CLOUD AND AEROSOL RESEARCH GROUP

SUMMARY OF FLIGHTS AND TYPES OF DATA
COLLECTED ABOARD THE UNIVERSITY
OF WASHINGTON'S CONVAIR-580 RESEARCH
AIRCRAFT IN IMPROVE-II: OROGRAPHIC STUDIES
(26 NOVEMBER–22 DECEMBER 2001)

Compiled
by
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FOREWORD

The second field phase of the Improvement of Microphysical PaRameterization through Observational Verification Experiments (IMPROVE) took place between 26 November and 22 December 2001 over the Oregon Cascade Mountains (hereafter referred to as IMPROVE-II). This report provides a guide to the measurements obtained aboard the University of Washington's (UW) Convair-580 research aircraft in IMPROVE-II.

Contained herein are listings of the instruments aboard the UW Convair-580 in IMPROVE-II, the flights carried out, and summaries of the main accomplishments of each flight.

This report is available at the ftp address:

ftp://ftp.atmos.washington.edu/debbie/IMPROVE-report/IMPROVE2-MASTER.pdf

Corrections and updates to this report will be posted at:

http://cargsun2.atmos.washington.edu/sys/research/improve/

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1. GOALS OF IMPROVE

The goals of IMPROVE are:

- To obtain comprehensive, quantitative measurements of cloud microphysical variables in a variety of cloud and precipitation systems.
- To obtain corresponding dynamic and thermodynamic measurements (3-D wind, temperature, and humidity fields) within and around these systems, to provide the meteorological context in which the cloud microphysical processes and precipitation events occurred.
- To perform simulations of a number of the case studies with a mesoscale model (MM5) that includes bulk microphysical parameterizations (BMP).
- To use the cloud microphysical measurements obtained in the field to evaluate the concentrations and size distributions of all the model-simulated hydrometeor variables.
- To perform tests of model sensitivity to parameters and assumptions in the BMP.
- In light of these studies, to make improvements as needed in the BMP.

To provide data for exercising the model simulations on a wide variety of precipitation systems, two field studies were carried out in support of IMPROVE. An overview of IMPROVE-I field studies, which concentrated on frontal precipitation systems, has been described by Hobbs

(2002).* The Convair-580 measurements in the second field study (IMPROVE-II), which concentrated on orographic precipitation, is described in this report.

2. OVERVIEW OF IMPROVE-II OROGRAPHIC STUDIES

The second field phase of IMPROVE, carried out between 26 November and 22 December 2001, concentrated on orographic precipitation. These studies were carried out in the west-central Oregon Cascade Mountains, between Mount Jefferson and North Sister Mountain. In this region, the Cascades consist of essentially one north-south oriented ridge, about 2,000 m high.

The facilities deployed in this region are depicted in Figure 1.1. As in IMPROVE-I, cloud and precipitation microphysical measurements were provided primarily by the UW Convair-580 research aircraft. Air motions, required to place the microphysical measurements in context, were provided by the fore-aft-scanning X-band Doppler radar on a NOAA WP-3D Orion (P-3) aircraft. The P-3 generally flew a prescribed flight path above the Convair-580 as the latter aircraft obtained in situ measurements across the Cascades.

Other field facilities included the NCAR S-Pol Doppler radar, a 915 MHz wind profiler, dedicated rawinsonde launches, special precipitation gauges, personnel on the mountain to observe snow crystal types, the Pacific Northwest National Laboratory PARSL remote sensing unit, and disdrometer measurements for raindrop size distributions on the ground (see Figure 1.1).

* Hobbs, P. V., "Summary of Flights and Types of Data Collected Aboard the University of Washington's Convair-580 Research Aircraft in IMPROVE-I (Frontal Studies) (4 January–14 February 2001)," Technical Report for IMPROVE-I Field Project, University of Washington, Seattle, WA, 67 pp, 2002.

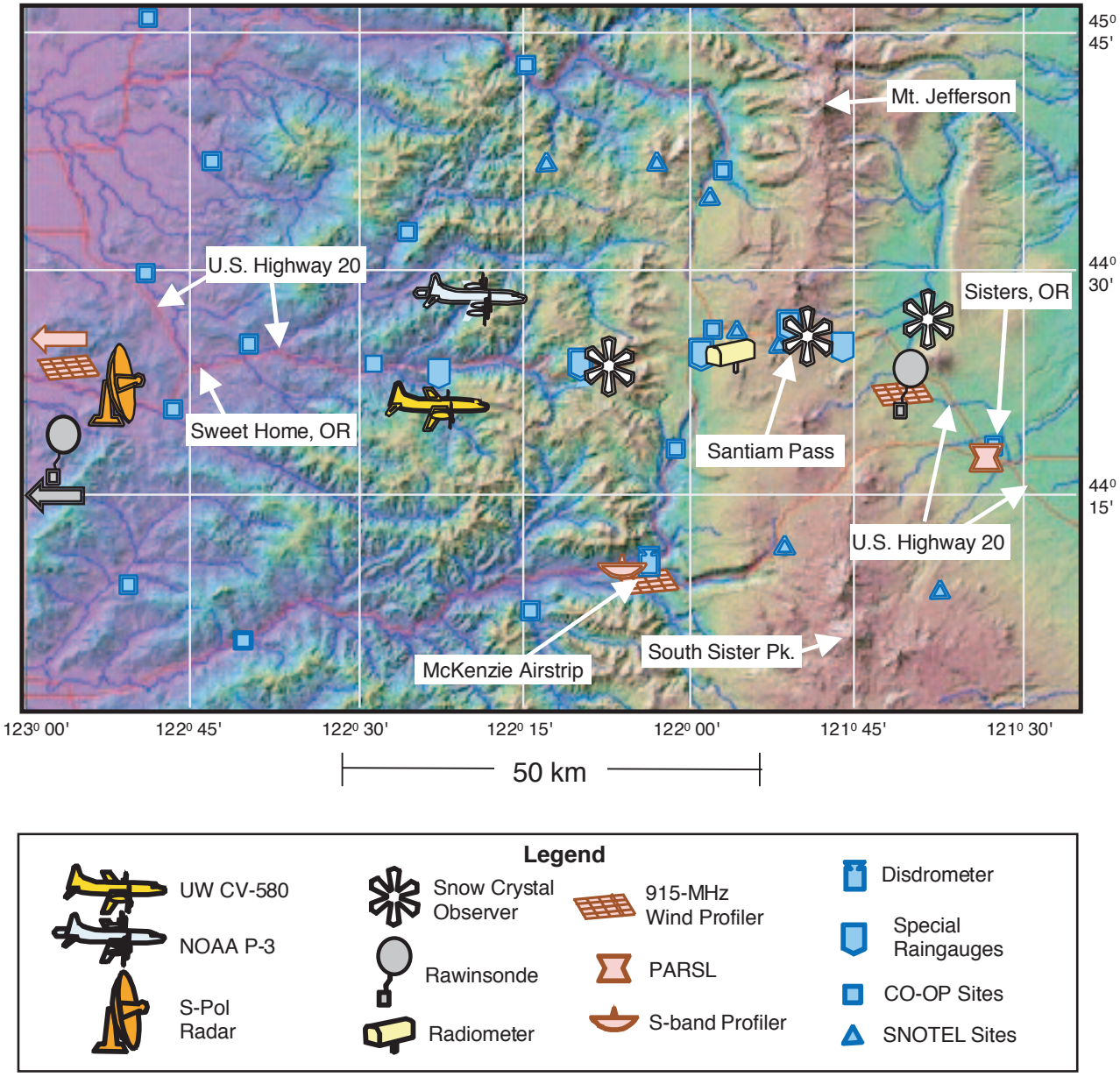


Figure 1.1. Observing facilities for IMPROVE-II.

3. INSTRUMENTS ABOARD THE UNIVERSITY OF WASHINGTON'S CONVAIR-580 RESEARCH AIRCRAFT IN IMPROVE-II

The instruments aboard the UW Convair-580 research aircraft for IMPROVE-II are listed in Table 3.1. In view of the goals of IMPROVE, emphasis was placed on obtaining in-situ cloud microphysical and precipitation measurements.

4. CONVAIR-580 FLIGHTS AND FLIGHT TRACKS IN IMPROVE-II

Sixteen flights, totaling about 59 research hours, were flown by the UW Convair-580 research aircraft in IMPROVE-II during the period 26 November through 22 December 2001. Table 4.1 lists the dates, times and main accomplishments for each of these flights.

Figures 4.1-4.16 show the flight tracks on both horizontal and vertical cross-sections for each of the Convair-580 flights.

5. SUMMARIES OF ACCOMPLISHMENTS OF THE CONVAIR-580 FLIGHTS IN IMPROVE-II

Two types of summaries for the Convair-580 flights in IMPROVE-II are provided in this section.

The first set of summaries (given in Section 5.1 below) are those written by the Convair-580 Flight Scientist. These contain brief statements on the main goals of each flight, the general location of the flight, weather conditions, the main accomplishments of each flight, the main instrument malfunctions, and (in most cases) a detailed timeline of activities during the flight.

Complete typed transcriptions are available for all of the in-flight voice recordings made on the Convair-580 in IMPROVE-II. These "blow-by-blow" accounts provide detailed information on what transpired on each flight. However, because of their large bulk, these transcriptions are

(Continued on Page 30)

TABLE 3.1. INSTRUMENTS ABOARD THE UNIVERSITY OF WASHINGTON'S CONVAIR-580 IN IMPROVE-II

(a) Navigation and Flight Characteristics				
Parameter	**Instrument Type**	**Manufacturer/Model**	**CARG Data System Parameters**	**Performance**
Latitude, longitude, ground speed, horizontal winds	GPS (Pilot's) and Trimble TANS Vector	Trimble TANS Vector	tans-lat, tans-lon, tans-alt, tans-grspeed, wind_dir, wind_spd,	No major problems.
True Airspeed	Variable capacitance	Rosemount Model F2VL 781A	tas	Iced over on UW Flights1894, 1895.
Heading	Standard GPS	Trimble TANS Vector	tans-azimth	No major problems.
Pressure	Variable capacitance	Rosemount Model 830BA	pstat	Instrument Problems: 1895.
Altitude above terrain	Radar Altimeter	Bendix Model ALA 51A	ralt	No major problems.
Altitude	Standard GPS	Trimble TANS Vector	tans-alt	No major problems.
Pitch and Roll	Standard GPS	Trimble TANS Vector	tans-pitch, tans-roll	No major problems.
(b) General Meteorological Parameters				
Parameter	**Instrument Type**	**Manufacturer/Model**	**CARG Data System Parameters**	**Performance**
Total Air Temperature	Platinum wire resistance	Rosemount Model 102CY2CG and 414 L Bridge	ttot (derived parameter: tstat)	Noisy, but usable.
Static Air Temperature	Reverse-flow thermometer	In-house	ttotr (derived parameter: tstatr)	No major problems. (This provides a better temperature than the platinum wire resistance temperature.)

(Cont.)

Table 3.1 (continued)

(b) General Meteorological Parameters (continued)				
Parameter	**Instrument Type**	**Manufacturer/Model**	**CARG Data System Parameters**	**Performance**
Dew Point	Cooled-mirror dew point	Cambridge System Model TH73-244	dp (derived parameter: rh_chl)	No major problems.
Absolute Humidity	IR optical hygrometer	Ophir Model IR-2000	rhovo (derived parameter: rh_o, dp_o)	No major problems.
UV hemispheric radiation, up and down	Diffuser, filter (0.295 to 0.390 um)	Eppley Lab. Inc. Model TUVR	uvup, uvdo (derived parameters: uvalb)	No major problems.
VIS-NIR hemispheric radiation, up and down	Eppley thermopile (0.3 to 3 um)	Eppley Lab. Inc. Model PSP	pyrup, pyrdo (derived parameter: pyralb)	No major problems.
Surface radiative temperature	IR radiometer 1.5 FOV (8 to 14 um)	Omega Engineering OS3701	irtemp	No major problems.
Video Image	Forward-looking camera and time code	Ocean Systems Splash Cam	SVHS tape.	No time code on UW Flight 1894, otherwise no major problems.

(Cont.)

Table 3.1 (continued)

(c) Aerosol				
Parameter	**Instrument Type**	**Manufacturer/Model**	**CARG Data System Parameters**	**Performance**
Cloud Condensation nucleus spectra	Thermal Diffusion chamber	Univ. of Wyoming/NCAR	ccnrt, ccnss, ccntoptemp, ccnvdet, ccnastat, ccndtemp, ccnlpower	No major problems.
Number concentration of particles	Condensation particle counter	TSI Model 3022A	cnc1	Instrument & piping problems on UW Flights 1891, 1892, 1894-1906
Number concentration of particles	Condensation particle counter	TSI Model 3025A	cnc2	Instrument & piping problems on UW Flights 1891-1894, 1899-1906
Size spectrum of particles	35 to 120 deg light-scattering	PMS PCASP-100X	pcaspn, pcaspt, pcaspdl, pcaspcc, pcaspcw, pcaspa (derived parameters: pcaspdn, pcaspdnc, pcasprt, pcaspa)	No major problems.
Size spectrum of particles	Forward light-scattering	PMS FSSP-100	fspn, fspt, fspdl, fspcc, fspcw (derived parameters: fspdn, fspdnc, fsprt, fspsa, fspsr)	No major problems.

(Cont.)

Table 3.1 (continued)

(d) Cloud Physics				
Parameter	**Instrument Type**	**Manufacturer/Model**	**CARG Data System Parameters**	**Performance**
Liquid water content	Hotwire resistance	Johnson-Williams	lwjw	Instrument never operated properly after lightning strike on UW Flight 1859 in IMPROVE-I.
Liquid water content; particle surface area; effective droplet radius	Optical sensor	Gerber Scientific Ins.	lwpvm, sapvm, erpvm	No major problems.
Size spectrum cloud particles	Forward light-scattering	PMS FSSP-100	fspn, fspt, fspdl, fspcc, fspcw, fspsa (derived parameters: fspdn, fspdnc, fsprt, fspsr, lwfsp)	No major problems.
Size spectrum of cloud and precipitation particles	Diode occultation	PMS OAP-200X (1D-C)	cpn, cpdl, cpd, cpt, cpcc, cpsa (derived parameters: cpdn, cpdnl, cpdv, cprt)	Data recorded on all flights but needs to be QA.
Images of cloud particles	Diode imaging	PMS OAP 2D-C	tdcn, tdccc, tdcd, tdcsv (derived parameters: tdcclassf, tdcdn, tdcrt)	Data recorded on all flights but needs to be QA.
Cloud and precipitation particle imagery	Digital Holographic camera	SPEC Inc. Model CPI-230	Separate data system.	Very little data was obtained with CPI in IMPROVE II; the instrument was off aircraft being repaired on many of the flights.
Size spectrum of precipita-tion particles	256 photodiode CCD array	SPEC Inc. HVPS	hvpsn – still in development (derived parameters: hvspdn, hvpsclassf)	No major problems. Particles "squeezed" in x-direction.

TABLE 4.1. OVERVIEW OF UNIVERSITY OF WASHINGTON'S CONVAIR-580 RESEARCH FLIGHTS IN IMPROVE-II (OROGRAPHIC STUDIES). FOR FLIGHT TRACKS SEE FIGURES 4.1-4.16.

Date (2001)	University of Washington Flight Number	Period of Flight (UTC)*†	Main Accomplishments (For more details see Section 5.)§	Comments on Instruments (For more details see Section 5.)
28 November	1891	1810-2329	Measurements in pre-frontal, frontal and post-frontal conditions across Oregon Cascades. Landed in Eugene. (P-3 flew.)	Problems with CPI, Cambridge dew point, Rosemount pressure sensor, and PMS 1-D cloud probe.
29 November	1892	0011-0129	Transit from Eugene, Oregon, to Paine Field, Washington. Good cloud and precipitation measurements in climb out from Eugene.	As for Flight 1891.
29 November	1893	1558-2039	1) Vertical profile from 15,000-2,000 ft between Sweet Home and Santiam Pass in post-frontal conditions. 2) CCN spectra measured in inflow to clouds just west of Sweet Home, and in outflow from clouds near Sisters Airport. 3) Profile through small cumulus over PNNL PARSL site at Sisters Airport. (P-3 did not fly.)	Discrepancy between FSSP-100 and PVM-100. CPI and HVPS had intermittent outages.

(Cont.)

* Local time = UTC – 8 hours.

† From engines on to engines off. (The Convair-580 took off and landed at Paine Field, Washington, unless noted otherwise.)

§ Classification of fronts and weather systems is provisional.

Table 4.1 (continued)

Date (2001)	University of Washington Flight Number	Period of Flight (UTC)*†	Main Accomplishments (For more details see Section 5.)§	Comments on Instruments (For more details see Section 5.)
1 December	1894	1456-1656	No measurements over Oregon Cascades. After crossing Columbia River, Convair-580 returned to Paine Field because of instrument cockpit problems.	—
4-5 December	1895	2247-0151	Vertical profile from 16,000-13,000 ft on west-east track over Santiam Pass. Landed in Eugene. (P-3 flew below Convair-580.)	CPI did not work. Possible problems with PMS 1-D cloud probe.
5 December	1896	2125-2249	Transit from Eugene to Paine Field. Long transit in ice clouds, virga at ~13,000 ft over Oregon.	CPI did not work.
8 December	1897	2018-2351	Profile from 7,000-17,000 ft through post-frontal rainband as it came onto Oregon Coast (P-3 below). Landed in Eugene.	CPI not aboard. Counts in clear air on PMS 1-D cloud probe.
9 December	1898	0024-0600	Takeoff from Eugene. Profile from 19,000-minimum altitudes over Santiam Pass in post-frontal conditions (possibly same rainband studied on Flight 1897).	CPI not aboard. PMS 1-D cloud probe counted in clear air.

(Cont.)

* Local time = UTC – 8 hours.

† From engines on to engines off. (The Convair-580 took off and landed at Paine Field, Washington, unless noted otherwise.)

§ Classification of fronts and weather systems is provisional.

Table 4.1 (continued)

Date (2001)	University of Washington Flight Number	Period of Flight (UTC)*†	Main Accomplishments (For more details see Section 5.)§	Comments on Instruments (For more details see Section 5.)
12-13 December	1899	2329-0549	Reasonably good mapping during moderate precipitation (possible frontal passage) over Santiam Pass. (P-3 did not fly.)	CPI not aboard. Problem with PMS 2-D cloud probe (?). Icing of FSSP-100. PMS 1-D cloud probe counted in clear air.
13-14 December	1900	2131-0327	Vertical profile from 20,000-14,000 ft in SW-NE orientation over Oregon Cascades in moderate to heavy precipitation associated with main rainband of a strong cold front. Landed in Eugene. (P-3 did "lawnmower" flight pattern.)	CPI not aboard. PMS 2-D cloud probe erratic.
14 December	1901	0438-0815	Take-off from Eugene. Vertical profile across Santiam Pass. Same storm as UW Flight 1900 but in post-frontal conditions (~6°C colder than UW Flight 1900). Most of Convair-580 measurements obtained after P-3 had left study area.	CPI not aboard. Some tans-alt dropouts.

(Cont.)

* Local time = UTC – 8 hours.

† From engines on to engines off. (The Convair-580 took off and landed at Paine Field, Washington, unless noted otherwise.)

§ Classification of fronts and weather systems is provisional.

Table 4.1 (continued)

Date (2001)	University of Washington Flight Number	Period of Flight (UTC)*†	Main Accomplishments (For more details see Section 5.)§	Comments on Instruments (For more details see Section 5.)
19-20 December	1902	2229-0419	Warm front and associated band moved north across region. North-south oriented vertical profile from 18,000-8,000 ft west of Oregon Cascade crest. West-to-east cross-mountain track in southern edge of rainband. Truncated north-south stack in rainband east of Cascade crest. Landed in Eugene. (P-3 not up.)	CPI did not work. PMS 1-D cloud probe data suspect.
20 December	1903	0506-0609	Transit flight from Eugene to Paine Field. High overcast north of warm front.	As for UW Flight 1902.
21-22 December	1904	2159-0043	Instrument test flight between Paine Field and Quillayute, Washington.	—
22 December	1905	1459-1752	Sampling of upper levels (20,000-18,000 ft) of weak, warm-frontal precipitating system. Landed in Eugene. (P-3 did not fly.)	CPI not installed.

(Cont.)

* Local time = UTC – 8 hours.

† From engines on to engines off. (The Convair-580 took off and landed at Paine Field, Washington, unless noted otherwise.)

§ Classification of fronts and weather systems is provisional.

Table 4.1 (continued)

Date (2001)	University of Washington Flight Number	Period of Flight (UTC)*†	Main Accomplishments (For more details see Section 5.)§	Comments on Instruments (For more details see Section 5.)
22 December	1906	1909-2300	1) Takeoff from Eugene. North-south oriented stack between 20,000-10,000 ft in same system as UW Flight 1905. (P-3 did not fly.) 2) Wind profile in Columbia Gorge.	CPI not installed.

* Local time = UTC – 8 hours.

