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-I (FRONTAL STUDIES)

(4 JANUARY-14 FEBRUARY 2001)

Compiled
by
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FOREWORD

The first field phase of the Improvement of Microphysical PaRameterization through Observational Verification Experiments (IMPROVE) took place between 4 January and 14 February 2001 off the Pacific coast of Washington State (hereafter referred to as IMPROVE-I). This report provides a guide to the measurements obtained aboard the University of Washington's (UW) Convair-580 research aircraft in IMPROVE-I.

Contained herein are listings of the instruments aboard the UW Convair-580 in IMPROVE-I, 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/IMPROVE-MASTER.pdf

Corrections and updates to this report will be posted at:

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

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CONTENTS

Page

FIGURES

TABLES

SUMMARY OF FLIGHTS AND TYPES OF DATA COLLECTED ABOARD THE UNIVERSITY OF WASHINGTON'S CONVAIR-580 RESEARCH AIRCRAFT IN IMPROVE-I (FRONTAL STUDIES)

1. GOALS OF IMPROVE

The main goals of the Improvement of Microphysical PaRameterization through Observational Verification Experiments (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 exercise the model simulations on a wide variety of precipitation systems, two field studies were carried out in support of IMPROVE. The first field study (IMPROVE-I), with which we are concerned here, concentrated on frontal precipitation systems. The second field study

(IMPROVE-II), which is described in a companion report, concentrated on orographic precipitation.

2. OVERVIEW OF IMPROVE-I

IMPROVE-I, which was carried out between 4 January and 14 February 2001, was concerned with frontal precipitation systems as they approach the Pacific coast of Washington State. These systems occur over a reasonably flat and uniform surface, and they are often well simulated by mesoscale models. To investigate how well the MMR model represented the observed cloud structures, and the microphysical mechanisms leading to the growth and fallout of precipitation, it is necessary to choose case studies in which the model simulated the 3-D air motions with some fidelity. Therefore, in IMPROVE-I the NCAR S-band (S-Pol) radar was located at Pt. Brown on the Washington coast (Figure 1.1) for the purpose of measuring air motions. In addition to Doppler capabilities, the S-Pol radar provided dual-polarization measurements which can be used to provide information on cloud and precipitation particle types. To provide 3-D air motions the S-Pol was operated as a dual-Doppler radar by locating two bistatic antennas ~60 km to the north and south of the S-Pol (Figure 1.1).

The S-Pol radar was also used to monitor in-coming storms so that the Convair-580 research aircraft could be deployed in a timely fashion into suitable areas of clouds and precipitation. Through radio communications between a scientist at the radar and the Flight Scientist aboard the Convair-580, measurements were obtained aboard the aircraft in regions of clouds and precipitation as they moved onto the Washington coast.

Other special facilities in IMPROVE-I were a 915 MHz wind profiler, dedicated rawinsonde launches, special rain gauges, and a PNNL remote sensing site (Figure 1.1).

