OR and WA and extending north of Vancouver, BC. For the proposed work, our WSU collaborators will identify one or two episodic periods and conduct runs of MM5/CMAQ for comparison to the aircraft and ground observations. This comparison will include both gas and particulate pollutants. The emphasis in this evaluation will be to develop an understanding of pollutant fate in the atmosphere. To address this, they will implement process analysis tools available within CMAQ along with a novel back-trajectory source footprint method that has been developed for use with their modeling systems.

3.4 Project personnel and Responsibilities

The project coordinators, L. Barrie and W. R. Barchet of PNNL, are responsible for the day-to-day activity on the project. A regional science team (Table 3) has been assembled to coordinate aircraft measurements with other air quality measurement and modeling activities in the region. Instrument mentors have been identified for the various measurements being made on board the G-1 (see section 3.2, Table 1).

Table 3 The regional science team for PNW2001.

Collaborator	***Affiliation***
Barrie, Leonard	Chief Atmospheric Chemist, PNNL, Science coordinator
Barchet, W. Richard	Manager, Atmospheric Science Technical Group, PNNL, Aircraft measurements coordinator
Fast, Jerome	Lead scientist for PNNL high resolution PEGASUS chemical transport model
Wilson, Robert	Regional meteorologist, EPA region 10, Air chemistry coordinato
Arnold, Jeff	EPA Region 10/ EPA (ORD), Air chemist, model evaluation
Westberg, Hal	Prof. Washington State U., VOC air chemistry and emissions
Lamb, Brian	Prof. Washington State U., EPA supported ozone/PM modeling
Larson, Tim	Prof. U. of Washington, EPA Northwest Centre for Particulate Ai Pollution and Health (Director J. Koenig)
Covert, Dave	Prof. U. of Washington, aerosol measurements
Jaffe, Dan	Prof. U. of Washington, gas and aerosol measurements Cheeka Pe
Mass, Cliff	Prof. U. of Washington, regional meteorological modeling, MM5
Harrison, Halstead	Prof. U. of Washington, atmospheric chemistry
Kircher, David	Puget Sound Clean Air Agency, Manager of Engineering Service
Maykut, Naydene	Puget Sound Clean Air Agency, Air quality scientist
Williamson, John	Washington State Department of Ecology, Northwest Regional O
Bowman, Clint	Washington State Department of Ecology, Air Quality
Thompson, Bruce	Pacific Yukon Region, Environment Canada, Pacific 2001 Coordinator
Li, Shao-Meng	Chief Scientist, Environment Canada, Pacific 2001 Campaign

3.5 Milestones And Deliverables

The proposed research will be carried out in two phases. Phase-1 in FY01 is the observational campaign and Phase-2 in FY02 is analysis, interpretation, presentation and publication of results. Table 4 gives the schedule for major activities and events in the project.

Table 4 Major project milestones and deliverables.

Date	*Activity*
early February, 2001	Preliminary coordination meeting of all major players
late April, 2001	Comprehensive planning workshop
early August, 2001	Instrumentation of the aircraft
13 - 31 August	Test flight and measurements within this 3-week field campaign
early 2002	Data analysis workshop in collaboration with Canadian Pacific 2001 researchers
mid 2002	Quality assured data set to NARTSO archive
December 2002	Special session at AGU in San Francisco.