† From engines on to engines off. (The Convair-580 took off and landed at Paine Field, Washington, unless noted otherwise.)

§ Classification of fronts and weather systems is provisional.

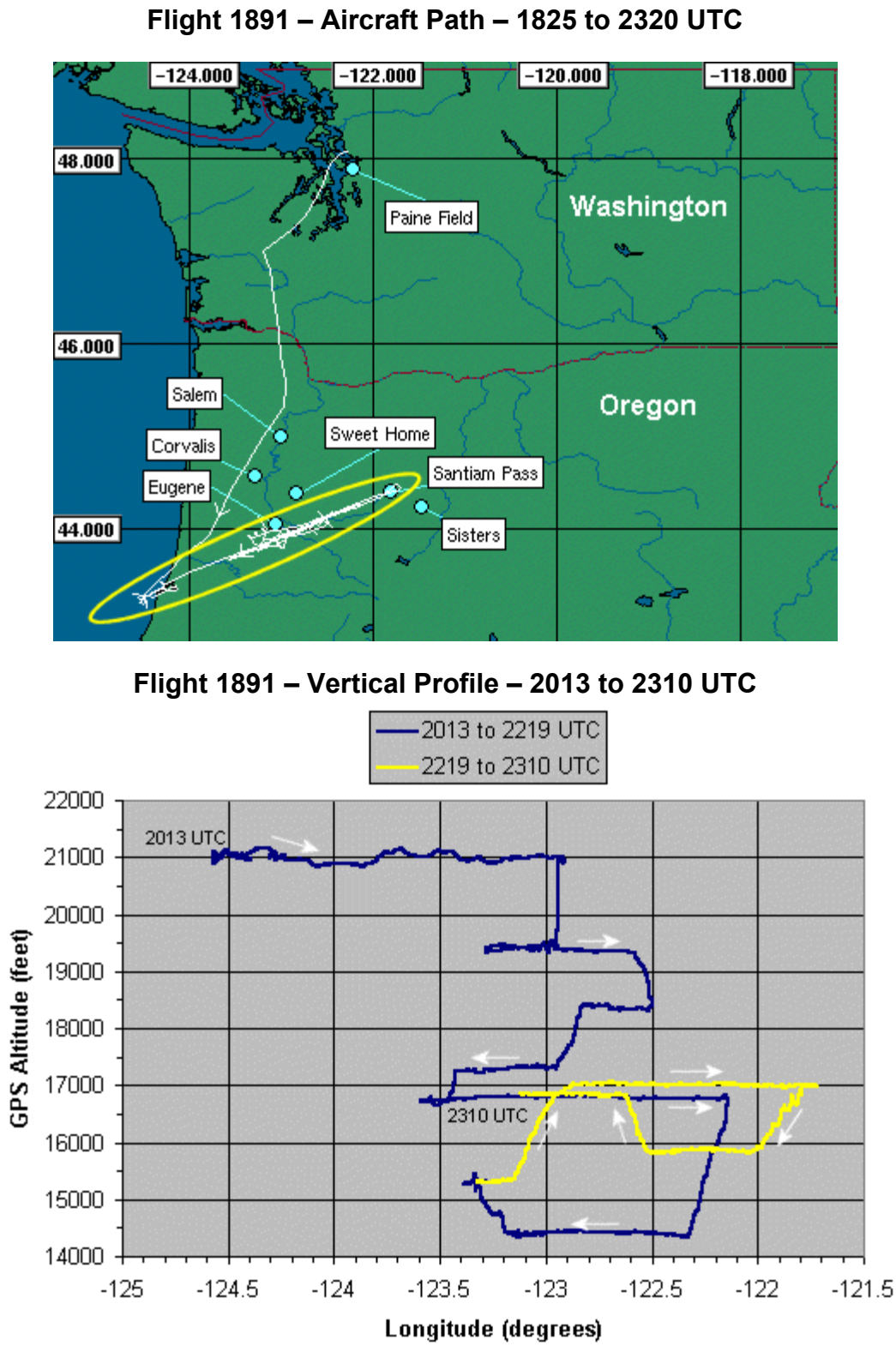
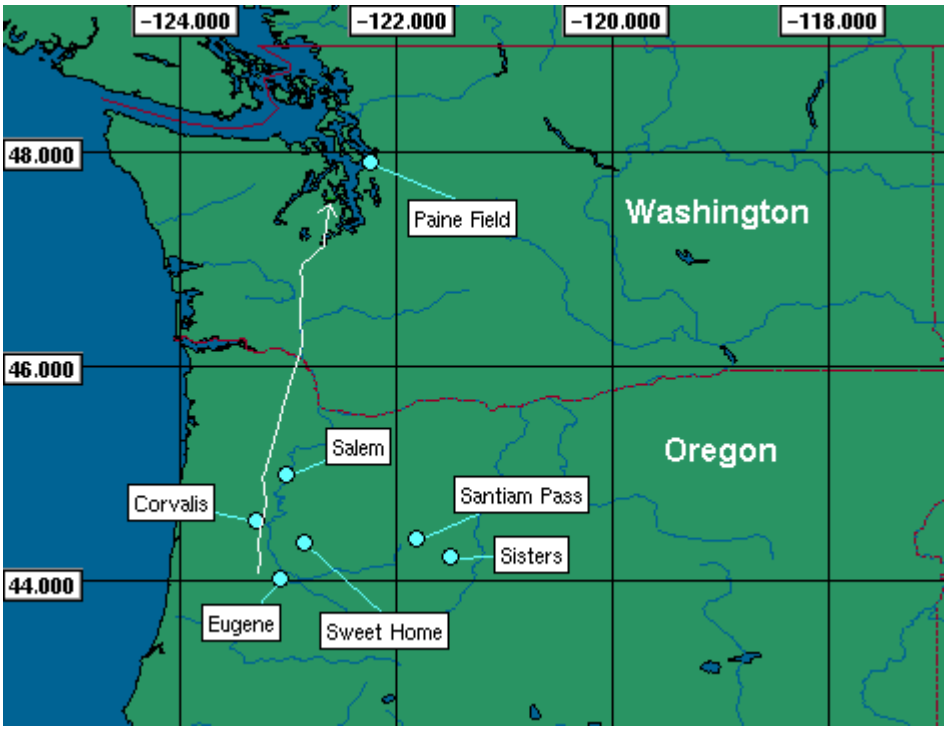


Figure 4.1. Flight track (white line) of the Convair-580 in IMPROVE-II on November 28, 2001 (UW Flight 1891).

Flight 1892 – Aircraft Path – 0023 to 0111 UTC



Flight 1892 – Vertical Profile – 0023 to 0111 UTC

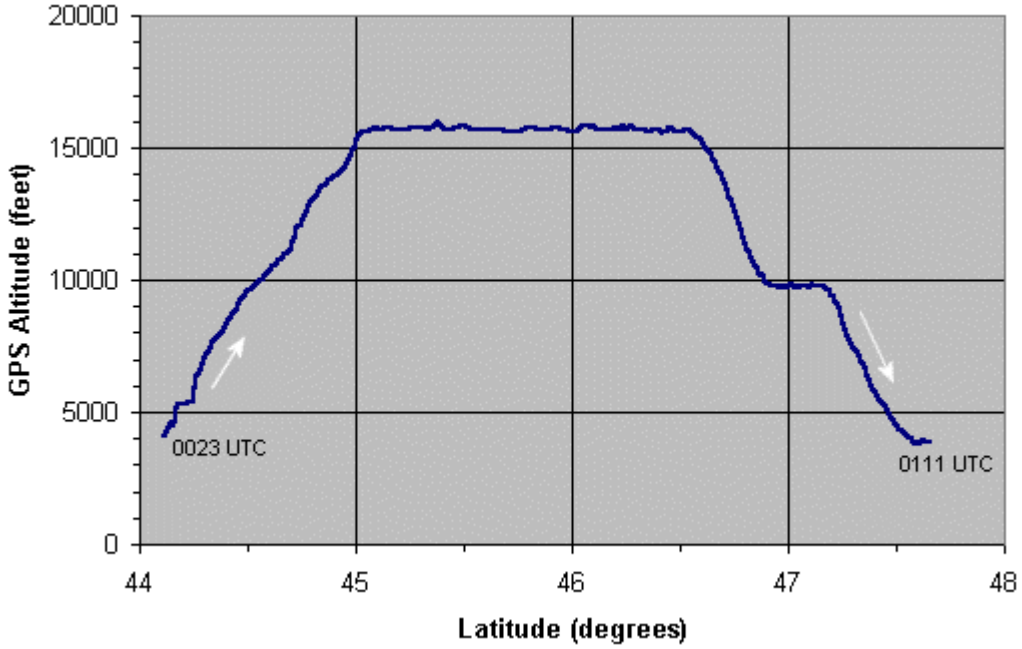
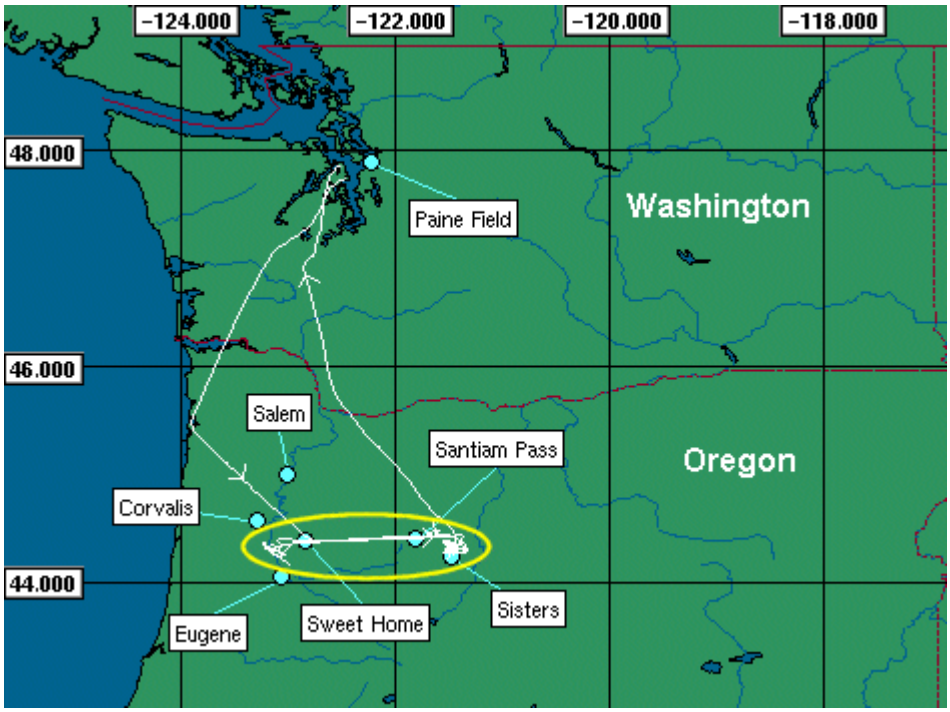


Figure 4.2. Flight track (white line) of the Convair-580 in IMPROVE-II on November 29, 2001 (UW Flight 1892).

Flight 1893 – Aircraft Path – 1612 to 2034 UTC



Flight 1893 – Vertical Profile – 1710 to 1832 UTC

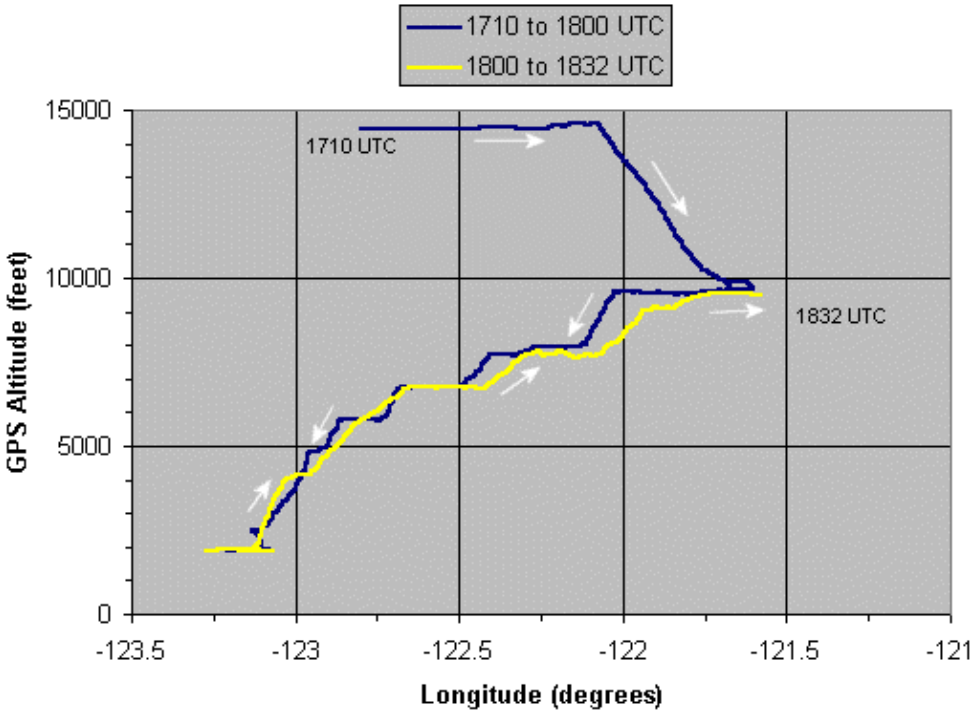
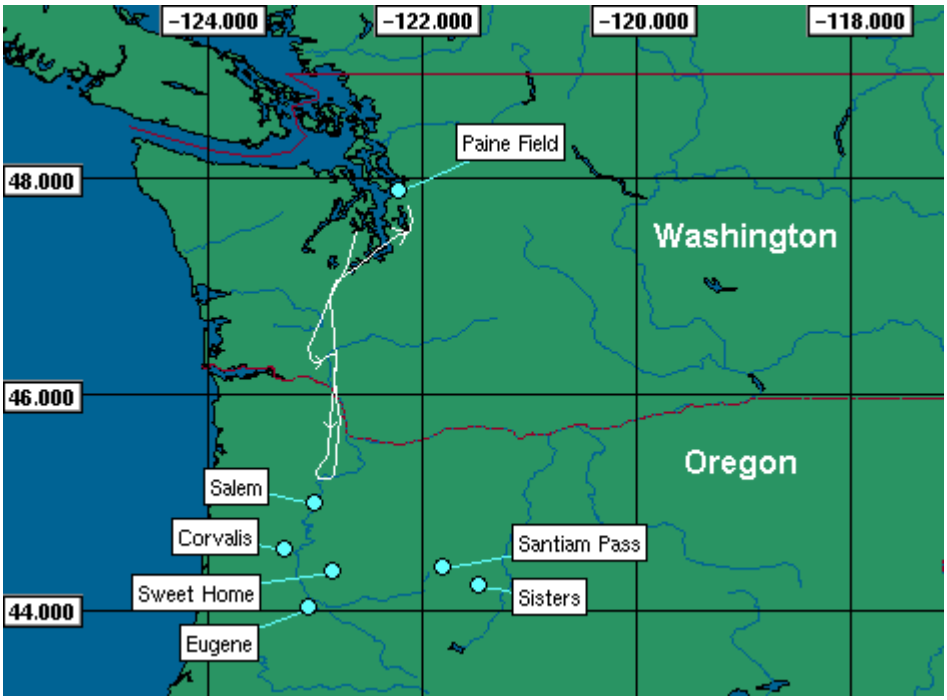


Figure 4.3. Flight track (white line) of the Convair-580 in IMPROVE-II on November 29, 2001 (UW Flight 1893).

Flight 1894 – Aircraft Path – 1527 to 1647 UTC



Flight 1894 – Vertical Profile – 1527 to 1647 UTC

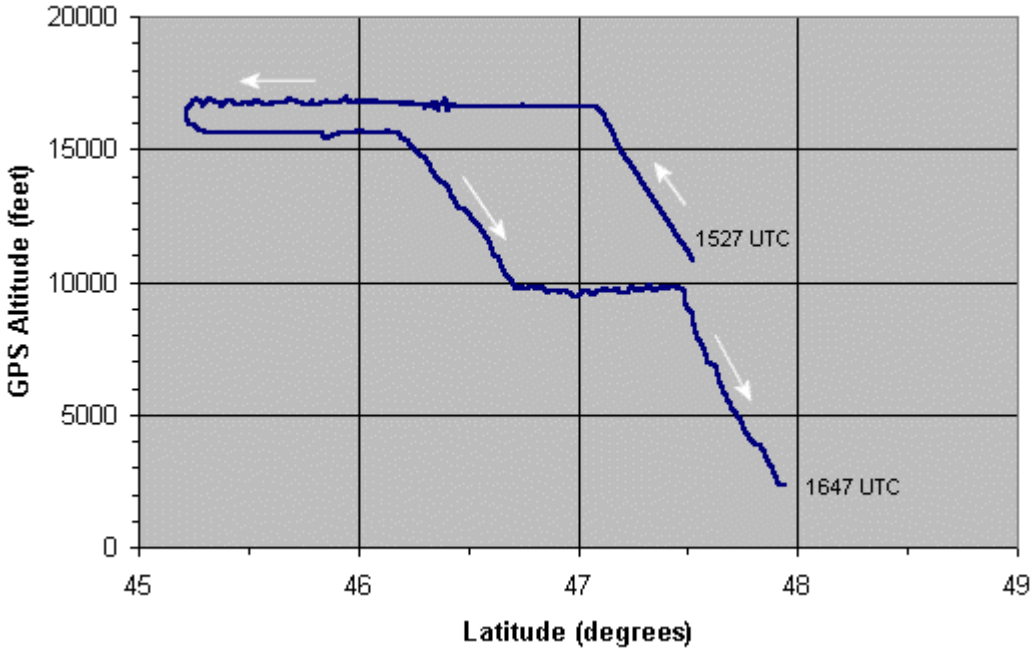
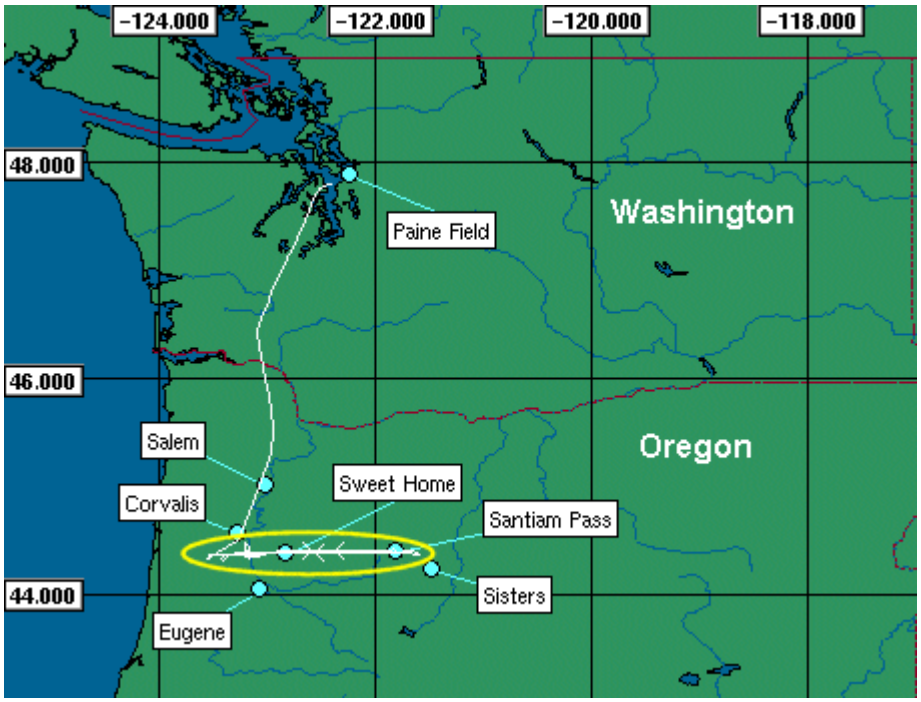


Figure 4.4. Flight track (white line) of the Convair-580 in IMPROVE-II on December 1, 2001 (UW Flight 1894).