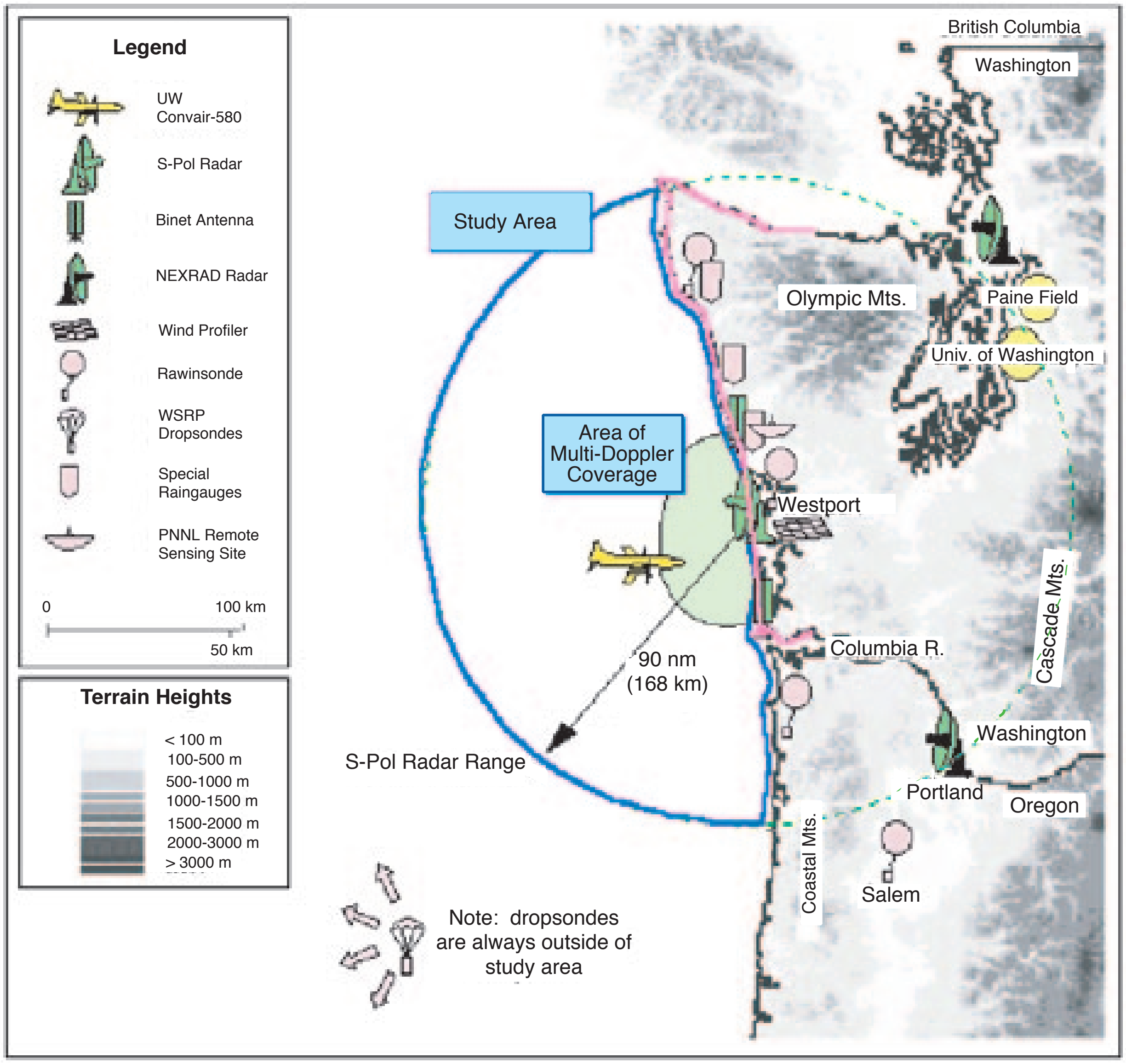


Figure 1.1. Observational platforms for IMPROVE-I Frontal Studies

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

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

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

Fifteen flights, totaling ~58 research hours, were flown by the Convair-580 research aircraft in IMPROVE-I during the period 4 January through 14 February 2001. Table 4.1 lists the dates, times and main accomplishments for each of these flights.

Figures 4.1-4.15 show the flight tracks on both horizontal and vertical cross-sections for each of the Convair-580 flights.

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

(a) Navigation and Flight Characteristics				
Parameter	**Instrument Type**	**Manufacturer/Model**	**CARG Data System Parameters**	**Problems**
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	No major problems
Heading	Standard GPS	Trimble TANS Vector	tans-azimth	No major problems
Pressure	Variable capacitance	Rosemount Model 830BA	pstat	No major problems
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**	**Problems**
Total Air Temperature	Platinum wire resistance	Rosemount Model 102CY2CG and 414 L Bridge	ttot (derived parameter: tstat)	Did not provide reliable measurements.
Static Air Temperature	Reverse-flow thermometer	In-house	ttotr (derived parameter: tstatr)	Some noise; data usable.
Dew Point	Cooled-mirror dew point	Cambridge System Model TH73-244	dp (derived parameter: rh_chl)	Some noise; data usable.