Flight 1895 – Aircraft Path – 2300 to 0141 UTC



Flight 1895 – Vertical Profile – 0003 to 0139 UTC

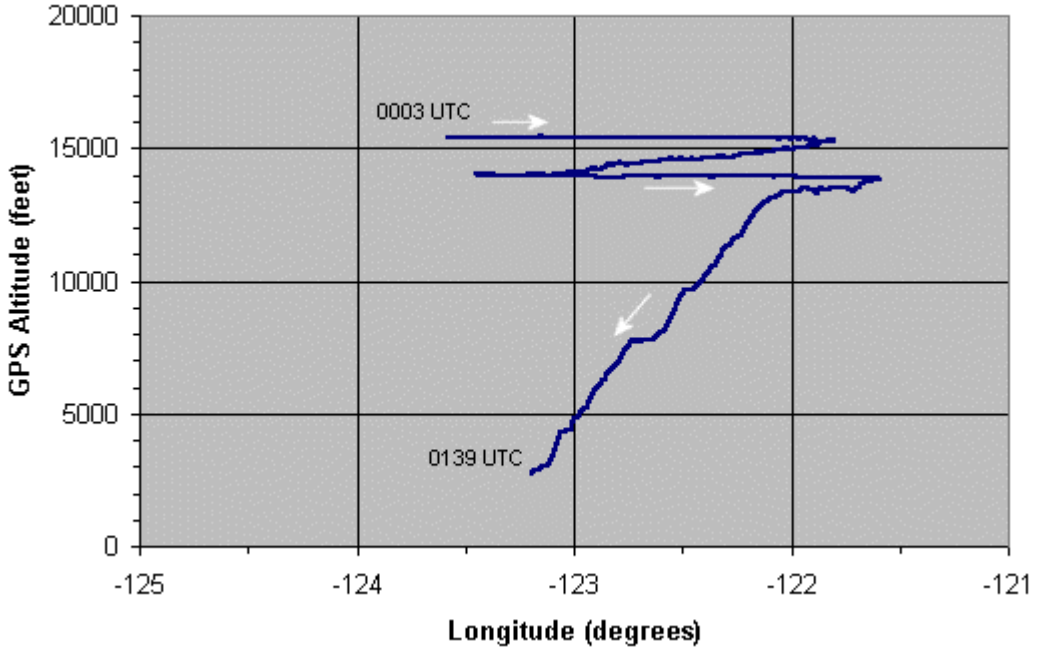
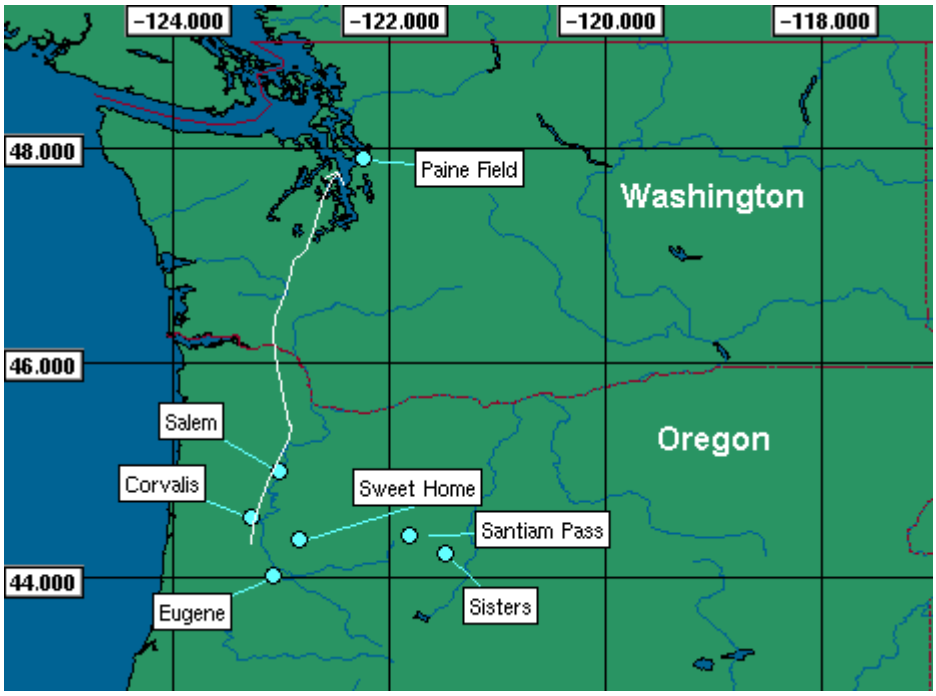


Figure 4.5. Flight track (white line) of the Convair-580 in IMPROVE-II on December 4-5, 2001 (UW Flight 1895).

Flight 1896 – Aircraft Path – 2140 to 2240 UTC



Flight 1896 – Vertical Profile – 2140 to 2240 UTC

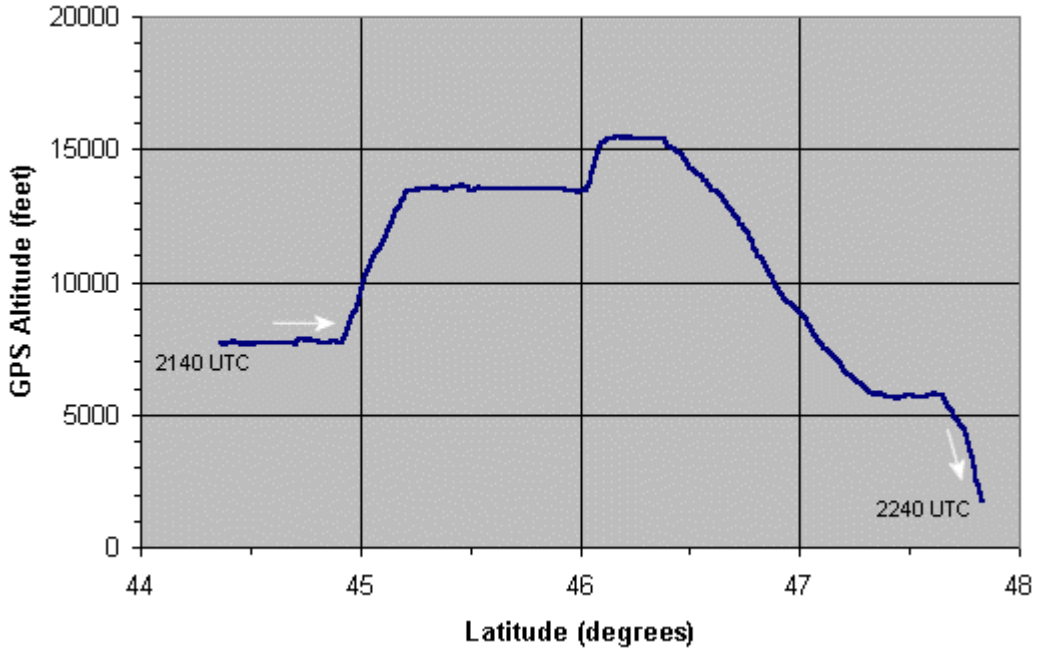


Figure 4.6. Flight track (white line) of the Convair-580 in IMPROVE-II on December 5, 2001 (UW Flight 1896).

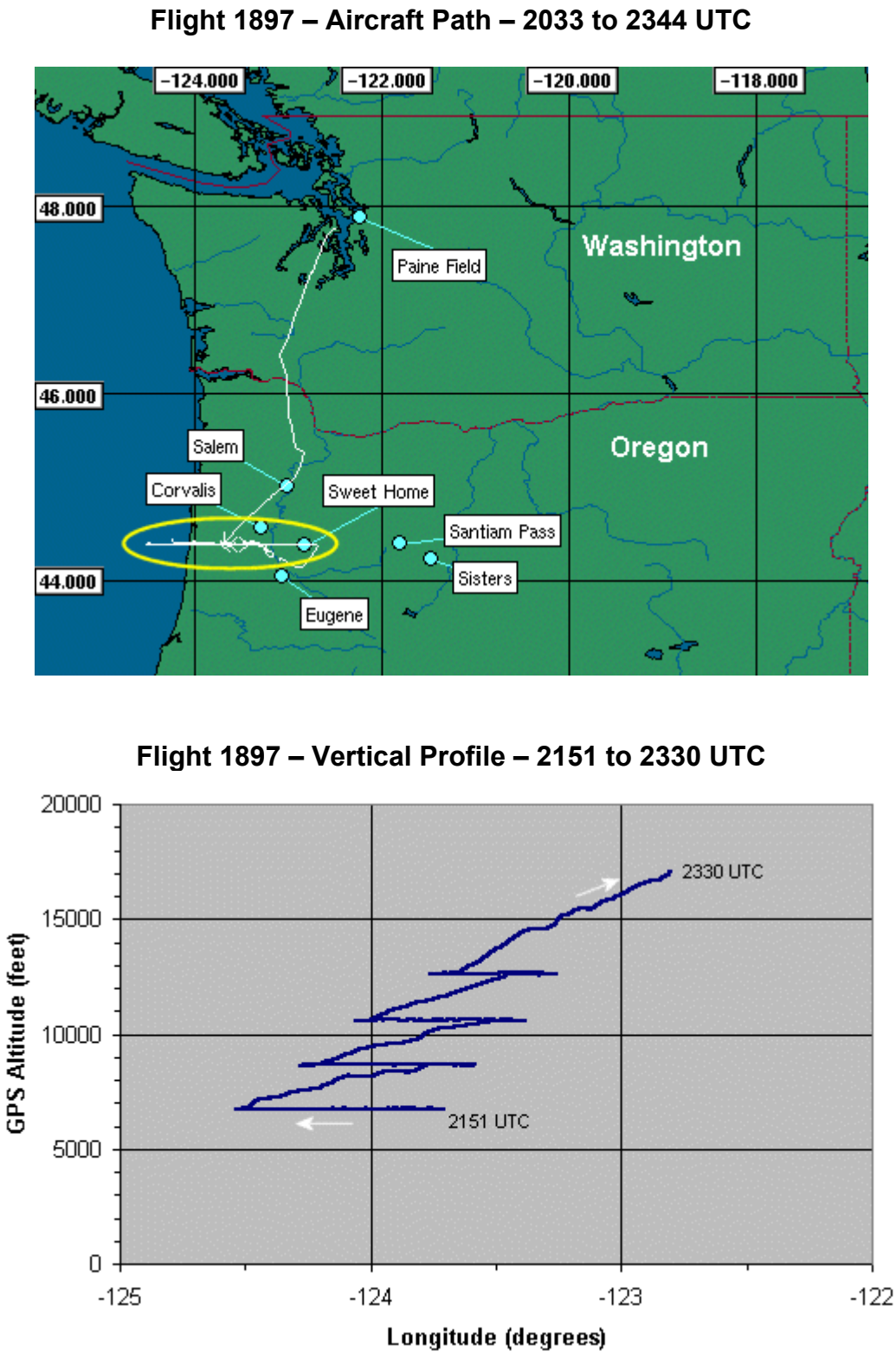
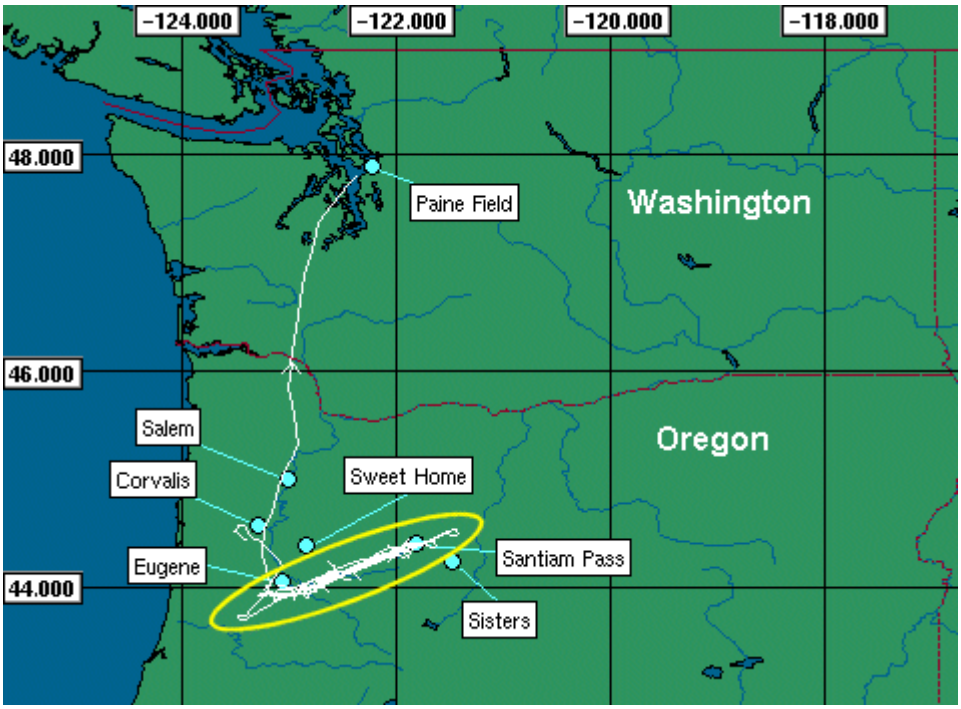


Figure 4.7. Flight track (white line) of the Convair-580 in IMPROVE-II on December 8, 2001 (UW Flight 1897).

Flight 1898 – Aircraft Path – 0045 to 0555 UTC



Flight 1898 – Vertical Profile – 0112 to 0442 UTC

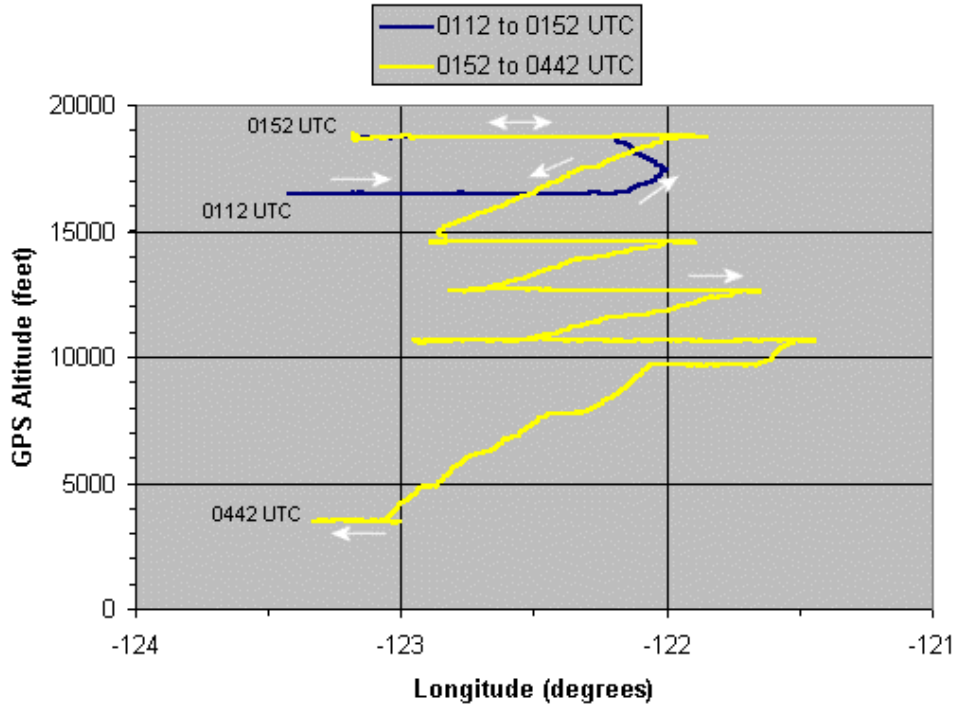
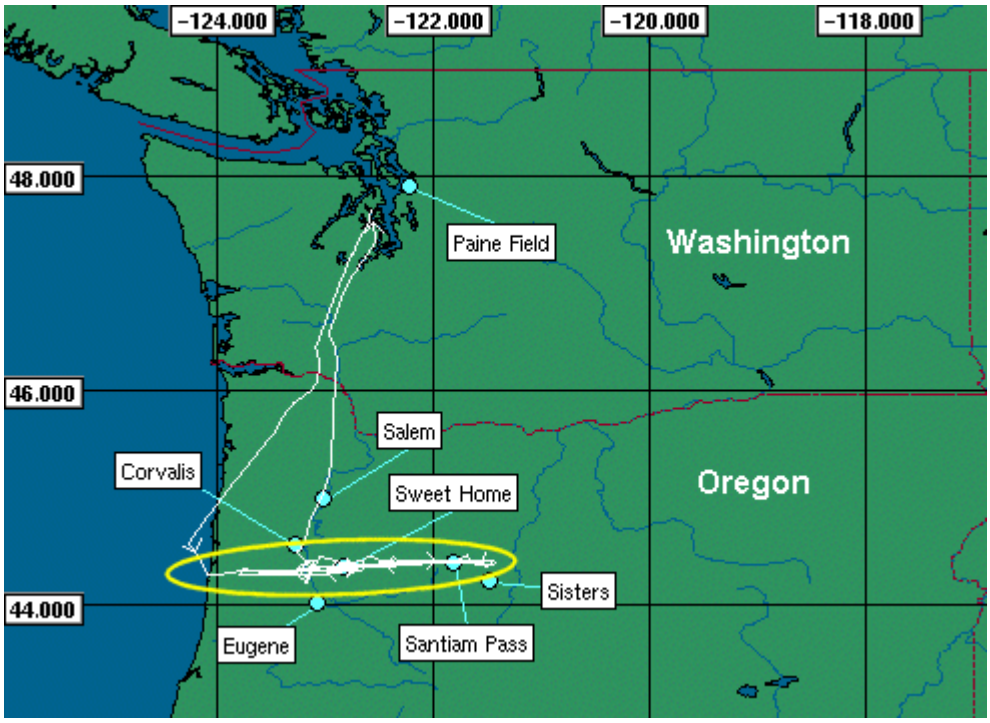


Figure 4.8. Flight track (white line) of the Convair-580 in IMPROVE-II on December 9, 2001 (UW Flight 1898).

Flight 1899 – Aircraft Path – 2351 to 0527 UTC



Flight 1899 – Vertical Profile – 0056 to 0359 UTC

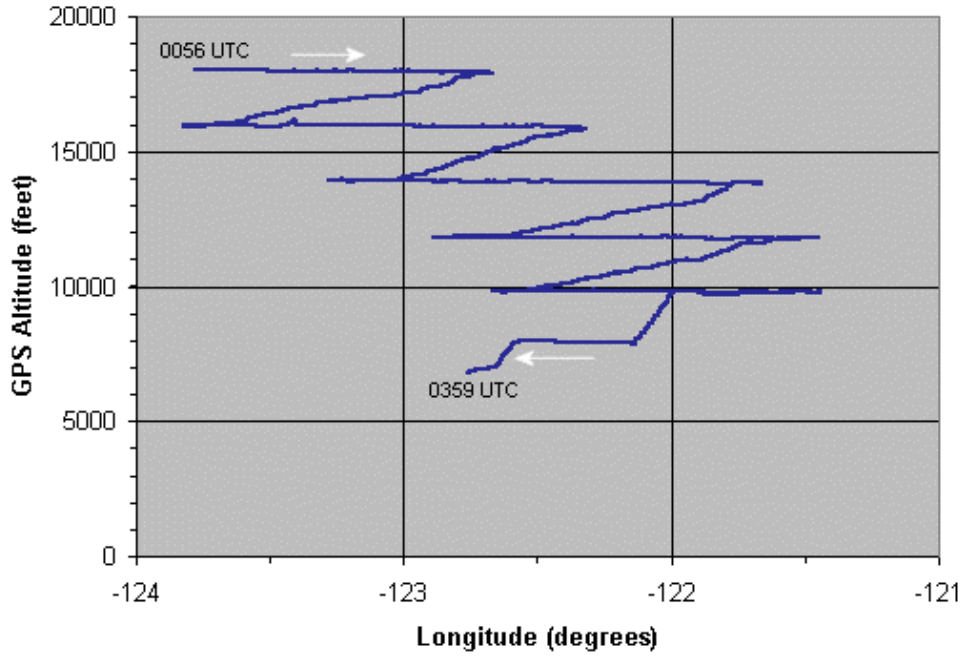
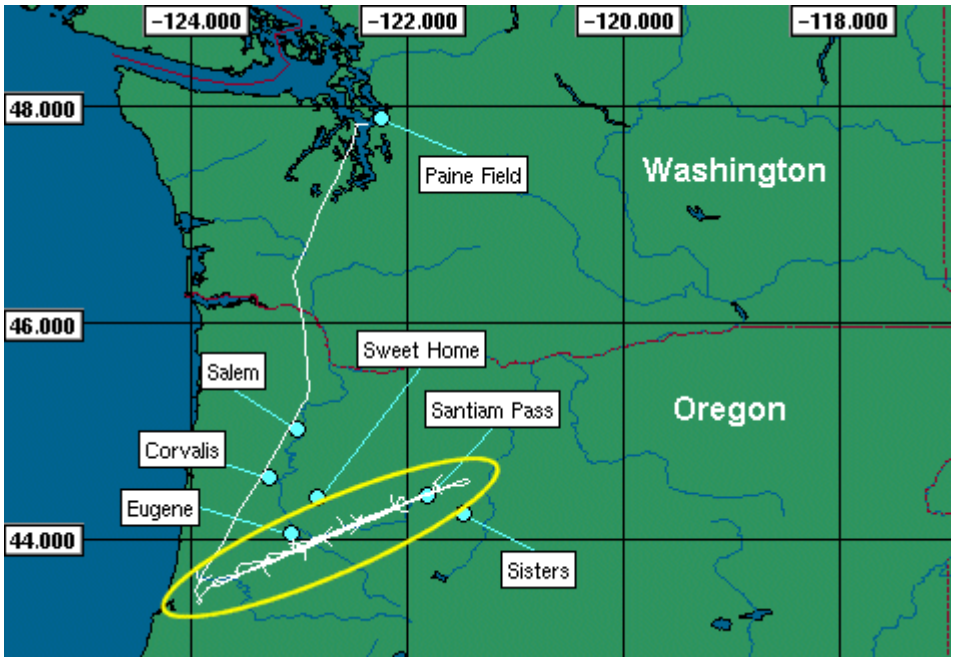


Figure 4.9. Flight track (white line) of the Convair-580 in IMPROVE-II on December 12-13, 2001 (UW Flight 1899).

Flight 1900 – Aircraft Path – 2147 to 0309 UTC



Flight 1900 – Vertical Profile – 2323 to 0307 UTC

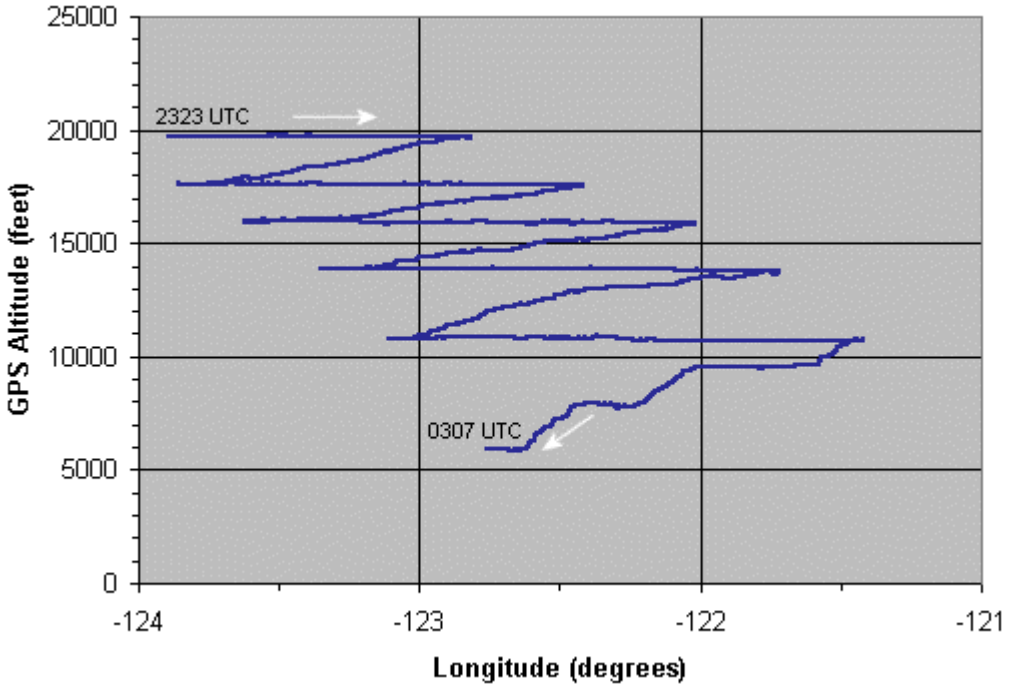
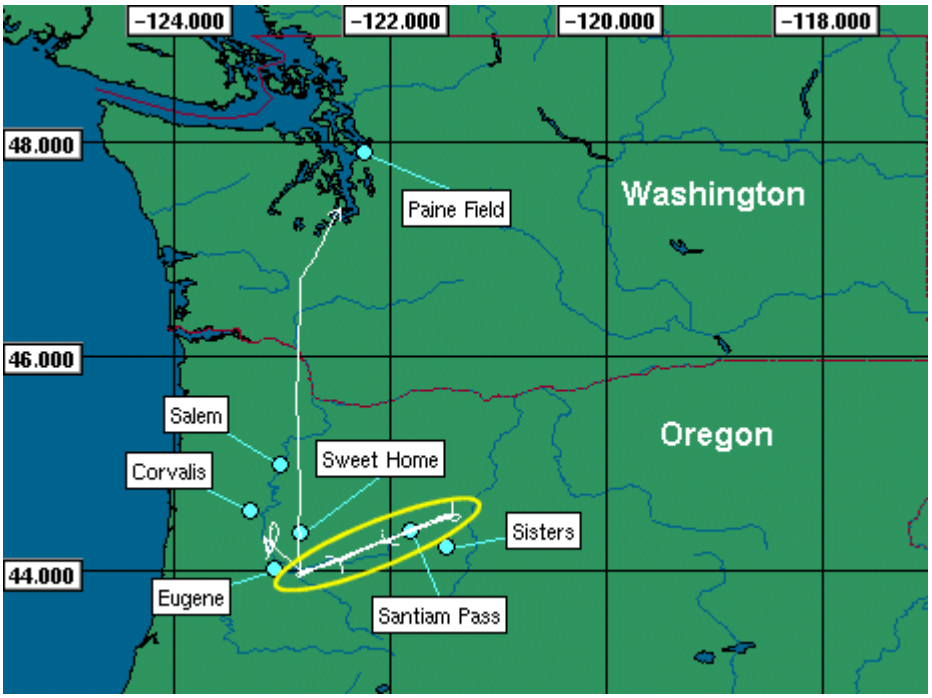


Figure 4.10. Flight track (white line) of the Convair-580 in IMPROVE-II on December 13-14, 2001 (UW Flight 1900).

Flight 1901 – Aircraft Path – 0454 to 0757 UTC



Flight 1901 – Vertical Profile – 0531 to 0701 UTC

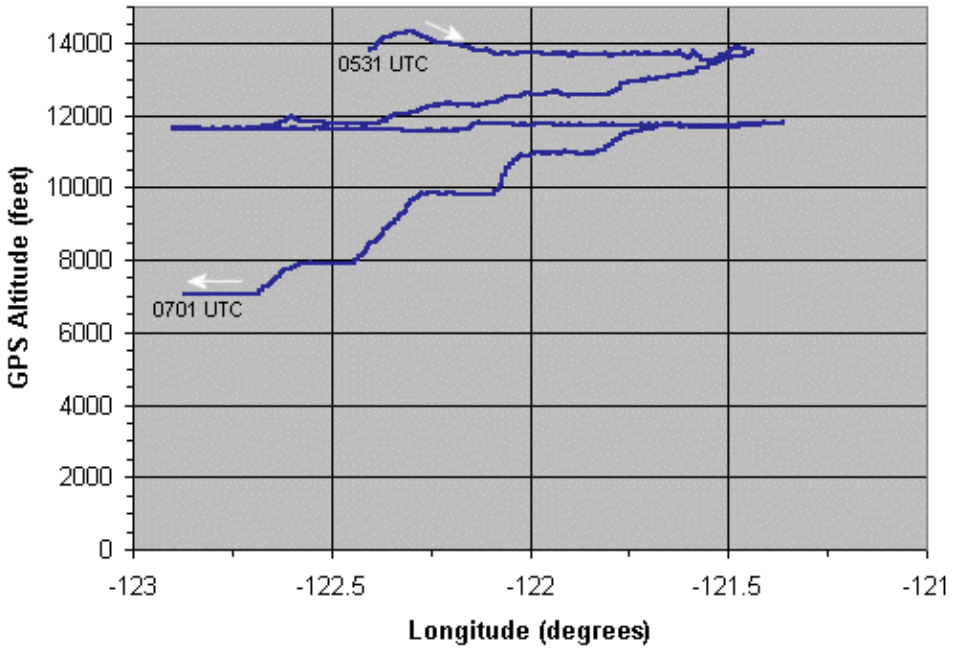
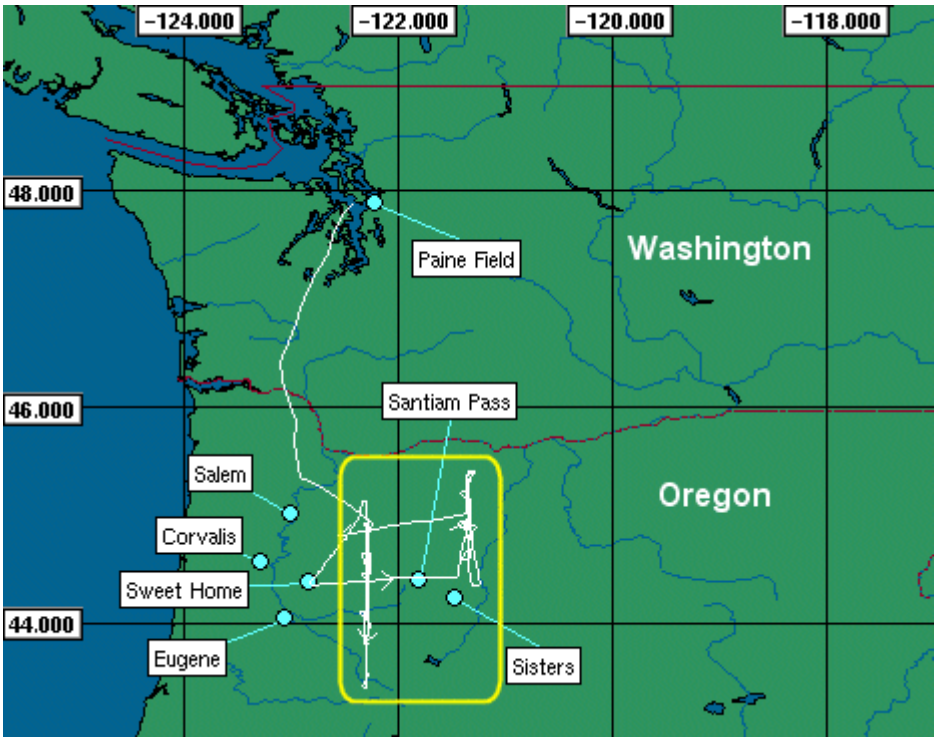


Figure 4.11. Flight track (white line) of the Convair-580 in IMPROVE-II on December 14, 2001 (UW Flight 1901).

Flight 1902 – Aircraft Path – 2246 to 0405 UTC



Flight 1902 – Vertical Profile – 2342 to 0348 UTC

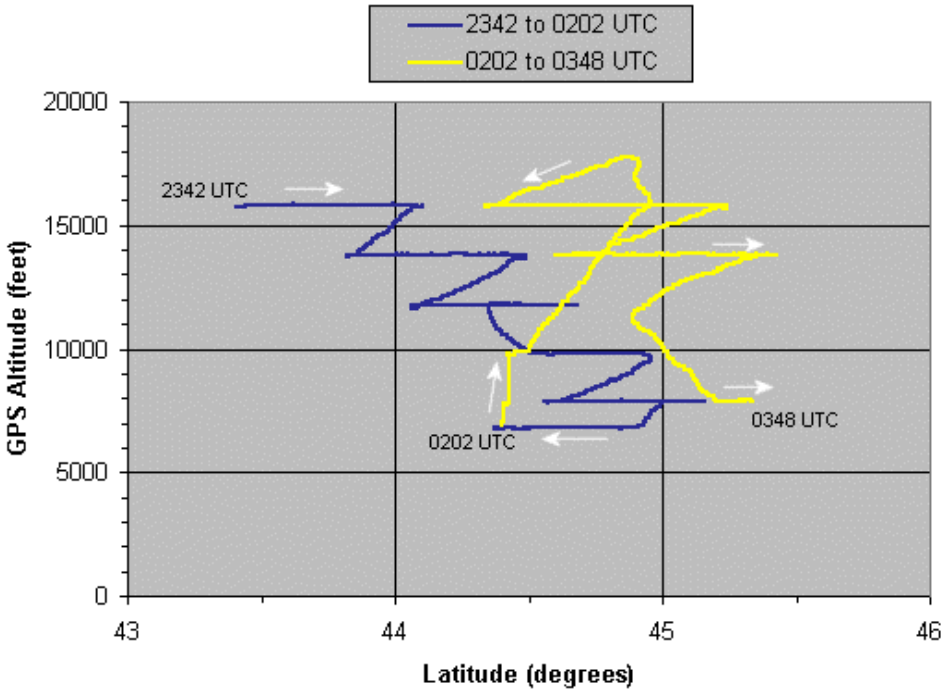
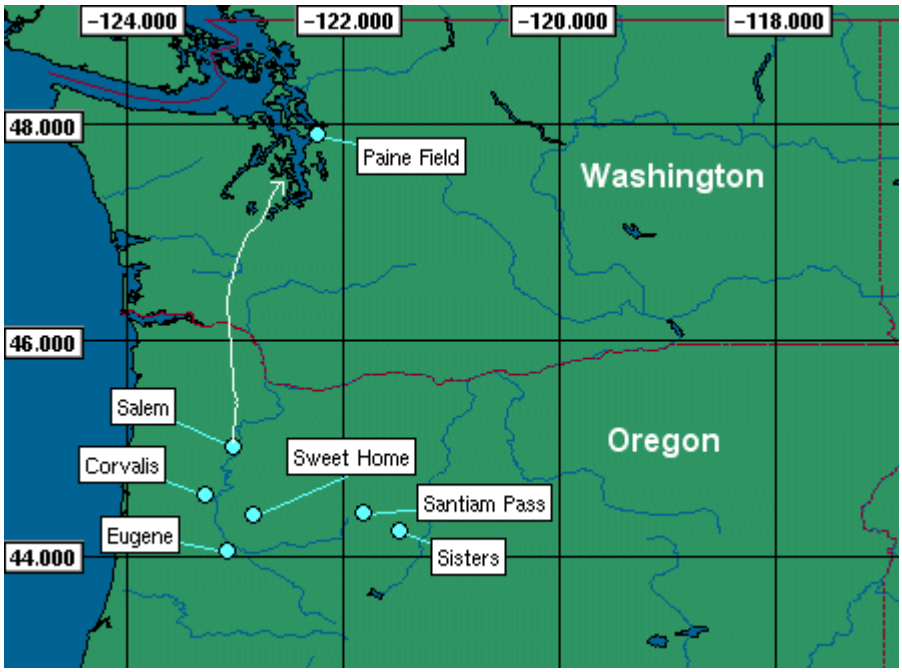


Figure 4.12. Flight track (white line) of the Convair-580 in IMPROVE-II on December 19-20, 2001 (UW Flight 1902).

Flight 1903 – Aircraft Path – 0519 to 0555 UTC



Flight 1903 – Vertical Profile – 0519 to 0555 UTC

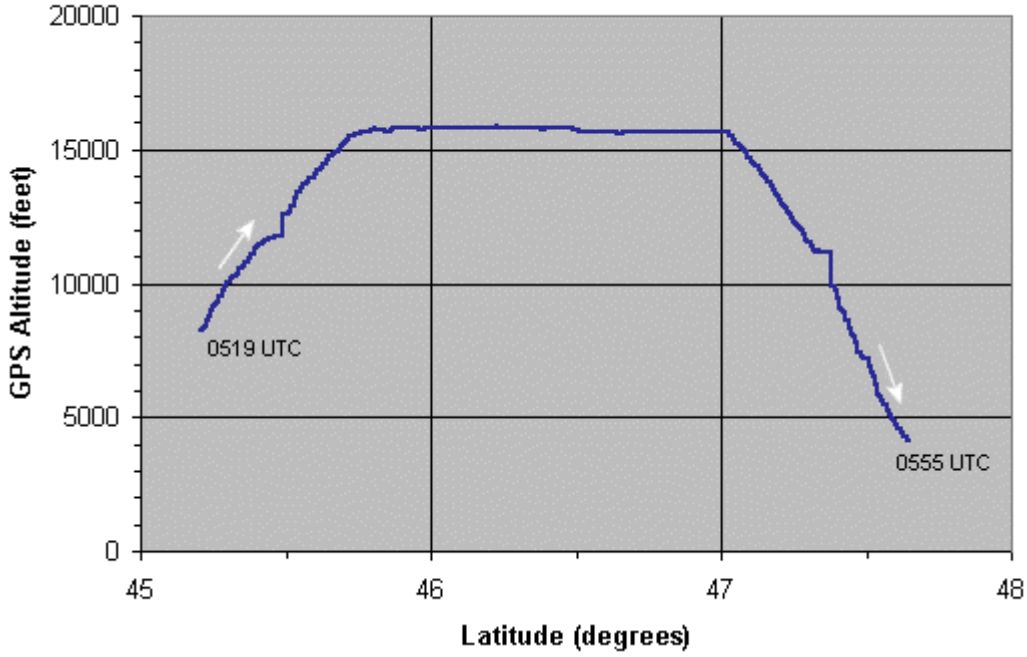
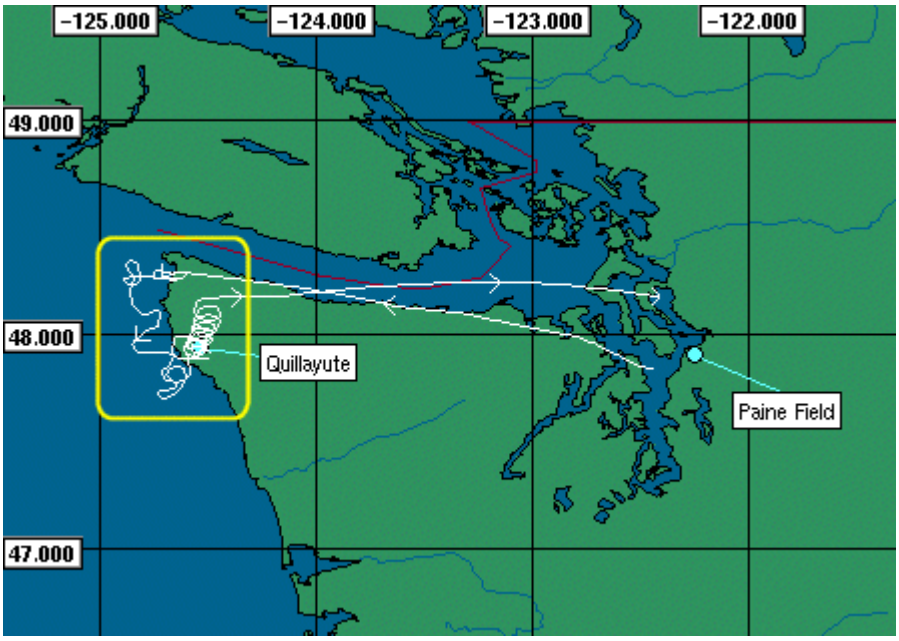


Figure 4.13. Flight track (white line) of the Convair-580 in IMPROVE-II on December 20, 2001 (UW Flight 1903).

Flight 1904 – Aircraft Path – 2213 to 0032 UTC



Flight 1904 – Vertical Profile – 2238 to 0007 UTC

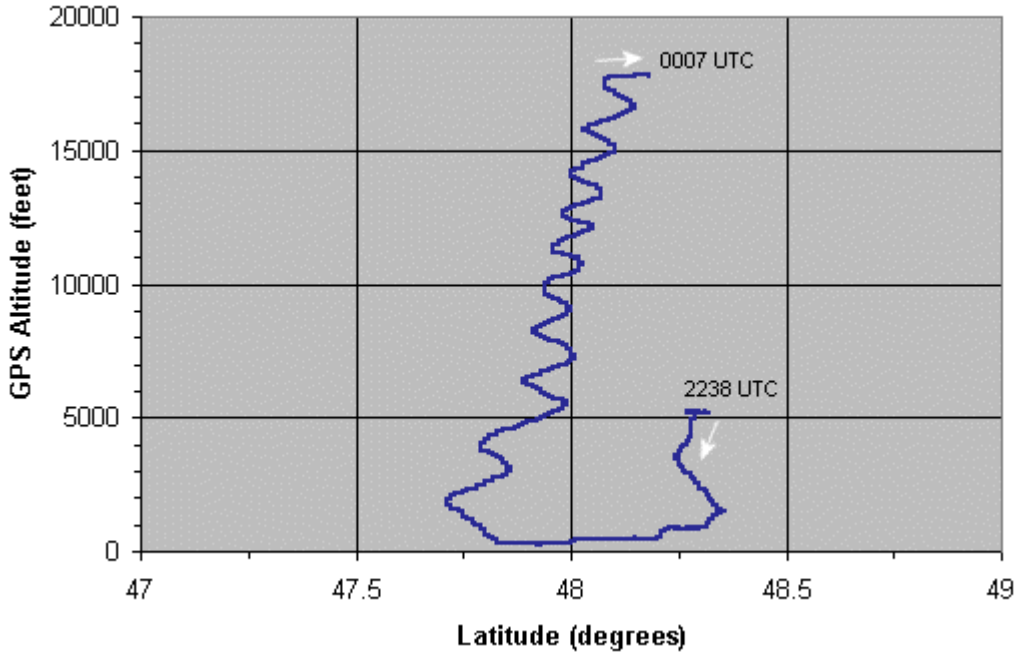
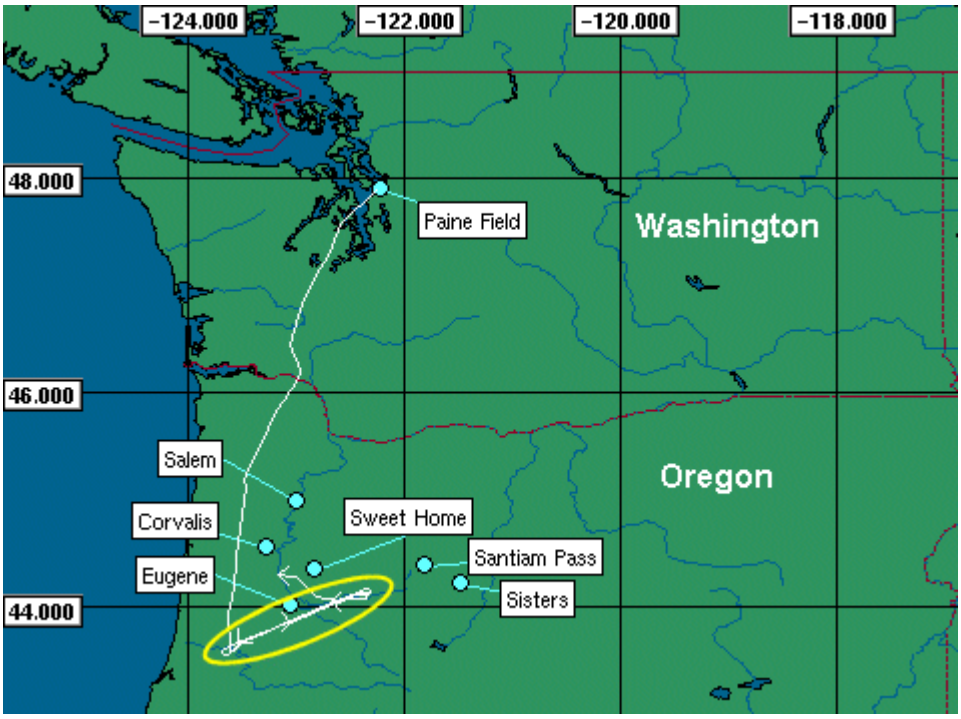


Figure 4.14. Flight track (white line) of the Convair-580 in IMPROVE-II on December 21-22, 2001 (UW Flight 1904).