Table 3.1 (continued)

(b) General Meteorological Parameters (continued)				
Parameter	**Instrument Type**	**Manufacturer/Model**	**CARG Data System Parameters**	**Problems**
Absolute Humidity	IR optical hygrometer	Ophir Model IR-2000	rhovo (derived parameters: rh_o, dp_o)	Values sometimes too high.
UV hemispheric radiation, up and down	Diffuser, filter (0.295 to 0.390 um)	Eppley Lab. Inc. Model TUVR	uvup, uvdo (derived parameter: uvalb)	Noisy signals for UW Flights 1847, 1849, 1855, 1856, 1857, 1858.
VIS-NIR hemispheric radiation, up and down	Eppley thermopile (0.3 to 3 um)	Eppley Lab. Inc. Model PSP	pyrup, pyrdo (derived parameter: pyralb)	Noisy signals for UW Flights 1847, 1849, 1854(pyrdo), 1855, 1856, 1857, 1858.
Surface radiative temperature	IR radiometer 1.5 FOV (8 to 14 um)	Omega Engineering OS3701	irtemp	No major problems when aircraft was close to surface.
Video Image	Forward-looking camera and time code	Ocean Systems Splash Cam	SVHS tape.	Noise due to "scrolling bars"; useable.

(c) Aerosol				
Parameter	**Instrument Type**	**Manufacturer/Model**	**CARG Data System Parameters**	**Problems**
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.

Table 3.1 (continued)

(c) Aerosol (continued)				
Parameter	**Instrument Type**	**Manufacturer/Model**	**CARG Data System Parameters**	**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.
Light-scattering coefficient	Integrating 3-wavelength nephelometer with backscatter shutter	MS Electron 3W-02	nepgrn, nepred, nepblu, bkspgr, bkspgr, bkspbl	Noisy during ~75% of each flight.

(d) Cloud Physics				
Parameter	**Instrument Type**	**Manufacturer/Model**	**CARG Data System Parameters**	**Problems**
Cloud and precipitation particle imagery	Digital Holographic camera	SPEC Inc. Model CPI-230	Separate data system.	Not installed on UW Flights 1846, 1847, 1848, 1849
Size spectrum of precipitation particles	256 photodiode CCD array	SPEC Inc. HVPS	hvpsn – still in development (derived parameters: hvspdn, hvpsclassf)	No data on UW Flight 1846. Occasional drop-outs and some noise on all flights.
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.

Table 3.1 (continued)

(d) Cloud Physics (continued)				
Parameter	**Instrument Type**	**Manufacturer/Model**	**CARG Data System Parameters**	**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)	Poor spectral data on UW Flight 1846. Not installed on UW Flight 1847. Concentrations may be low.
Images of cloud particles	Diode imaging	PMS OAP 2D-C	tdcn, tdccc, tdcd, tdcsv (derived parameters: tdcclassf, tdcdn, tdcrt)	No data on UW Flights 1846, 1847, 1848, 1849.
Liquid water content	Hot wire resistance	Johnson-Williams	lwjw	Some random noise spikes on all flights, but data usable through ≈0910 UTC on UW Flight 1859.
Liquid water content; particle surface area; effective droplet radius	Optical sensor	Gerber Scientific Ins. PVM-100A	lwpvm, sapvm, erpvm	Some random noise spikes on all flights, but data usable.
Liquid water content	Hot wire	Droplet Measurement Technologies	lwdmt	Excessive drift in low LWC clouds and in clear air. Good for high LWC.

Table 3.1 (continued)

(e) Remote Sensing				
Parameter	**Instrument Type**	**Manufacturer/Model**	**CARG Data System Parameters**	**Problems**
Radar Reflectivity	Pulsed 35 GHz radar	In-house	Separate data system.	Installed but data not recorded until end of UW Flight 1852. Up-down switch did not work at low temperatures.
Weather Radar	Pilot's radar	Bendix/King	Data not recorded.	—

TABLE 4.1. OVERVIEW OF UNIVERSITY OF WASHINGTON'S CONVAIR-580 RESEARCH FLIGHTS IN IMPROVE-I. FOR FLIGHT TRACKS SEE FIGURES 4.1-4.15.