Flight 1905 – Aircraft Path – 1517 to 1748 UTC



Flight 1905 – Vertical Profile – 1633 to 1729 UTC

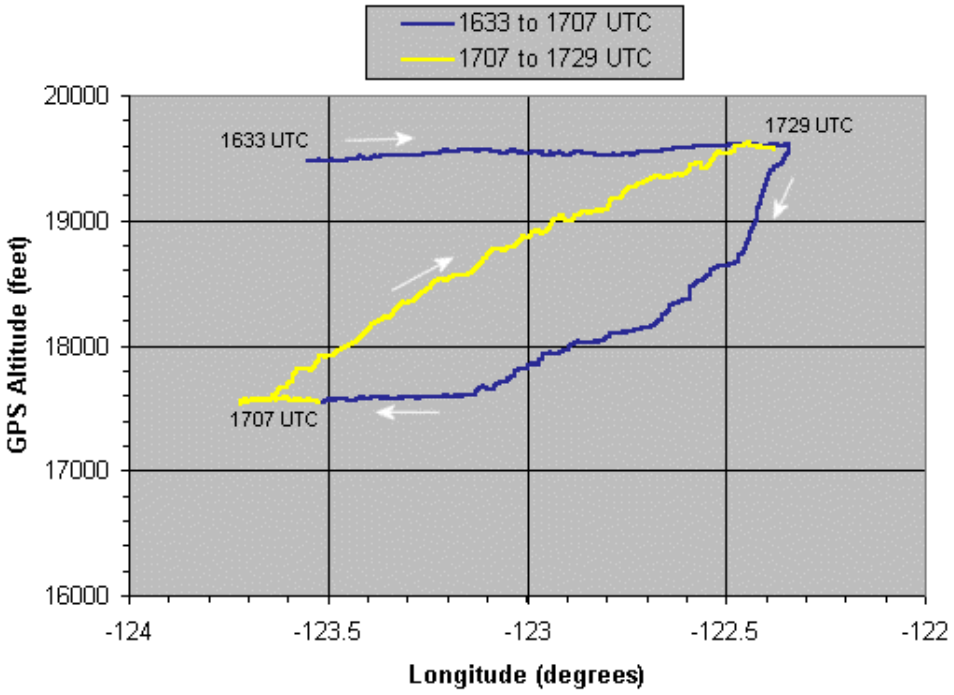
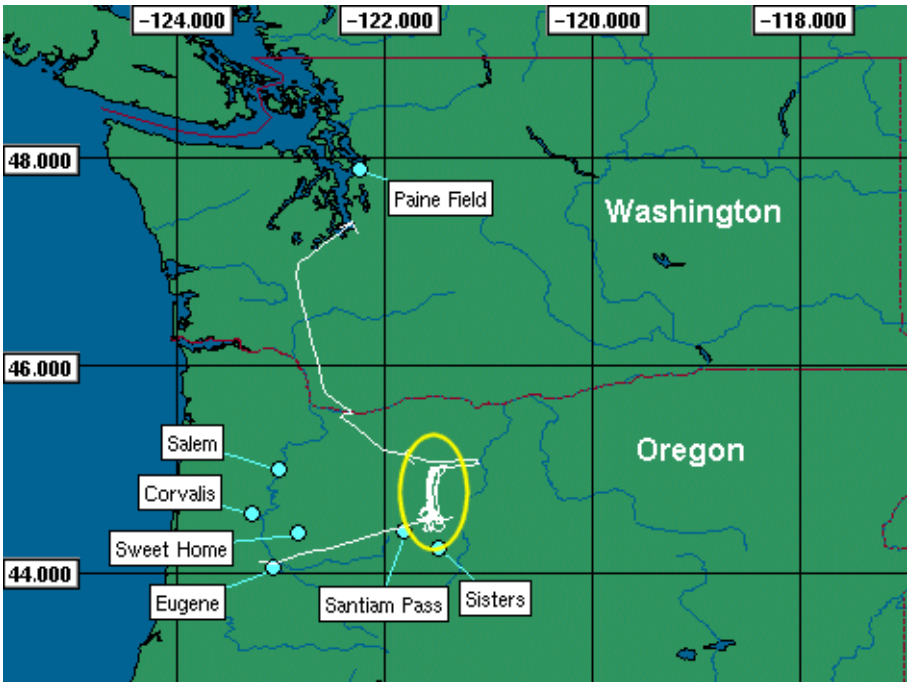


Figure 4.15. Flight track (white line) of the Convair-580 in IMPROVE-II on December 22, 2001 (UW Flight 1905).

Flight 1906 – Aircraft Path – 1921 to 2249 UTC



Flight 1906 – Vertical Profile – 1937 to 2147 UTC

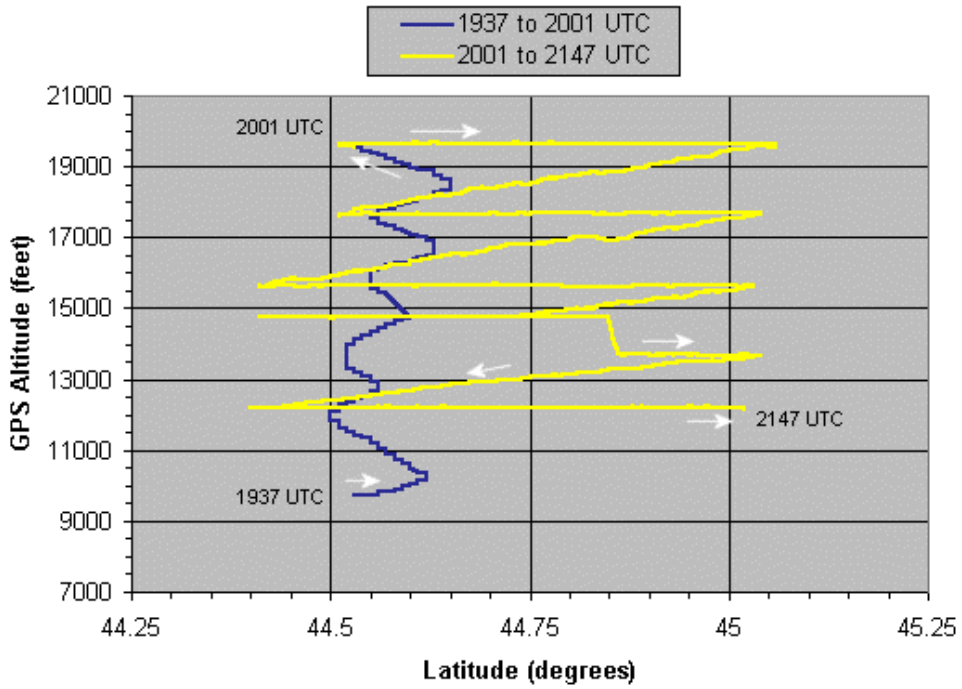


Figure 4.16. Flight track (white line) of the Convair-580 in IMPROVE-II on December 22, 2001 (UW Flight 1906).

not reproduced here in their entirety.* Instead, we give in Section 5.2 typed transcriptions of the verbal *summaries* that crew members recorded aboard the aircraft toward the end of the flights. Although subsequent data analyses might reveal important aspects of a flight, and of the data collected, that were unknown to crew members at the time of the flight, these summaries have the advantage of spontaneity.

5.1. Flight Scientist's Summaries

(a) University of Washington Flight 1891 (28 November 2001)

Period of Flight (UTC):§ 1810-2329

Accomplishments of Flight:

Measurements in pre-frontal, frontal and post-frontal conditions across Oregon Cascades. Landed in Eugene, Oregon. (P-3 flew.)

Instrument Problems:†

SPEC CPI, Cambridge dew point, Rosemount pressure and PMS 1-D cloud probe.

Flight Scientist: Peter V. Hobbs

* Requests for copies of the complete transcriptions for specific flights should be sent to:
Professor Peter V. Hobbs
University of Washington
Department of Atmospheric Sciences
Box 351640
Seattle, Washington 98195-1640

§ Engines on to engines off.

† The SPEC CPI was either not aboard or did not function properly throughout most of IMPROVE-II.

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
1822	Takeoff from Paine Field
1822-2015	Transit to Oregon.
2035-2048	At 43˚16.1'/124˚29.9' (on Oregon coast SW of Santiam Pass) SW point and headed N at 12,000 ft.
2048-2053	NE → SW descending.
2053-2107	SW-NE at 19,500 ft.
2109-2132	NE → SW descending to 17,000 ft.
2134-2148	SW → NE at 17,000 ft.
2149-3	NE → SW descending to 14,500 ft. Picked up significant ice on descent to 14,500 ft. Circled in clear air at SW point to shed ice.
~2225-2240	SW → NE at 17,000 ft.
2240-	Return to SW with slow descent (more icing in Cu).
	Land at Eugene.
2329	Engines off.

(b) University of Washington Flight 1892 (29 November 2001)

Period of Flight (UTC): 0011-0129

Accomplishments of Flight:

Transit from Eugene, Oregon, to Paine Field, Washington. Cloud and precipitation measurements on climb out from Eugene..

Instrument Problems:

As for Flight 1891.

Flight Scientist: Peter Hobbs

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
00??	Takeoff.
0016-0031	Climb to 10,000 ft. Cloud tops ~15,000 ft.

(c) University of Washington Flight 1893 (29 November 2001)

Period of Flight (UTC): 1558-2039

Accomplishments of Flight:

Vertical profile from 15,000 ft down to 2,000 ft between Sweet Home and Santiam Pass, Oregon, in post-frontal conditions. Measured CCN spectra in inflow to clouds over Cascades and in outflow. Profile through small cumulus clouds over PNNL PARSL site at Sisters Airport on east side of Cascades.

Instrument Problems:

Discrepancy between FSSP-100 and PVM-100. Intermittent outages of HVPS.

Flight Scientist: Peter V. Hobbs

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
1606	Takeoff.
1606-1709	Transit to Sweet Home.
1709-1725	Sweet Home → Santiam → 15,000 ft → 10,500 ft. No cloud at this height.
1725-1750	Return to Sweet Home → descending to get into cloud tops, 10,000 ft → 5,000 ft → 2,000 ft.
1755-1810	CCN spectra in inflow air to clouds just west of Santiam at 2,000 ft.
1810-1830	West → Sweet Home → Santiam.
1830-1855	To PARSL site.
1857-1912	CCN spectra in outflow below cloud base near PARSL site.
1914-1922	Spiral up over Sisters Airport (PARSL site).
1922	Transit home.

(d) University of Washington Flight 1894 (1 December 2001)

Period of Flight (UTC): 1456-1656

Accomplishments of Flight:

Convair-580 returned to Paine Field just after crossing the Columbia River due to instrument cockpit problems.

Instrument Problems:

—

Flight Scientist: Peter V. Hobbs

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
1508	Takeoff.
1508-~1610 PST	Transit to south of Columbia River.
~1610-1656	Return to Paine Field.

(e) University of Washington Flight 1895 (4-5 December 2001)

Period of Flight (UTC): 2247-0151

Accomplishments of Flight:

Vertical profile from 16,000 to 13,000 ft on west-east track over Santiam Pass. (P-3 flew below Convair-580.) Landed in Eugene.

Instrument Problems:

Possible problems with PMS 1-D cloud probe.

Flight Scientist: Peter Hobbs

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
2257	Takeoff.
2257-~0001 (12/5)	Transit to start point.
~0001-0023	West → east, 16,000 ft.
~0023 → 0050	East → west desc. to 14,500 ft.
0050 → 0115 (waiting for clearance)	West → east at 14,5000 ft.
~0118 → ~0125	East → west desc. to 13,000 ft.
~0125	Broke off at ~0125 UTC on west bound leg due to pilot's airspeed indicator going out. Measurements on descent into Eugene.
0151	Engines off.

(f) University of Washington Flight 1896 (5 December 2001)

Period of Flight (UTC): 2125-2249

Accomplishments of Flight:

Transit flight from Eugene, Oregon, to Paine Field, Washington. Passage through ice clouds and virga at ~13,000 ft over Oregon.

Instrument Problems:

As for UW Flight 1895.

Flight Scientist: Peter V. Hobbs

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
No timeline form.	

(g) University of Washington Flight 1897 (8 December 2001)

Period of Flight (UTC): 2018-2351

Accomplishments of Flight:

Profile from 7,000 to 17,000 ft through post-frontal rainband on Oregon coast (P-3 flew below Convair-580). Landed in Eugene.

Instrument Problems:

Counts in clear air on PMS 1-D cloud probe.

Flight Scientist: Peter V. Hobbs

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
2028	Takeoff.
2028-2151	Transit.
2151-2206	East → west through front at 7,000 ft.
2209-2219	West → east climb 7,000 ft → 9,000 ft.
2223-2232	East → west at 9,000 ft.
2235-2244	West → east at 11,000 ft.
2244-2255	East → west at 11,000 ft.
2257-2310	West → east climb to 13,000 ft.
2310-2317	East → west at 13,000 ft.
2318-	West → east climb to 17,000 ft.

(h) University of Washington Flight 1898 (9 December 2001)

Period of Flight (UTC): 0024-0600

Accomplishments of Flight:

Takeoff from Eugene, Oregon. Profile from 19,000 ft down to minimum allowable altitude over Santiam Pass in post-frontal conditions (possibly same rainband in which measurements were obtained on UW Flight 1897).

Instrument Problems:

Counts in clear air on PMS 1-D cloud probe.

Flight Scientist: Peter V. Hobbs

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
0032	Takeoff.
0032-0056	Transit to start point southwest at 17,000 ft.
0056-0130	Southwest → northeast at 17,000 ft.
0130 → 0151	Northeast → southwest climb to 19,000 ft.
0151 → 0206	Southwest → northeast at 19,000 ft.
0211 → 0225	Southwest ← northeast desc. to 15,000 ft.
0230 → 0240	Southwest → northeast at 15,000 ft.
0243 → 0258	Southwest ← northeast desc. to 13,000 ft.
0300 → 0312	Southwest → northeast at 13,000 ft.
0318 → 0337	Southwest ← northeast desc. to 11,000 ft.
0341 → 0400	Southwest → northeast at 11,000 ft.
0400-0430	From northeast to southwest at minimum altitude above terrain. (Little icing picked up—rainband?)
0430-0447	CCN spectra measurements below cloud base just south of Eugene in in-flow air to orographic clouds.

(i) University of Washington Flight 1899 (12-13 December 2001)

Period of Flight (UTC): 2329-0549

Accomplishments of Flight:

Profile over Santiam Pass in moderate precipitation (frontal passage?).

Instrument Problems:

PMS 1-D cloud probe counting in clear air. PMS 2-D cloud probe (?). Icing of FSSP-100.

Flight Scientist: Nick Bond

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
2329	Engines on.
2334	Out of blocks.
2345	Takeoff.
2356	Potential science power problems.
0005	HPVS and 2-DC probes look okay.
0020	Lat 46˚/long 123˚, undercast just below flight level 16,000 ft.
0031	45˚34'/123˚33'. 17,000 ft, wind 290 @ 27 m s^{-1}. In clear air between undercast and thin overcast; some ice settling from aloft.
0046	44˚41'/124˚14'. Changed west point 30' east.
0049	44˚31'/124˚11'. Main cloud decks coming together. Surprising winds (from ~300˚). Beginning first run at 18,000 ft. 2-DC and HVPS probes functioning. Temp –19˚C, wind ~300 @ 25 m s^{-1}.
0057	Very near cloud top; only small crystals showing on HVPS.
0106	44˚20'/122˚48'. Hitting heavier ice crystal conc. but near east end of precipitation band.
0109	End of first east-west run; starting westward descent.
0114	Suspicious winds (52 m s^{-1}!).
0117	HVPS acting odd last 5 min.
0119	Out of precipitation, co-pilot's airspeed indicator out → bad winds.
0126	End of second east-west run; between decks.
0128	Beginning third east-west run at 16,000 ft..
0137	Early part of leg mostly in clear air.
0138	44˚24'/122˚48'. Considerable conc. of ice; some relatively large.
0139	Airspeed and winds back (200˚ @ 24 m s^{-1}).
0142	End of third leg, TA -14.
0143	Airspeed/winds bad again. Heading west.
0147	44˚24'/122˚31'. Heavier precipitation here, light chop, winds back. Little precipitation aloft at west end of leg.
0158	End of fourth leg; CLR.

0200	Begin fifth east-west at 14,000 ft; between decks.
0209	44˚25/122˚18'. In light precipitation.
0348	Shed ice on viewing bubble.
0350	In fairly thick cloud; few or zero large particles.
0353	At 8,000 ft wind 250˚ @ 20 m s^{-1}. Ice building up again.
0356	Mostly out of precipitation; shedding ice again.
0358	2-DC probes temporarily obscured.
0359	Descending to 6,000 ft.
0400	Descending to 4,000 ft. Freezing level about 5,000 ft.
0405	Descending to 3,500 ft for CCN legs, then 3,000 ft, then 2,500 ft.
0410-0415	Trying to find locally higher cloud bases.
0417	Starting CN counter. Short intervals of diffuse thin clouds.
0420-0424	Mostly in cloud, CN measurements compromised.
0431	Finished low-level work not much below cloud base.
0436	Freezing level about 8,000 ft.
0458	In ice on ferry home. T ~–15˚C.
0509	Ice over.
0526	Shutting down data systems.
0544	Landed.
0549	Engines off.

(j) University of Washington Flight 1900 (13-14 December 2001)

Period of Flight (UTC): 2131-0327

Accomplishments of Flight:

Profile from 20,000 to 14,000 ft in southwest-northeast direction over Oregon Cascades in precipitation associated with main rainband of a strong cold front. (P-3 did "lawnmower" flight pattern for air motion measurements.) Convair-580 landed in Eugene, Oregon.

Instrument Problems:

PMS 2-D cloud probe erratic.

Flight Scientist: Nick Bond

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
2131	Engines on.
2136	Out of blocks.
2143	Takeoff.
2203	Ferry in constant precipitation 2-DC down.
2218	Winds 250° @ 28 m s^{-1} (15,000 ft).
2220	2-DC back up but images look bad and suspiciously low concentrations.
2230	Trying to restart 2-DC probe system.
2244	HVPS temporarily down.
2249	Larger crystals on HVPS.
2304	2-DC looking okay.
2322	At southwest starting point; begin first run, 20,000 ft, wind 250° @ 45 m s^{-1}, T = –18° to –19°C.
2334	End of first leg.
2338	Second leg heading southwest (20,000-18,000 ft).
2352	No visual sign of back edge of band.
2357	End of second leg.
2359	Starting third leg heading northeast, 18,000 ft, wind 245° @ 45; T= –16° to –17°C.
0005	S-Pol and P-3 reporting echo tops of 7 & 8 km; latter seems more likely.
0012	End of third leg.
0015	Start of fourth leg (18,000-16,000 ft).
0025	Everything working fine; appears to be low LWC (~0.01 g/m^3).
0035	Wind speeds dropping off 42 to 32 m s^{-1}.
0039	End of fourth leg.
0041	Start of fifth leg heading northeast, 16,000 ft, wind 250° @ 31; T = –14° to –16°C. 2-DC looks kind of bad (will cycle power).
0057	End of fifth leg.
0101	Start sixth leg, head southwest, 16,000-14,000 ft.
0120	A bit more intense precipitation, stronger winds and turbulence at southwest end of leg. End of sixth leg; clear slot at flight level right at end.

0130	Start of seventh leg, heading northeast, 14,000 ft, wind 250° @ 40 m s^{-1}; T –12° to –13°C. Light to occasionally moderate chop at southwest end of leg.
0141	Much smoother ride.
0145	End of seventh leg.
0148	Start of eighth leg heading southwest (14,000-12,000 ft).
0149	Locally enhanced winds over Santiam Pass (~48 m s^{-1}).
0200	Some riming and small patches of high LWC.
0217	End of eighth leg.
0221	Start of ninth leg heading northeast, 11,000 ft, wind 255° @ 32 m s^{-1}, T ~–8°C.
0228	Hitting some clear patches.
0229	2-DC out then back.
0237	End of ninth leg; considerable precipitation in lee of Cascade crest (aloft).
0240	Start of tenth leg (stepped descent).
0243	Apparently cracked a window. Short patches without precipitation in lee of crest, 10,000 ft, T ~–6°C.
0257	Hitting moderate chop.
0304	Shed ice on window.
0309	End last leg; heading for Eugene.
0324	Landed at Eugene.
0327	Engines off.

(k) University of Washington Flight 1901 (14 December 2001)

Period of Flight (UTC): 0438-0815

Accomplishments of Flight:

Takeoff from Eugene, Oregon. Profile across Santiam Pass in same storm system as UW Flight 1900 but in post-frontal conditions. (P-3 up only during initial portion of flight).

Flight Scientist: Nick Bond

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
0438	Engines on.
0450	Takeoff.
0500	CCN instrument on.

0505	Winds at 3,000 ft 280° @ 18 m s^{-1}.
0520	Broke off level work & climbing.
0521	Many parameters not updating.
0526	Hitting up to 0.4 g/m^3 LWC and sizable ice crystals.
0532	Heading for Santiam Pass. Cloud below 14,000-15,000 ft.
0533	PVM zeroed.
0536	Skimming tops at 13,700 ft.
0540	Lighter but still continuous precipitation in lee until just before endpoint.
0541	End of first leg.
0545	Start second leg, heading southwest (13,700-12,000 ft).
0547	Spotted some capped columns.
0555	44°17'/122°9'. Out of most precipitation.
0609	End of leg 2; continuous precipitation in last portion of leg.
0613	Begin third leg heading northeast, 12,000 ft, wind 270° @ 17 m s^{-1}.
0620	44°16'/122°11'. Winds now 245-250° @ 25 m s^{-1}.
0625	Precipitation cut off in immediate lee (some occasional bursts).
0629	End of third leg.
0633	Starting fourth leg (12,000-10,000 ft).
0636	Sizeable patches of precipitation in lee.
0643	Dropping to 10,000 ft west of pass.
0649	Large flakes at ~9,000 ft and T ~–10°C.
0654	Dropping to 6,000 ft, columns appearing.
0658	End of fourth leg; some needles near end. Heading to Paine Field.
0706	Ascent for ferry heading due north over S-Pol radar, precipitation up to 166.
0810	Landed.
0815	Engines off.

(l) University of Washington Flight 1902 (19-20 December 2001)

Period of Flight (UTC): 2229-0419

Accomplishments of Flight:

North-south oriented vertical profile from 18,000 to 8,000 ft west of Oregon Cascade crest. West-to-east cross-mountain track in southern edge of rainband. Truncated north-south stack in rainband east of Cascade crest. Landed in Eugene, Oregon.

Instrument Problems:

PMS 1-D cloud probe (?).

Flight Scientist: Nick Bond

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
2229	Engines on.
2231	Out of blocks.
2241	Takeoff.
2253	No TANS/winds.
2257	2-DC & HVPS working.
2302	Winds now working 160° @ 5 m s^{-1} @ 576 mb.
2322	Lat. 45°45'. Winds 218° @ 20-25 m s^{-1}. Possible significance of warm front aloft.
2336	Decide to ascend to 18,000 ft.
2340	Starting first southbound (18,000-16,000 ft). Wind 215° @ 22 m s^{-1}, T ~–21°C. Solid cloud.
2348	Conversation with S-Pol radar operator indicates that legs should be shorten because of back edge of system approaching.
0008	CPI not working; open ground visible below.
0010	End of leg 1.
0012	Start of leg 2 (north bound at 16,000 ft).
0020	End of leg 2 (whole leg in precipitation).
0023	Start of leg 3 (south bound 16,000-14,000 ft). Winds 205° @ 20 m s^{-1}, T ~–14°C, solid cloud.
0027	End of leg 3 (steep descent).
0029	Start of leg 4 (north bound @ 14,000 ft).
0033	Heavier precipitation; bigger crystals. Wind 210° @ 22 m s^{-1}. LWC 0.04 → 0.1 g m^{-3}.
0038	End of leg 4.

0041	Start of leg 5 (south bound 14,000-12,000 ft).
0049	End of leg 5.
0050	Possible computer problem; displays not updating.
0056	Data displays back.
0058	End of leg 6.
0100	Start of leg 7 (south bound 12,000 ft).
0107	End of leg 7; descent at turn.
0108	Start of leg 8 (north bound, 10,000 ft). Wind 212° @ 18 m s^{-1}. T ~–5°C.
0116	End of leg 8.
0120	Start of leg 9 (south bound 10,000-8,000 ft).
0124	2-DC temp. down.
0127	End of leg 9.
0128	Start of leg 10 (north at 8,000 ft). Wind 185° @ 15 m s^{-1} but noisy. T ~–2° to –4°C. Low LWC (0.05-0.1 g m^{-3}).
0132	Some chop.
0136	End of leg 10 (last north-south). Ferry to Pt. M.
0141	Descending to 7,000 ft.
0145	Moderate chop; near freezing level.
0150	Near cloud base.
0156	At Pt. M; lining up to cross mountain
0202	Climb to 8,000 ft.
0208	Begin climb to 10,000 ft.
~0213	Turn and climb for north-south stack.
0228	Start first run south bound (18,000-16,000 ft).
0231	Wind 200 @ 14 m s^{-1}. T ~–20°C. Still in light precipitation.
0236	Lighter precipitation in south end.
0237	
0239	Start of second leg north (16,000 ft). Wind 210° @ 23 m s^{-1}. T ~–17°C.
0251	End of second leg.
0254	Start of third leg south (16,000-14,000 ft). Wind 212° @ 16 m s^{-1}.
0305	End of third leg.
0307	Start of fourth north (14,000 ft).
0311	Break in precipitation.
0320	End of fourth.

0322	Start of fifth south (14,000-11,000 ft). Wind 210° @ 17 m s^{-1}.
0326	Relatively heavy precipitation near 45°10'.
0332	End of fifth leg.
0334	Heading north (descending to min ~8,000 ft).
0340	Winds 125° @ 22 m s^{-1} at 8,000 ft.
0341	End of descent to 8,000 ft.
0345	Quasi-isothermal in climb from 8,000 to 11,000 ft; veering wind.
0349	End of south bound climb. Ferry to Salem.
0401	Mod. chop and precipitation. Over crest and foothills.
0414	Landed.
0419	Engines off.

(m) University of Washington Flight 1903 (20 December 2001)

Period of Flight (UTC): 0506-0609

Accomplishments of Flight:

Transit flight from Eugene, Oregon, to Paine Field, Washington.

Instrument Problems:

PMS 1-D cloud probe (?).

Flight Scientist: Nick Bond

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
0506	Engines on.
0514	Takeoff.
0530	In light precipitation.
0603	Landed.
0609	Engines off.

(n) University of Washington Flight 1904 (21 December 2001)

This was an instrument test flight between Paine Field and Quillayute, Washington.

(o) University of Washington Flight 1905 (22 December 2001)

Period of Flight (UTC): 1459-1752

Accomplishments of Flight:

Weak warm-frontal rainband from 20,000 to 18,000 ft. Landed in Eugene, Oregon.

Instrument Problems:

PMS 1-D cloud probe (?).

Flight Scientist: Nick Bond

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
1459	Engines on.
1509	Takeoff.
1547	Hit clouds at ~46° N/123°9'.
1603	Broke out of clouds; still some small crystals from aloft.
1612	Back in clouds; 2-DC temporarily out.
1614	44°31'/123°35'. Winds 155-160° @ ~22 m s^{-1}. (~5 m s^{-1} greater than forecast).
1631	Turning for start of first leg; popped into clear briefly.
1633	Start of leg 1 (northeast at 20,000 ft). Wind 168° @ 31 m s^{-1}. T ~–27°C. Sun dimly visible; only small crystals implying not much growth above.
1648	End of leg 1; brighter here.
1650	Start of leg 2 (southwest 20,000 →18,000 ft).
1651	Dropping down to 18,000 ft due to traffic.
1703	Ground becoming visible.
1710	End of leg 2; shallow CBs ahead.
1712	Start leg 3 (northeast 18,000-20,000 ft).
1719	Intercepted cloud/precipitation. Wind 167° @ 25 m s^{-1}. T ~–26°C.
~1728	End of leg 3.
1732	After conversations with S-Pol radar operator decided to break off pattern and land at Eugene to wait for surface front.
1749	Landed.
1752	Engines off.

(p) University of Washington Flight 1906 (22 December 2001)

Period of Flight (UTC): 1909-2300

Accomplishments of Flight:

1) Takeoff from Eugene, Oregon. North-south oriented profile from 20,000 to 10,000 ft in same system as UW Flight 1905.
2) Wind profile in Columbia Gorge. Landed at Paine Field, Washington.

Instrument Problems:

PMS 1-D cloud probe (?).

Flight Scientist: Nick Bond

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
1909	Engines on.
1916	Takeoff.
1931	In precipitation in vicinity of Santiam Pass. LWC = 0.1-0.2 g m^{-3}. Descent in precipitation east of crest.
1937	Beginning spiral ascent to 20,000 ft.
1941	Leveling at 12,000 ft for traffic.
2002	Getting bright above 18,000 ft.
2004	First north-south run (north at 20,000 ft) near top. Wind 150° @ 16 m s^{-1}. T ~–29°C.
2010	At north end; turning.
2012	Start of second (south, 20,000 → 18,000 ft).
2021	End of second; turning.
2023	Third north-south (north at 18,000 ft). Wind 165° @ 18 m s^{-1}. T ~–24°C.
2030	End of third; turning.
2032	Start of fourth (south, 18,000-16,000 ft).
2043	End of forth; turning.
2045	Fifth north-south (north at 16,000 ft). Wind 170° @ 14 m s^{-1}. T ~–20°C.
2052	End of fifth leg; turning.
2054	Start of sixth (south, 16,000-14,000 ft).
2104	Broke into clear slot.
2106	Hit liquid H_2O cloud at south end.

2107	End of sixth; turning.
2109	Start of seventh north-south (north at 14,000 ft). Wind 175° @ 12 m s^{-1}. T ~–17°C.
2117	End of seventh leg (somewhat greater precipitation at north end.
2119	Start eighth (south 14,000-12,500 ft).
2126	Hit clear zone.
2131	End of seventh leg.
2134	Start eighth leg north-south (north 12,500 ft). Wind 225° @ 8 m s^{-1}.
2145	End of eighth leg.
2146	Proceeding northeast and descending to 10,000 ft in very light precipitation.
2152	Heading for Troutdale to do a missed approach.
2202	Crossing crest at 45°10'. Little precipitation reaching surface.
2209	Winds into Troutdale at 4,000 ft, 185° @ 10 m s^{-1}; 2,500 ft, 110° @ 15 m s^{-1}.
2213	Over runway 080° at 10 m s^{-1}.
2215	Rapid wind shift at 2,000 ft. with some turbulence.
2216	Ferry to Paine Field.
2257	Landed.
2300	Engines off.

5.2. Transcriptions of In-Flight Summaries[*]

(a) University of Washington Flight 1891 (28 November 2001)

10:41 PM

PH: I'm going to do a quick summary of this flight. We got off about 2 hr late because of unexpected, unforecast snowfall at Paine Field. We then headed to a point that was on the coast southwest of Santiam Pass in Oregon. We started our planned profile near 21,000 ft heading to the northeast. Then we dropped down and worked our way backward and forward, southwest to northeast, using lat/longs given to us from the S-Pol radar. On the descent from 17,000 to 14,500 ft on our northeast to southwest leg, we picked up more icing than we were happy with, and we knew that if we continued to descend the icing would get even worse. So we decided not to go lower. Instead we did another track back

[*] Speakers: AR = Art Rangno, BE = Bob Eatwell, CB = Charlie Black, CI = Calvin Ingram, EC = Eric Cooper (pilot) KM = Ken McMillen (pilot), LS = Larry Sutherland (pilot), PH = Peter Hobbs, RR = Roy Rasmussen, TW = Tom Wilson, VS = Vidal Salazar, ZS = Zan Sutherland (pilot)

at 17,000 ft from southwest to the northeast. We just finished that leg, and we are now heading back to the southwest descending from 17,000 ft as we head toward Eugene.

The instruments worked pretty well. Good liquid water measurements on the PVM and the FSSP-100. The J-W, however, is very intermittent; it was out most of the time just occasionally coming into play, so there is some loose connection there. Good 2-DC data. Good HVPS data. Some CPI data, but the images are not very distinct. The P-3 was up; I think it did most of its prescribed pattern beneath us. It also got into icing problems and had to break away at one point. They've also lost their deicing equipment on one engine. So it remains to be seen what effect that has on their future flying.

Not a bad flight, a little tough one with which to start the project, because we couldn't complete the full vertical profile, which would have been nice, but safety comes first. So I think we've got some reasonable data, and we may do better next time.

PH: Art, would you like to give a summary?

AR: Roger. I thought this was a fantastic flight. Certainly nothing like we've seen before. We had the 850-mb wind at 50 knots or so. This was, of course, predicted by the model, we didn't actually measure that, and 10,000-ft winds of about 70 knots, again predicted by the model, and of course, our 500-mb winds approaching 90 knots. So it was an exceptional situation mainly warm-sector flying. I think, as we traversed out from Paine Field, there was a temperature gradient that we went through about 15 min to 30 min we may have hit some higher-level representation of the warm front or something going on there. I have to correct that. Actually the temperature was falling, which would go with the _____ advection at that level, which is accompanied by temperature falls. The cloud development here was one where we generally had moderate convection I would say inside this stuff with protruding tops up to about 20,000-25,000 ft when we first arrived. Then, as the day wore on, the tops seemed to become more stratified, although there was embedded convection within it that produced liquid water contents up to about half a gram I think was the maximum that I saw. On top the tops sloping upward from the valley to the Cascades keeping in mind that strong flow toward the Cascades, not of course perpendicular to it, but having a component toward the Cascades. So I thought it was one of our better quasi-steady state situations. I think for me, one of the big surprises, microstructurally, was to find bursts of drizzle inside the snowstorm that was occurring over the Cascades. That remains a bit of a mystery right now, but our guest here, Roy Rasmussen, told me this is fairly common and I'll certainly join the club on that in this situation. I'll have to look at the data and see what exactly was going on here. I only wish we could have pounded out that lowest level, although it would have been hazardous and possibly causing our death, but to see what happened to that drizzle on the way down and especially whether the boys at the ground were seeing drizzle on the ground. That would have been incredible. Droplet concentrations very maritime, very low, and indicating little modification and hence the ability of collision coalescence to be rampant today.

PH: Roy, would you have to give a summary?

RR: I also thought this was a very nice flight for us. The CCN instrument worked well. We got very low CCN measurements, 20-30/cc. The presence of some freezing drizzle was exciting for me and confirmed what we've seen in the mid-west and the east that when we get the cloud tops near –12˚C or slightly warmer that we do get freezing drizzle. What I was seeing is that as soon as we got significant amounts of dendritic or otherwise crystals the drizzle went away. As the crystal concentration went down, which was likely due to the warmer cloud tops, we got more drizzle forming. So these pockets I suspect are due to warmer cloud tops and so I'm excited to go back and look at the higher cloud top temperatures if we can see the cloud tops with satellite and see what's going on and also go back and look at the data. So all in all it was a good flight.

PH: Good. This descent we're doing now should be good as well. We're getting good profile here as we descend through 16,000 ft as we head toward Eugene. Does Vidal want to say anything?

VS: Roy already said pretty much everything about the CCN, good data from the CCN. At the beginning of the flight, we had some problems with the CN counter, so one of the recommendations that I have is that we'll probably have to check the formulative rules. We'll look at the data from the CCN that has been recorded and I guess we need to check the connections on the CN for future flights.

PH: The CN may have needed a long warm-up time, because it started off very cold. It got cold soaked overnight and that instrument does take a while to come up. We do need to check the methanol level, maybe that's something you can check every time, Vidal. Don can show you how we to do it. You have to be careful with that methanol though because it's a nasty liquid to work with. You don't want to be spilling it anywhere.

VS: Yes. I'm familiar with the CN counter. I actually had to plug one of the power strips into a power supply because it was off the instrument. That's what I meant.

PH: Tom, anything?

TW: I don't think so. I've written down everything I need to do or kind of look over.

PH: But do you want to make a note on what instruments from your point of view were not working?

TW: The J-W, but you've already mentioned that, and the CPI. Those were the two biggies I think.

PH: Also the PMS 1-DC is not working at all.

TW: I'm pretty sure Don was aware of that and he just didn't have time to look at it.

AR: Exactly.

(b) University of Washington Flight 1892 (29 November 2001)

1:09 AM

PH: A quick summary of this flight, which was basically a transit flight in postfrontal conditions back to Paine Field from Eugene. We did get a nice profile in climbing out of Eugene up to about 15,000 ft. Good cloud physics measurements, but thereafter not much by way of cloud measurements on the way back to Paine Field.

(c) University of Washington Flight 1893 (29 November 2001)

7:22 PM

PH: A summary of this flight. This was in a weak post cold frontal-type situation that had, I think, already passed over the Cascade crest by the time we got there. So we started out at Sweet Home and headed east to Santiam starting out at 15,000 ft. But even though we decreased our altitude to 10,500 ft on that easterly leg, we didn't get into any cloud. We then returned to the west back to Sweet Home descending in altitude from about 10,000 ft down to near 2,000 ft when we were just west of Sweet Home, which put us in cloud as we descended. In fact, we picked up quite a bit of icing during that descent. Then we did CCN spectrum measurements in the below cloud base just west of Sweet Home at 2,000 ft and got, I think, two sets of measurements there, which Vidal will describe. Then we headed back east through Sweet Home to Santiam Pass following minimum altitudes over the rising terrain, which again gave us a good set of cloud physics measurements. On the east side of the Cascade crest, we headed to Sisters Airport where PNNL has its microwave radiometer for measuring total liquid and vapor water paths. At that site we first of all did another set of CCN spectral measurements below cloud base, in what might have been the outflow from the cloud system over the Cascade crest. After we finished that, we spiraled up through a cloud that had just passed over the Sisters Airport at about 1914 UTC. From 1914 to 1922 UTC we spiraled up through that cloud and out to cloud top at about 9,000 ft for comparison with the PNNL microwave radiometer.

It was not a very strong weather system today, but we got some pretty good measurements in what there was. The PMS 1-DC probe is still not working. The J-W looks as if it is certainly out; it's giving some measurements, but they're not correct. The CPI started off fairly good but then packed up. Art couldn't get it back up again. The P-3 didn't fly today because they're fixing a deicing problem, so we've been by ourselves up here.

That's it. Art, summary.

AR: Roger. Today was a classic postfrontal day but with well capped cloud tops. An inversion was capping them at about 10,500 to 12,500 ft. Mounding cloud tops extending occasionally to that highest temperature, which was I'd have to say about –13˚ to –15˚C. Cloud bases on the west side running about 0˚C to 2˚C. On the east side, cloud bases in the lee clouds forming and coming off the Cascades at about –6˚C. Droplet concentrations

very maritime, surprisingly maritime for being an inland site I thought, again in the tens per cc, and along with that lots of formation of drizzle drops with a collision-coalescence process being active again. Also tremendous amounts of ice also in pockets. It resembles yesterday even though we have less wind pounding against the mountains and more in the neighborhood of 20 to 30 knots at cloud level in the west-northwest and lower cloud base temperatures today than we had yesterday, but nevertheless the tens per cc of droplet concentrations producing the broad spectrum required for collision-coalescence to operate in these clouds at supercooled temperatures. The other thing that we had on the way down here was a great example of seeing the influence of the warm water on clouds over the coast and just inland, which were producing large mounds above the general stratocumulus cloud tops (very cumuliform looking), and then just as they crossed the coastline the peak went out of those things. The air went out of them and essentially they became stratocumulus clouds, probably within 30 miles of the coastline. That's pretty much what we see along the Washington coast. Then over the Cascades the lifting, overcoming the cold surface by producing similar mounds of clouds above the general stratocumulus level, but on a scale that was different than the type seen over the water. The mounds looked broader and probably didn't stick up above the general level of the clouds that much. So I found that quite interesting looking at the clouds going from the ocean to the valley where there was no convection whatsoever, and then the forced convection producing mounds as the air uplifted over the Cascades.