Date (2001)	University of Washington Flight Number	Period of Flight (UTC)*†	Main Accomplishments§ (For more details see Section 5)	Comments on Instruments
4 January	1846	1907-2138	Measurements in warm-sector rainbands producing light to moderate and steady precipitation.	SPEC CPI not aboard. Problems with PMS 2D and 1D cloud probes and SPEC HVPS probe. Good liquid water measurements. 35 GHz radar not recorded.
7-8 January	1847	2300-0500	Measurements in light precipitation from a warm occlusion-type system.	SPEC CPI and PMS 1D cloud probe not installed. Problems with PMS 2D cloud probe. Good liquid water measurements. 35 GHz radar not recorded.
9 January	1848	1734-2116	Vertical profile from near surface to top of pre-occluded front rainband. (Landed at Hoquiam to refuel for second flight.)	SPEC CPI not installed PMS 2D cloud probe not working. PMS 1D cloud probe working.
9-10 January	1849	2233-0202	Took off from Hoquiam. Sampled incoming occluded front (same system as UW Flight 1848). Measurements across Olympic Mountains en route back to Paine Field.	See UW Flight 1848 above.

(Cont.)

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

† Local time = UTC – 8 hours.

§ Classification of fronts and rainband type may change following post-flight analysis.

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
13 January	1850	1503-2050	Measurements in well defined but weak cold or warm-frontal rainband. Good measurements over Olympics on return to Paine Field and in descent to Paine Field.	First flight in which all of the most important microphysical probes and 35 GHz radar worked well, 35 GHz but not recorded. (SPEC CPI installed and worked. PMS 2D probe worked.)
18 January	1851	2016-2330	Profile of clouds and precipitation in advancing but weakening diffuse cold front.	35 GHz radar not recorded. Some problems with SPEC HVPS.
20 January	1852	1635-2028	Measurements in rainband along and to east of advancing occluded front. (Landed at Hoquiam to refuel for second flight.)	Most instruments work. 35 GHz radar data recorded near end of flight.
20-21 January	1853	2128-0050	Took off from Hoquiam. Measurements in encroaching warm-frontal type rainband (same system as UW Flight 1852).	See UW Flight 1852 above.
23 January	1854	1805-2158	Measurements in a quasi-stationary rainband ahead of a low-level (cold?) windshift line.	SPEC CPI had delayed start. Most other instruments worked.

(Cont.)

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

† Local time = UTC – 8 hours.

§ Classification of fronts and rainband type may change following post-flight analysis.

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
28-29 January	1855	2358-0445	Measurements in two rainbands (within dual-Doppler area) ahead of strong cold front. Olympic Mountain transect on return to Paine Field.	Poor images on SPEC CPI. Most other instruments worked.
1-2 February	1856	2224-0333	Comprehensive measurements from 1,000 to 21,000 ft in pre-frontal rainband in dual-Doppler area. (Landed at Hoquiam in heavy rain).	Poor images on SPEC CPI; improved as flight progressed.
1 February	1857	0449-0556	Flight from Hoquiam to Paine Field. Good measurements on west side of Olympics in rainband studied in UW Flight 1856.	Some SPEC CPI dropouts.
8 February	1858	0153-0655	Measurements in rainband associated with occluded front.	Instruments worked well.
10 February	1859	1430-2005	Measurements from 2,000 to 20,000 ft in wide cold-frontal (?) rainband. (Landed at Hoquiam to refuel for second flight.)	Johnson-Williams failed and SPEC CPI dropped out temporarily when aircraft discharged electrically (or was struck by lightning) at 1703 UTC. Generally good measurements.

(Cont.)

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

† Local time = UTC – 8 hours.

§ Classification of fronts and rainband type may change following post-flight analysis.

Table 4.1 (continued)