In the Willamette Valley the air channeled out of the southwest and then with a northwest flow above the boundary layer, let's say at 850 mb and higher when turning to the northwest, much as we see in the Seattle area. The southwest wind with northwest wind aloft and that producing upsloped flow from the southwest and when we were sampling the radar CCN sample that was advected into the mountains going northeast, but then as it rose up it got caught in that gradient flow from the northwest and then tracked back toward the southeast as it traversed the Cascades. So I guess that's it, way too much.

PH: Fine, that's good. Vidal.

VS: It was a very exciting day for CCN measurements for me. The first cycle that we did over the town of Sweet Home was relatively clean air, with CN counts of around 250 cm^{-3}. So we did two cycles of CCN and the data was like 60 counts per cc at 0.2%, around 80 per 0.3%, around 90 for 0.5%, around 100 for 0.7%, and around 120 for 1% supersaturation. So this was relatively clean air compared to the last one we did over the town of Santiam.

(End of tape 1, side 2)

VS: The second set of CCN measurements, which we did over the Sisters Airport on the east side of the Cascades, was up to 2,000 particles per cc. At 0.2% we got 2 counts per cc, 0.3% around 30, 0.5% around 250, 0.7% around 500, and for 1% supersaturation around 1,000 cm^{-3}. So it was a really exciting day for CCN measurements.

PH: Good. Tom, anything?

TW: Yes. Pretty much the same instruments were out that we were having problems with yesterday, except for the CNC-1 (TSI 3022). The serial cable on the back was connected to the wrong instrument. I fixed that and it's connected to the correct instrument now. That's about it.

PH: Okay.

PH: I'll take a look at that CCN-1 and see what it does on the way back home.

7:33 PM

PH: Well the CCN-1 reading has declined as we climb here. It's come down into the hundreds. Vidal, were your CCN measurements at one particular supersaturation higher on the west side or the east side?

VS: Let me check my notes. Hold on a second.

7:34 PM

VS: My CCN measurements on the west side were around at 0.3% supersaturation were around 40 to 50 numbers per cc, and on the east side they were more around 60s to 70s numbers per cc.

PH: That's what we would expect. Probably some activation and growth of the CCN in clouds, then we see the enhanced CCN expelled in the outflow on the east side.

(d) University of Washington Flight 1894 (1 December 2001)

PH: To summarize, we didn't get to the IMPROVE-II research area because of a problem with the co-pilot's airspeed indicator. We've just turned around south of the Columbia River and are now headed back to Paine Field. We're over the southern part of the Puget Sound. The P-3 was up. The decision was to let the P-3 continue flying and try to serve the role of both planes. We'll see whether or not it's of any value for us to try to get in the air again today, assuming we can fix the problem in the cabin. Art, do you want to add something on the summary. You can say something about the weather at least.

AR: This was pretty much going to be virtually an identical case in terms of the upper level pattern and surface pattern to the one we flew on Wednesday. So I was kind of looking forward to getting down there and seeing if there was any differences, and whether we had really nailed this collision-coalescence process and the occurrence of low droplet concentrations. So I'm kind of disappointed. We traversed a number of dying ember cumulonimbus clouds that as they came inland lost their warm bottoms, of course, getting away for the ocean and essentially tend to fall apart and end up being mainly glaciated and lacking in turrets but having a residual shelf clouds. So we did get some sample of that. The CPI seemed to be working pretty well at the times I looked at it, but that was kind of a minimal amount of time. The HVPS is in and out as per usual. The 2-D…

PH: Art, could you bring up the CPI now so we see again as we come into land whether it's working or not?

AR: Yes. That's a good point. I will do that. Let's see. The FSSP spectrum, as Peter pointed out, although it was mainly in ice crystals when I was looking at it, did appear to have too many counts in the first channel. That maybe needs some attention. That generally is an alignment situation.

4:37 PM

PH: I might add that we got some activity on the J-W on this flight. It's below the FSSP and generally below the PVM as well, but at least it appears to be alive. The PVM was generally below the FSSP in the liquid water.

4:40 PM

PH: One good piece of news is the CPI is working better than it has on previous flights. On the other hand the HVPS has been in and out. I also not that we're not seeing in real-time display here the frequent noise blips on the temperature that Art was concerned about from the last flight. The PMS 2-DC is working as we go through cloud here.

4:41 PM

PH: Also I don't know when it happened, but sometime during the flight the t-statr suddenly went out and is now recording like 85˚C or something like that. It was working at the beginning of the flight.

TW: For the record I tried to bypass the VCR character generator because Art was saying there was random characters appearing on the video tape. So hopefully that doesn't occur at this time.

PH: Do we have video tape recording this time?

TW: It's recording, but there were characters blocking the screen a little bit on previous flights. So I'm going to check to see if that has been fixed.

PH: Did we did have video on all of the previous flights?

AR: Yes. I did check. I checked the last flight actually.

PH: But no date and time?

AR: That's affirmative and the image is impacted by having characters blinking in front of the cloud scene.

PH: Do we have date and time today on the video?

TW: No. That's a pretty big job to get that working again.

PH: That's certainly not top priority. But if you've got time down the line, do it. I notice that although the J-W came in for awhile back there about 15 min ago. It's now out again, not giving any readings.

4:45 AM

PH: This is a disappointing day. Everything was setup ideally timewise, and the P-3 is on station and we had to return.

(e) University of Washington Flight 1895 (4-5 December 2001)[*]

This flight took place in a deep frontal cloud shield with light westerly flow and rather low temperatures (-20° C at 600 hPa). Malfunctions of the pilot's airspeed indicators caused an early termination of the flight and landing at Eugene, Oregon, for a repair of the instrument overnight in Eugene.

Cloud and ice crystal observations were not made en route to the research site flight by the Flight Meteorologist (FM) due to the considerable amount of time spent in attempts to get the CPI started. Despite numerous attempts, the CPI could not be made to work. Also, the 2-DC probe did not function during the ferry leg but began to work just after the beginning of the first W-E research leg heading toward Santiam Pass at 16,000 feet MSL. The PMS 1-DC probe had high (>1000 per liter) counts in clear air, making its data questionable.

The true airspeed (TAS) measurements were also subject to malfunctions or errors, which prevents the calculation of reliable winds at flight level and accurate sample volumes for the probes (estimates of TAS will have to be used for particle sample volumes). Finally, pstat (and thus, pressure altitude) did not work properly, with pstat indicating erroneously high pressure (e.g., 928 hPa when the plane was at 16,000 feet MSL).

Virtually no icing occurred on this flight in a featureless ice cloud (as indicated by only traces of icing on the airframe at the time of the termination of the research portion of the flight at about 0125 UTC). During the rapid descent to Eugene, the aircraft passed through the only appreciable liquid water cloud (maximum liquid water contents of a few tenths per gram per cubic meter) beginning at about 7000 feet and terminating near the surface at Eugene.

(f) University of Washington Flight 1896 (5 December 2001)

PH: This flight has looked pretty good. We'll do a quick summary. We got our TANS back up, we got our true airspeed. The pilots' true airspeeds are back. We've run the PMS 2-D and the 2-D images and the HVPS throughout the flight. They all look good. The only thing we haven't got up is the CPI.

AR: Roger. The CPI we couldn't get started. Static pressure came back and worked fine this whole flight after not working on the previous flight or at least over reporting the pressure

[*] No verbal summary of this flight was recorded onboard the aircraft. This summary was written post-flight by A. Rangno and P. Hobbs.

and subsequently that impacting our standard pressure altitude calculation. Along with that the things that Peter mentioned about true airspeed, our winds are back.

10:35 PM

PH: Art, do you want to put anything by way of summary on the tape?

AR: Well I kind of made those comments about instruments. That's pretty much it. We flew in some higher overcast altostratus with some virga. I doubt the precipitation we flew in actually got to the ground because we were intercepting it at such a high altitude, but if it was it was very, very light because of that dry layer below the altostratus. Just here coming into Puget Sound we had some nice sort of plumped up stratocumulus clouds, tops –8˚C to –7˚C with a little ice in them, and then precipitation to the ground out there sort of south and east-west of Paine Field. I didn't see anything unusual other than that.

PH: Well this has been a pretty promising flight.

AR: Right. We had quite a few things working and maybe we can still get that CPI going some how.

PH: Don't give up on that. Keep working on it.

AR: Right.

(g) University of Washington Flight 1897 (8 December 2001)

11:23 PM

PH: I'm going to give a quick summary of the first flight of today. It wasn't quite what we expected. We were heading out to do our standard profile over Santiam Pass. But because the front was moving in slower than predicted, we ended up doing east to west tracks through the cold front as it came onto the Oregon coast and inland starting at 7,000 ft and moving steadily upward to where we are now, which is at 15,000 ft with the P-3 below us mapping out the airflow.

LS: Peter, the Center has us on vector so we'll probably be going a little bit south maybe not on our track.

PH: Okay. I understand based on the radar and satellite observations and so on it was a pretty well-defined nice cold front maybe fairly narrow. It should be moving into the Santiam Pass area in the next few hours so the second flight today we hope to do our standard profile over the Oregon Cascades. As far as instruments go everything seemed to be working fairly well.

LS: Peter, we're climbing to 17,000 ft and we're out at 15,500 ft. We'll be climbing about 500 ft per minute if that's okay.

PH: That's okay. Didn't have the CPI on board, but the other cloud physics instruments worked except for the J-W. We're not sure if we got any CN measurements. I think the CCN was working okay. It looks as if from my trace of the CNC-2 that it was working okay up until about 5 min ago.

VS: That's correct. The CNC-2 was working okay until about 5 min ago. When it was working it showed particles in concentrations of about 200 particles per centimeter cubed. CCN during the entire flight was working okay and it was showing concentrations between 20 and 30 numbers per cc.

PH: Good. Art, would you like to give a summary?

AR: Yes. I thought the PMS 2-D imagery worked the best of any flight previously. It has not gone down. HVPS also worked probably the best of any flight, just a brief outage.

As far as the weather goes, it's going to be a little bit complicated. From our observations flying down at 810 mbar when we were down around that level about 5,500 to 6,000 ft, we encountered a windshift and a temperature drop well ahead of where the front was supposed to be. It was supposed to be offshore and this was actually on the eastside of the coast range that that happened on just the last couple of minutes for our ferry flight. Then as we flew westbound we encountered another windshift from about 270˚ to 290˚, something in that category, out offshore where the front was apparently located via radar. So it will make an interesting case. Generally no icing in all these legs except for a trace all the way up to our present flight level, which is coming up on TANS-alt about 6,000 ft. That probably was a little unexpected from this vantage point. I thought we would hit some ice in this particular frontal system because of the strength of it looking on the satellite imagery this morning. So really the only icing was picked up in the middle levels en route to the research area where the icing was protruding over an inch from the top of the Pilewskie rod.

11:35 PM

PH: Vidal, did you want to put any summary on the tape?

VS: Just want to mention that the CCN was working pretty well. The counts were pretty stable between 20 to 30 number per cc. The CN was working mostly all the flight, but CN-2 was working before the flight showing 200 particles per centimeter cubed, but we're still having that problem with the CN-1 and we need to check the pipe.

PH: Right. As long as we have one CN counter then that's okay. Did you look at the PMS 1-D probe today, Art?

AR: Yes I did.

PH: Did it look okay?

AR: As far as I could tell, it didn't look too bad. The peak of the spectra was not out at the larger size channels that we had been seeing before.

(h) University of Washington Flight 1898 (9 December 2001)

4:02 AM

PH: By way of summary, we've done a pretty thorough vertical profile over the Oregon Cascades here on a southwest to northeast track taking us over Santiam Pass from 19,000 ft down to our present altitude of 11,000 ft. On the last track, yet to be done, we'll be following terrain out to the southwest. The cold front probably went through before we got up and over the Cascades on this second flight of today. It was probably already at the crest heading east. So we've been flying in mainly postfrontal conditions. The surprising thing is very negligible, hardly any liquid water at all throughout the whole profile. There were plenty of crystals to look at. The P-3 was beneath us at least up until an hour or so ago doing its tracks. It must have gone through the front in the first flight today when we went out to the coast, but the vertical profile we did on the coast was again probably in a postfrontal rainband. So a bit of mistiming here and misinterpretation on the part of the ground people as to where the front was, which resulted in the fact that we didn't accomplish the main objective, which was to sample prefrontal, frontal and postfrontal conditions. Instead we got a bit of a front and mainly postfrontal.

Instruments worked pretty well today. The CPI not on board that's the major thing, and the J-W not working. The CNC-1 didn't come up, but we had CNC-2 for most of the flight. Everything else seemed pretty good. The chief pilot did lose airspeed indicator again, in this case, left side airspeed indicator; the co-pilots' airspeed indicator remained okay. That's in the absence of any icing. Art, would you like to do a summary?

AR: Sure. I think we're going to pick up some liquid water on this pass, just looking ahead and the fact we nipped some tops there on this pass. I'm hopeful we'll pick up a little more liquid water on this last pass. But the thing that struck me was the homogeneity of this postfrontal situation and my interpretation from looking at the cloud top.

AR: The system we flew in today was pretty much the same type of ice crystals from one end to the other and other the sizes changing a little bit, that's about all that did change. So in some cases I suppose it would be a nice case in that you can look at the growth of these crystals on the way down over this mountain range and maybe try and put that together with the predictions of crystal growth. Kind of an inert storm situation not a lot of dynamics ramming the air up against the mountains produce a deep orographic cloud.

PH: Art, there's some liquid water there, the highest we've had I think on this second flight.

AR: Well actually they've gone a little bit higher than this, but you're right, Peter, here it comes. We're going to get into that stuff, which makes it a little more interesting.

PH: Still east of Santiam Pass.

AR: That's right, just about coming up on it. So that's promising for what's ahead then. I'm making this a little too long. But anyway I'd say that I'm almost positive that the humped tops that we noticed in the middle of our highest pass in this second flight was the remnants of that postfrontal rainband that we had sampled offshore. That the radar folks initially thought was the front. I'm almost positive that would be the same feature. So we did probably did stick with that.

PH: I think that's very likely the case.

AR: The other thing those hump tops, I'll just make an estimate, probably extended at least 1 kilometer at our highest pass they were probably a good 1 kilometer higher than that. To the east of that, we sampled just the top of the clouds, which was visual at that time. On the west side or upwind side, we actually were sampling small crystals, but they were falling out from this higher shield that extended back from those elevated tops. In that situation, there was the higher shelf to the west. Then the tops were surfing down below us or sort of a wedge pattern on the west side of the Cascades. The other thing was, I think Peter brought this up, but anyway winds being southwesterly at high levels and then veering here to the last wind I saw on the west side at 11,000 ft was 290˚, so they've really come around reflecting that postfrontal situation.

4:47 AM

PH: So to complete the summary of the flight, we did get our CCN spectrum measurements below cloud base just south of Eugene. So we pretty much accomplished everything we set out to do today, except for some problems with the timing of the front; but that will all come out in the wash.

(i) University of Washington Flight 1899 (12-13 December 2001)[*]

(Perhaps the most dangerous flight of all in IMPROVE-II, due to extensive amounts of supercooled drizzle and prolonged cloud icing conditions encountered in the lower sampling legs after a higher ice-producing cloud shield moved away.)

In the ferry portion of flight from Paine Field to central Oregon, flown at 15,000 ft MSL (-14°C), the Convair began sampling an ice cloud consisting of unrimed crystals, with occasional embedded altocumulus-like clouds, around 0001 UTC, which was soon after reaching cruising altitude. This situation continued until 0026 UTC when the aircraft climbed to 18,000 ft MSL above cloud top into drier air at –19°C.

Cloud and precipitation ice, with embedded droplet clouds, were again encountered as the aircraft turned southeastward to begin its first research leg over the research area at about 0050

[*] No verbal summary of this flight was recorded onboard the aircraft. A summary has been reconstructed from other comments recorded on the flight.

UTC. Snow and cloud ice, consisting of unrimed crystals with brief regions of lightly rimed ice particles, dominated along this eastbound leg. Most of the droplet clouds encountered on this leg were located at the east end of the leg, or over Sweet Home, Oregon. Droplet concentrations in these clouds were very low (10-20 cm^{-3}) and liquid water contents (LWCs) were generally less than 0.15 g m^{-3}. The ice particles encountered on this leg appeared to be mainly single crystals (quasi-spherical crystals that might have been due to short thick columns or plates). Also, larger single ice particle in the PMS 2-DC imagery appeared to be due to bullet rosettes, whose rounded portions suggested a period of evaporation before reaching the flight level of the Convair.

In the return, westbound leg (0106 to 0125 UTC), the aircraft gradually descended from 18,000 ft to 16,000 ft MSL. The degree of riming of ice particles was noticeably greater on this leg, with some of the particles appearing to have originated as frozen drops. The lower portions of the droplet clouds, intercepted at the east end of the previous leg, were re-intercepted as this leg began. Droplet concentrations were similar but with lower LWC.

About halfway through the westbound descent leg at 17,000 ft MSL (-17°C), the aircraft exited from all cloud and until about midway (0135 UTC) through the return eastbound leg, which was at 16,000 ft MSL. Embedded droplet clouds within ice cloud and precipitation characterized the remaining portion of this leg. There was little LWC in the droplet clouds, suggesting that this was the base height of some of the clouds previously intercepted above this level. The crystals on this leg were unrimed to lightly rimed dendritic aggregates, with single plates and stellar crystals among many irregular crystals. There appeared to be less riming on this leg than on the one just above this level. This incongruous finding suggests that an enhanced liquid cloud feature had moved away from the earlier flight track and was replaced by clouds with little liquid water content overhead as the aircraft flew on a geographically fixed track. (The wind direction was from the west-northwest.) There was a malfunction in the Shadin true airspeed (TAS) measurement on this leg, which may have been due to icing. From 0106 UTC until 0138 UTC the TAS climbed steadily to an indicated value in excess of 200 m s^{-1}! The ramifications of this error are that the static temperatures, corrected for TAS, are too low during the descent leg and in the subsequent level leg at 16, 000 ft MSL. This malfunction occurred again between 0154 and 0232 UTC, in the leg that descended from 16,000 to 14,000 ft MSL, and affected the level leg at 14,000 ft MSL that followed.

On the return leg to the west, the aircraft gradually descended from 16,000 to 14,000 ft MSL (-14°C). Droplet clouds were intercepted in the eastern portion of the leg amid largely unrimed or lightly rimed crystals and dendritic aggregates. The aircraft exited all cloud or precipitation, about halfway through the descent leg at about 0149 UTC.

The eastbound leg was flown at 14,000 ft MSL between 0200 and 0216 UTC. The first clouds were intercepted about halfway through the leg at 0209 UTC and consisted of mainly droplets, with isolated drizzle drops. A transition to mixed phase and then all ice particles occurred near the east end of the leg at 0212-0214 UTC. Both heavily rimed and unrimed particles were encountered in this portion of the leg. The crystals were irregulars, plates, columns, bullet rosettes and dendritic crystals.

The return leg to the west, from 0219 to 0238 UTC, consisted of a gradual descent from 14,000 to 12, 000 ft MSL and to a temperature of about –7.5°C. This leg is of particular interest because a completely different microstructure was encountered compared to the previous passes. For example, no ice was encountered, with the exception of a few possible frozen drizzle drops. Instead, all liquid clouds with numerous localized regions of drizzle drops in high concentrations (10s to 100s per liter) were present. The highest LWCs observed were modest, only 0.25 g m^{-3}.

Also, drop concentrations increased noticeably from 10-20 cm^{-3} to 50-60 cm^{-3} in the western third of the leg. These observations suggests that a separate ice-producing cloud layer had drifted away (or lifted far above the aircraft) as the descent leg began, and that tops of the clouds that were flown in were probably within a few hundred meters or less of the aircraft (as inferred from the sizes of the drizzle drops).

The return leg to the east was flown at 12,000 ft MSL (about –7.5°C) between 0240 and 0252 UTC in the clouds with higher droplet concentrations. LWCs ranged from about 0.1 to 0.25 g m^{-3}. Drizzle drops were relatively isolated in occurrence on this pass. Droplet concentrations continued to be considerably higher than in the clouds above, mainly 50-100 cm^{-3}, suggesting that these clouds may have formed in the boundary layer. Due to the buildup of ice on the previous legs, the pilot requested "loitering time" in dry air at the end of this leg to help rid the airframe of the ice buildup that had taken place.

The return leg to the west consisted of a gradual descent from 12,000 to 10,000 ft MSL (–7.5° to about –3.5°C). During this leg, carried out between 0300 and 0318 UTC, both high concentrations (100s per liter) of drizzle drops and ice particles in separate regions were encountered. The ice consisted of quasi-spherical particles, which probably arose from the freezing of drizzle drops, and needles and sheaths. Low temperature crystals were not encountered. During this leg, the FSSP-100 iced up, so the spectra data are not valid after 0317 UTC. The ice apparently melted off the FSSP-100 by 0343 UTC, when normal operation resumed and valid spectra were again acquired. LWCs, as indicated by the PVM-100, reached 0.5 g m^{-3} on several occasions during this leg, particularly at the west end.

The return leg to the east at 10,000 ft MSL (-3.5°C) took place between 0322 and 0332 UTC. Relatively contiguous droplet cloud was encountered until just past halfway through the leg at which time only isolated patches of ice particles were found. However, the LWCs were considerably lower, on average, than on the previous pass. This result, along with encountering extensive regions of clear air at the halfway point in the leg, indicates that a discrete convective feature had passed to the east-southeast away from the aircraft track during the time the aircraft made its turn at the west end and began the east leg.

The final research leg was flown toward the west, between 0336 and 0353 UTC. It consisted of a stepped descent from 10,000 to 6000 ft MSL in which the temperature increased from about –3.5° to -1°C. A windshift from 290° to 250° occurred between the 10,000 and 8,000 ft MSL levels during this descent. A frontal inversion/stable layer was also observed between 9,000 and 8,000 ft MSL. The cloud microstructure was similar to that on the previous pass: alternating regions of very high concentrations (>100 per liter) of drizzle drops, probable frozen drizzle drops, needles and sheaths, until passing below the freezing level at about 4,000 ft MSL. After that time, intermittent drizzle and very light rain were encountered. The rain and drizzle present interfered with attempts to make CCN measurements under the bases of the lowest clouds in the Willamette Valley upwind of Eugene. This latter effort was abandoned at 0432 UTC, and the Convair departed the research region for Paine Field.

The climbout was through a drizzle-producing, two-tiered stratocumulus deck with bases at 2500 ft MSL (4°C) and a top temperature of about -2°C at 8,000 ft MSL. Droplet concentrations were low in this cloud, about 30-40 cm^{-3}.

The lower layers are of interest since they likely the cloud decks being lifted over the Cascades that were sampled by the Convair in the previous two hours which also contained drizzle precipitation. The lower cloud, which topped-out at 4,200 ft MSL, was characterized by decreasing

temperature throughout, while the base of the higher layer at 6,000 ft MSL was contained in the frontal isothermal layer. The wind was southwest in the lower cloud, veering to west-northwest near the top of the higher layer at 8,000 ft MSL.

The remainder of the ferry leg, flown at 16,000 ft MSL (about -16°C) was largely in clear air, punctuated by a few ice crystals.

(j) University of Washington Flight 1900 (13-14 December 2001) [*]

This flight took place as one of the strongest of all IMPROVE-2 frontal systems passed over the Oregon Cascades. The winds at 850 and 600 hPa were 50-80 knots out of the southwest, with extensive warm air advection producing overrunning cloud layers and a well-developed orographic cloud over the Cascades. The satellite imagery before the flight showed two rainbands with a thin zone of separation between them about to make landfall on the Oregon coast. The first rainband appeared to be the stronger, or at least had the colder tops.

The ferry portion of the flight consisted of a stepped ascent to near 20,000 ft MSL by the time the research legs began at the southwestern end point. Embedded droplet clouds (shallow altocumulus-like clouds) were encountered intermittently above the freezing level within otherwise a deep, featureless ice cloud. However, there was little ice buildup en route to the research area, indicating very low liquid water contents and small droplets.

The first research leg, starting from the SW endpoint at 20,000 ft MSL was flown in deep and diffuse precipitating cloud with little internal detail or indication of layering. A thinning in the ice and precipitation occurred a few minutes en route to the NE end point at 2328 to 2334 UTC. At this time a droplet, altocumulus-like cloud estimated 3,000-4,000 ft above the aircraft and some blue sky could be seen above the aircraft through a "haze" of ice precipitation.

Other than this brief respite, deep and diffuse clouds with little internal detail were flown in until reaching the 14,000 ft MSL in the series of slantwise descents from 20,000 ft MSL. Embedded droplet clouds were encountered at almost every level and leg. Droplet concentrations were very low (~10-30 cm^{-3}). During the descent from 16,000 to 13,000 ft MSL the aircraft encountered more droplet clouds with substantially higher droplet concentrations (>50 cm^{-3}) and higher liquid water contents (LWC). The LWC reached as high as 0.4 g m^{-3} in the wettest regions of these clouds. Supercooled drizzle drops were briefly encountered in these clouds at -13°C and still more (concentrations >300 per liter) at about -9°C adjacent to regions with extremely high ice concentrations (some >500 per liter) consisting of mainly sheaths and needles. The supercooled drops resulted in a rapid but brief icing buildup on the aircraft. Also, brief regions were encountered in these lower clouds where precipitation did not appear to be falling into them from the higher layer; at other times, irregular rimed aggregates, probably dendrites, were observed.

It was in these lower clouds, beginning around 13,000 ft MSL that heavily rimed particles were observed in the 2-DC imagery for the first time on this flight. Thus, while droplet clouds were frequently present at elevations above 13,000 ft MSL, the low liquid water contents and small droplets apparently did not affect precipitation tremendously through appreciable riming, but rather they were indicators that water saturated conditions existed throughout this storm in spite of high ice particle concentrations (10s to 100s per liter).

No stars were visible at any time above the aircraft, even when snow was not falling from the relatively thick cloud layer above, and the aircraft was above the lower deck of droplet clouds encountered at about 13,000 ft MSL.

During the final leg, in which the aircraft descended along the "MVA" altitudes toward the SW en route to a landing at Eugene, Oregon, liquid water and high ice particle concentrations in the hundreds to thousands per liter were simultaneously observed in the lowest portions of these clouds,

[*] No verbal summary of this flight was recorded onboard the aircraft. A summary has been reconstructed from other comments recorded on the flight.

a somewhat unusual occurrence that demonstrated the high rate of production of condensate in the upslope regions of the Oregon Cascades in this powerful storm.

Increases in temperature during level flight, and sometimes increases in droplet clouds at 20,000, 18,000, 14,000, and in the descent leg to 11,000 ft MSL in the research area, and at the end of the level pass at 11,000 ft MSL, suggested that the aircraft flew through a frontal boundary. However, little change in wind direction was noted with the temperature changes.

A cooling of 2°C was also observed at about 5500 feet in the very short, level leg to Eugene. This demonstrated strong cold air advection behind the front.

Instrument problems consisted of erratic operation of the 2-DC. Early in the flight it had several outages and was restarted several times. Also, even when working, ice concentrations were unrealistically low at times. An entire 2-DC buffer would contain only one or two ice particles because the probe was not separating one particle from another, but rather counting many particles as a single particle while calculating the volume of the entire strip. Such 2-D buffers will have to be excised lest particle concentrations be erroneously low. Normal operation of the 2-DC occurred later in the flight.

There was no CPI data, and the DMT and J-W hot wire probes did not function. However, reliable LWCs were obtained with the FSSP-100 and the PVM-100 probes. The latter probes were in good agreement with one another during the flight.

The 1-D spectra are suspect in flight since quasi-Gaussian shapes were being produced for spectra instead the Marshall-Palmer shape normally produced by this probe in precipitation. For example, for the whole flight, Channel 11 averaged about 3 times more than adjacent Channels 10 and 12.

(k) University of Washington Flight 1901 (14 December 2001) [*]

Takeoff from Eugene, Oregon, in post-frontal conditions with strong west-southwesterly flow. The 700 hPa winds were west-southwest at 50 kts and the 800 hPa winds 40 kts (aircraft measured). The flight took place after nightfall, so visual observations of clouds were minimal.

The flight began with aerosol (CCN) measurements, sampling at and below bases of scud clouds and in spotty light rain in the Willamette Valley south of Eugene. However, these measurements were abandoned when an extensive clear region below cloud, and one also free of rain, could not be found. The bases of the lowest clouds over the Willamette Valley were 1.5°C at 896 hPa.

Thereafter, the Convair-580 climbed to above the tops of orographic clouds on the west slopes of the Cascades breaking on top at 13,500 ft MSL to begin the first SW-NE research leg. The temperature at cloud top was about -18°C. The climb continued to 14,500 ft MSL in clear air before descending back to 13,500 to re-enter the clouds. In the climb, several layers of droplet clouds were sampled with LWCs peaking at 0.3-0.4 g m^{-3}. Drizzle drops were encountered in the climb. Droplet concentrations were again very low, 10-30 cm^{-3} in these clouds.

From this point, the aircraft was in and out of tops (numerous stars often seen above the aircraft) en route to the east side at 13,500 feet MSL. A variety of types of cloud microstructures were encountered, typical of post-frontal conditions, including all liquid regions with LWCs to about 0.5 g m^{-3} (from the PVM-100), and various types of precipitation including small quasi-spherical particles, stellar ice crystals and dendritic aggregates. These particles were mainly unrimed or lightly rimed, suggesting little LWC above the flight level. The sizes of the aggregates (several mm in maximum dimension) in some locations indicated that some cloud tops were appreciably above the aircraft and were likely higher than the original cloud top found near 14,000 ft MSL during the climb from Eugene. (Normally in these situations, the smallest precipitation-

[*] No verbal summary of this flight was recorded onboard the aircraft. A summary has been reconstructed from other comments recorded on the flight.

sized drops and ice crystals are found in the very top of the clouds.) The temperature increased steadily in leg to the northeast.

On the return leg, descending from 13,500 to 12,000 ft MSL, the aircraft was again in and out of clouds. Droplet clouds were encountered, some regions free of precipitation, with droplet concentrations 10-40 cm^{-3}. Drizzle drops were also encountered, as were heavily rimed aggregates. The ice particles in general showed more riming than they had in the pass at 13, 500 ft MSL.

In the level return leg to the northeast at 12,000 ft MSL, regions of large aggregates, and several regions of drizzle drops, and indications of recently frozen drizzle drops, were encountered. Riming varied from light to heavy. A substantial temperature increase of several degrees centigrade that occurred near the east end turnaround point of this leg may have been due to entering the downslope wind regime east of the Cascade crest. A noticeable increase in drop concentrations to a peak of about 50-100 cm^{-3} with LWCs rising to over 0.25 g m^{-3} was also encountered near the mid-point of this leg, also accompanied by some drizzle drops.

The return southwest bound leg was along the minimum allowable altitude transect. The aircraft was in and out of heavy snow with some aggregates larger than 15 mm in the 2-DC imagery. The rather rapid descent from passed the stellar dendritic temperature regime (<-12°C) to near the top of the needle temperature regime of about -7°C at 800 hPa. Sheaths and short columns were observed at temperatures above -10°C in concentrations of hundreds per liter. Needles were observed between -7˚ and -8°C. Dendritic aggregates were also observed in these regions. Droplet concentrations in the lowest liquid cloud sampled were about 50 cm^{-3} with LWCs of 0.1 gm. The tail of the droplet spectrum (the largest FSSP-100 measured droplets in concentrations of 3 cm^{-3}) indicated that these clouds contained droplets large enough to produce splintering of droplets during riming. The low LWCs at 800 hPa suggested that the aircraft may have been very near cloud base at that level.

After dipping momentarily to 800 hPa, the aircraft began its ferry flight to Seattle by climbing to 16,000 ft MSL. Three thin droplet layers encountered during this climb out with uppermost at located 16,000 ft at -26°C. Liquid water clouds were encountered on several other brief occasions on the return leg at this level.

The generally smaller sizes of the ice particles at 16,000 ft MSL suggest that the flight level was near to cloud top. Roundish particles, suggesting frozen drizzle drops, were occasionally encountered though caution must be used in this interpretation since small, rimed plates or germs of bullet rosettes can also assume these forms in the PMS 2-DC imagery.

The microstructure encountered in flight 1901 largely replicated that of flight 1891, 28 November 2001. The earlier flight also took place in post-frontal conditions with strong flow and in clouds with similar top temperatures.

(l) University of Washington Flight 1902 (19-20 December 2001)

5:17 AM

AR: Summary of Flight 1902 (given on Flight 1903, since I forgot to do it on Flight 1902). Weatherwise semi-cutoff low was situated off the coast of northern California and was elongated toward the north such that southerly flow reached up across the Oregon Cascades. Also, a shortwave was rotating around the low and was passing over Oregon this evening. Along with that a warm front marked by (the models were indicating anyway) a southeast flow at 850 ahead of it and southerly flow behind it. About 100 nautical miles to the north of that at 700 mbar the model was predicting southeast flow and south flow behind the warm front. We intercepted the band over the Cascades. It looked like pretty good timing over the experimental site. Cloudwise didn't see any stars just a tinge of blue there once or twice. Cloud tops estimated to 2 kilometers at least above

18,000 ft. The crystals were almost completely unrimed all the way down to the bottom. The bottom being say 10,000 to 8,000 ft where we did encounter some droplet clouds down there and some Hallett-Mossop riming-splintering going on with very high concentrations of ice crystals on the west side on, I think, our lowest pass. I should also mention from time to time there were a couple of scruffy little droplet clouds at altocumulus level that were encountered over the Cascades and generally those not amounting too much except on one occasion where they produced a couple of tenths of liquid water content of what probably would have altocumulus castellanus clouds.

After doing those legs on the west side, north-south direction, we did some legs on the east side, north-south direction, and those crystals were all unrimed and very little liquid water content until we got around to, I think, 12,000 ft again intercepting altocumulus castellanus-like turrets. Also that last leg ascending, stepping down through the frontal zone indicated by a isothermal layer between about 14,000 and 11,000 ft and a nice windshear from southeast to southwest. Other than that it was pretty uneventful flight. Mostly unrimed crystals or very lightly rimed crystals, bullet rosettes, lots of bullet rosettes seen, indicating that crystals were forming at temperatures probably below –30˚ and falling to flight level.

(m) University of Washington Flight 1903 (20 December 2001) [*]

This was a ferry flight from Salem to Seattle. The takeoff was in light precipitation. The aircraft then climbed steadily to 16,000 ft MSL and about -21°C for the leg to Seattle with flight recorded data beginning at 7,000 ft MSL. Numerous droplet clouds encountered between 9,000 and 12,500 ft amid the precipitation, the thickest based between about 10,000 and 12,500 ft MSL. High concentrations (>100 per liter) of secondary ice, in the form of sheaths (but no needles), were encountered as well as drizzle drops in this thickest cloud. Also encountered were dendritic aggregates that fell into this layer from an ice cloud aloft.

Once into the ice and precipitation cloud above the droplet cloud layer mentioned above, it was a relatively uneventful flight in light snow with little microstructural change. Crystals appeared to be short columns, irregulars, and rimed, or rounded from evaporation, bullet rosettes having little mass. Occasionally, small regions of small, quasi-spherical irregular particles were found, suggesting that the aircraft was near cloud top or cloud base (where the crystals are evaporating). The most notable meteorological event was the 2000 ft deep frontal isothermal layer found between 13,000 and 11,000 ft MSL during the descent to Paine Field near the end of the flight. The winds backed markedly with decreasing altitude from 200° above this layer to 100-120° below the isothermal layer. The winds below the isothermal layer also increased in strength slightly from those in the layer (10 kts vs. 13 kts below the layer).

Note: while the aircraft flew in light snow, none of this reached the ground north of the Oregon border during the flight (representing the characteristics of an altostratus cloud shield.)

[*] No verbal summary of this flight was recorded onboard the aircraft. A summary has been reconstructed from other comments recorded on the flight.

(n) University of Washington Flight 1904 (21-22 December 2001)

12:08 AM

AR: Today's flight was for calibration against the NWS rawinsonde launched from Quillayute at 00 Z, 22 December. En route approximately 8,000 ft we sampled the tops of ice producing stratocumulus clouds at about –8˚C or so and lots of needles and short columns. So that was kind of an interesting case there. Picked up a far amount of icing and liquid water content was 0.3 or so in those clouds. Then we got a nice profile because we descended through it or/and I think also the base of it was lifting as we descended. So it was kind of a double-barreled ascending of this cloud. For a couple of minutes, not too long, we had trouble finding a hole to go though to get down underneath the many layers of stratiform clouds out there but we finally did. Got out underneath and tried some CCN measurements for Vidal. The flow was offshore and about 20-30 knots it appeared down in the boundary layer. Unfortunately, we also saw some rain. We couldn't really avoid it because it was fairly widespread out there. Also we couldn't get into Quillayute because of the low ceilings. As a result we had to start out with the sounding ascending offshore and a hole in the stratocumulus that we did find. As soon as we got above it at a couple thousand feet we headed back toward the area of the sounding. From there on out we just climbed up through it sampling the stratocumulus layer again that was up around 6,000 to 8,000 ft. The top was –8˚C and producing very heavy virga here and there. We didn't actually get into the heaviest virga, but we got a good measurement of the young part of the cloud and then all the way up to about 17,800 tans-alt and the very dry air. Dew point spread off to 20˚C. Everything looked pretty good. So that's the end. We're about ready to land. So I'm going to step away here.

(o) University of Washington Flight 1905 (22 December 2001)

AR: Summary for Flight 1905 (given on Flight 1906, since I forgot to give it on Flight 1905). A northwest-southeast oriented band moving up from the south. South-southeast winds pretty much all levels. This band had a line of altocumulus castellanus and otherwise thick altocumulus with heavy virga using the lead echoes. Then we underflew the ice cloud shelf over that and then we entered a band producing most of the precipitation and past out the back side underneath a high shelf. Then the band looked like there were at least two areas of thickening ice crystals. I would call it a weak band in terms of what we flew in. No liquid water was encountered, except at times at cloud top it looked like there may have been some globular elements of cloud top. There was not much solid cloud visible through the ice crystals either when that was possible. So it didn't seem like there was as much lifting over the mountains, real solid clouds as near as I could tell. Otherwise it was pretty uneventful.

(p) University of Washington Flight 1906 (22 December 2001)[*]

This flight took off from Eugene, Oregon, to intercept a west-east oriented frontal rain/snow band located in the northern Cascades of Oregon. The band had been sampled earlier in the day in UW flight 1905 and appeared to be on the wane, which caused the earlier flight to be terminated. However, according to the radar operators at Sweet Home, Oregon, the band appeared to strengthen shortly after the plane landed at Eugene. Therefore, the Convair was re-launched from Eugene toward the northern Oregon Cascades with the mid-point of the band about 50 km NNE of Santiam Pass.

Takeoff occurred in multi-layered clouds based mainly above 9,000 ft MSL that thickened and lowered toward the Cascades. The tops of a broken altocumulus-stratocumulus deck with low droplet concentrations (20-30 cm^{-3}) were intercepted at 10,000 ft MSL (about -10°C) over Santiam Pass with an overcast ice and precipitation cloud above. Unrimed dendritic aggregates fell into these lower clouds which also contained drizzle drops (again!). At 1938 UTC the aircraft began a slow spiral climb through the ice cloud to 20,500 ft MSL, reaching the top of the spiral at 2000 UTC. Crystal sizes in general diminished with increasing height, but were not uniformly the same size in the spiral; rather one portion of the spiral (to the southwest), in a heavier fallstreak or part of the band, had larger snowflakes than the other portions of the spiral, a situation that was noticeable for several thousand feet in the lower and middle levels of the spiral. The largest snowflakes were aggregates of dendritic type crystals at least several mm in size. At the top of the spiral (temperature about -31°C) the crystals appeared to be mainly irregular bullet rosette germs and spherical particles (probably thick plates) mainly smaller than 500 μm in those saddle regions virtually at cloud top. Millimeter-sized ice particles were first reached at about 18,000 ft MSL in the descent.

The ice cloud structure in the uppermost regions of this ice cloud was strongly reminiscent of the Barrow cirrus flights: amorphous ice cloud, topped by a highly structured ice cloud with lots of complex structure with saddles and raised tops (wave or roll-like features). The aircraft appeared to fly within 1,000 ft of the highest cirriform cloud tops over the Cascades.

The sun's position was visible intermittently in the climb through 14,000 ft MSL at 1945 UTC, and then was plainly visible thereafter until near the bottom of the descent at 2150 UTC. At this point the aircraft conducted slantwise and level passes through the W-E band down to 10,000 ft MSL for the last pass. Passes below the "saddle" and enhanced regions of cloud tops continued during these passes. Of note was the lack of fern-like crystals in the dendritic temperature zone of –12.5°C to -18°C during the lowest passes, suggesting the air was less than supersaturated with respect to ice. In some regions, very small, spherical ice crystals were encountered similar to those sampled at cloud top in the lowest passes, suggesting that such crystals were evaporating in much of these lowest legs.

After the last pass at 10,000 ft MSL through the band, the Convair headed to Troutdale Airport, Oregon, on the Columbia River for a "missed approach" to document the wind profile and depth of the easterly flow channeled within the Columbia Gorge.

In the ascent from Troutdale the aircraft ascended to 12,000 for the ferry flight back to Seattle. During the ascent, the aircraft passed through a clump of ice-producing stratocumulus

[*] No verbal summary of this flight was recorded onboard the aircraft. A summary has been reconstructed from other comments recorded on the flight.

clouds with top temperatures of only about -5°C. Oddly, though considerable precipitation appeared to fall from these clouds, needles were few and encountered near the cloud edge upon exit and most of the ice particles appeared to be frozen drops.

Another similar group of ice-producing clouds were sampled during the descent into Puget Sound from 2240 to 2250 UTC. Needles were common in these clouds as were a few aggregates of dendritic crystals that fell into them from above. Other than this, no clouds or precipitation were encountered in the ferry flight.