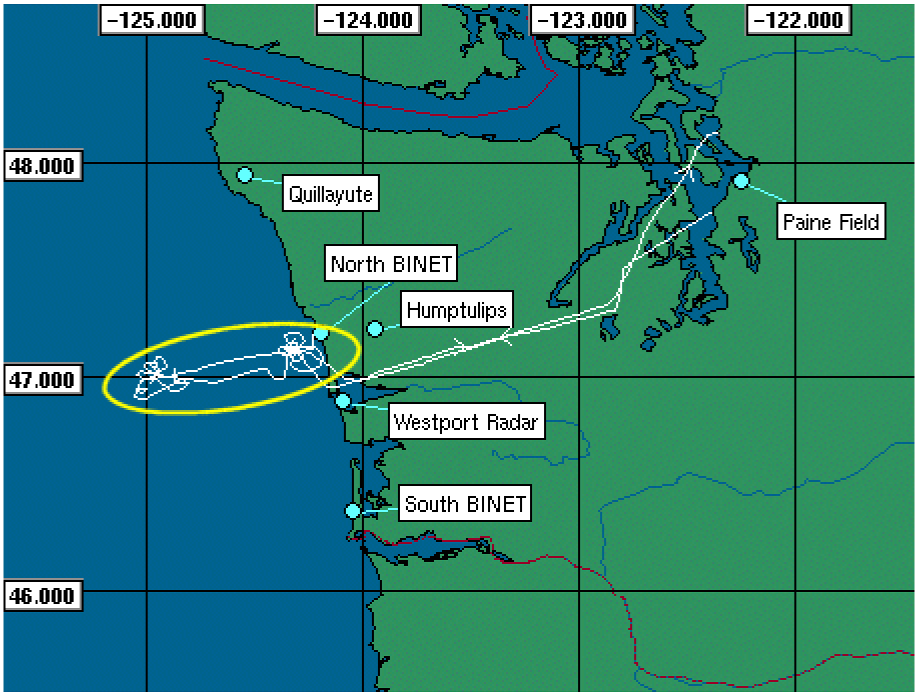
Date (2001)	University of Washington Flight Number	Period of Flight (UTC)*†	Main Accomplishments§ (For more details see Section 5)	Comments on Instruments
10-11 February	1860	2148-0225	Took off from Hoquiam. Continued to sample same rainband as UW Flight 1859. Band almost stationary. May show effects of aging on rainband structure.	Good measurements, but no Johnson-Williams.

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

† Local time = UTC – 8 hours.

§ Classification of fronts and rainband type may change following post-flight analysis.

(a) Flight 1846 – Aircraft Path – 1920 to 2132 UTC



(b) Flight 1846 – Vertical Profile 1950 to 2100 UTC

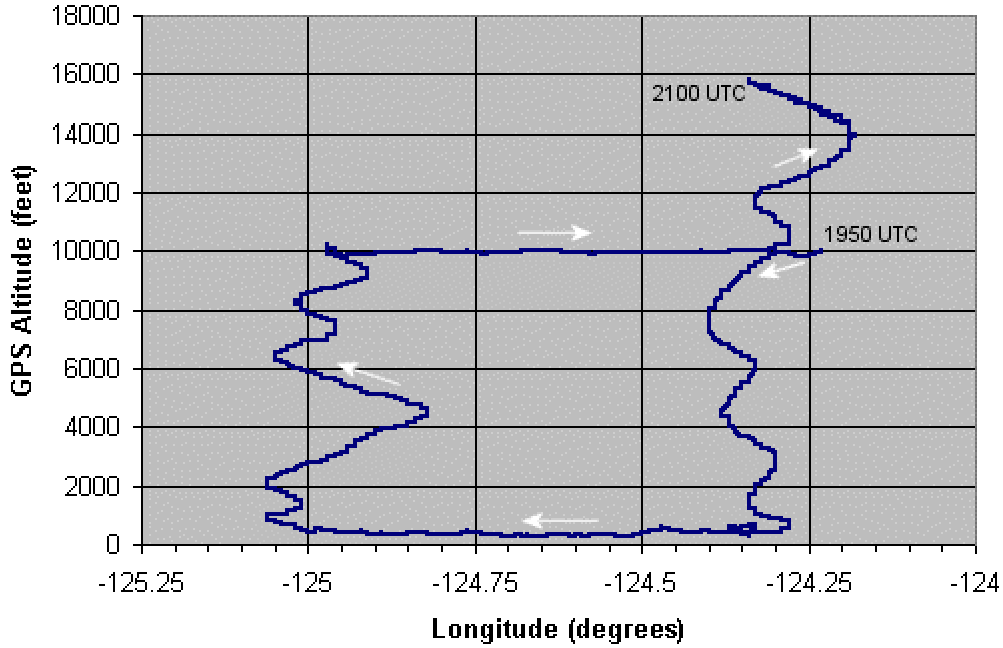


Figure 4.1. Flight track (white line) of the Convair-580 in IMPROVE-I on January 4, 2001 (UW flight 1846).

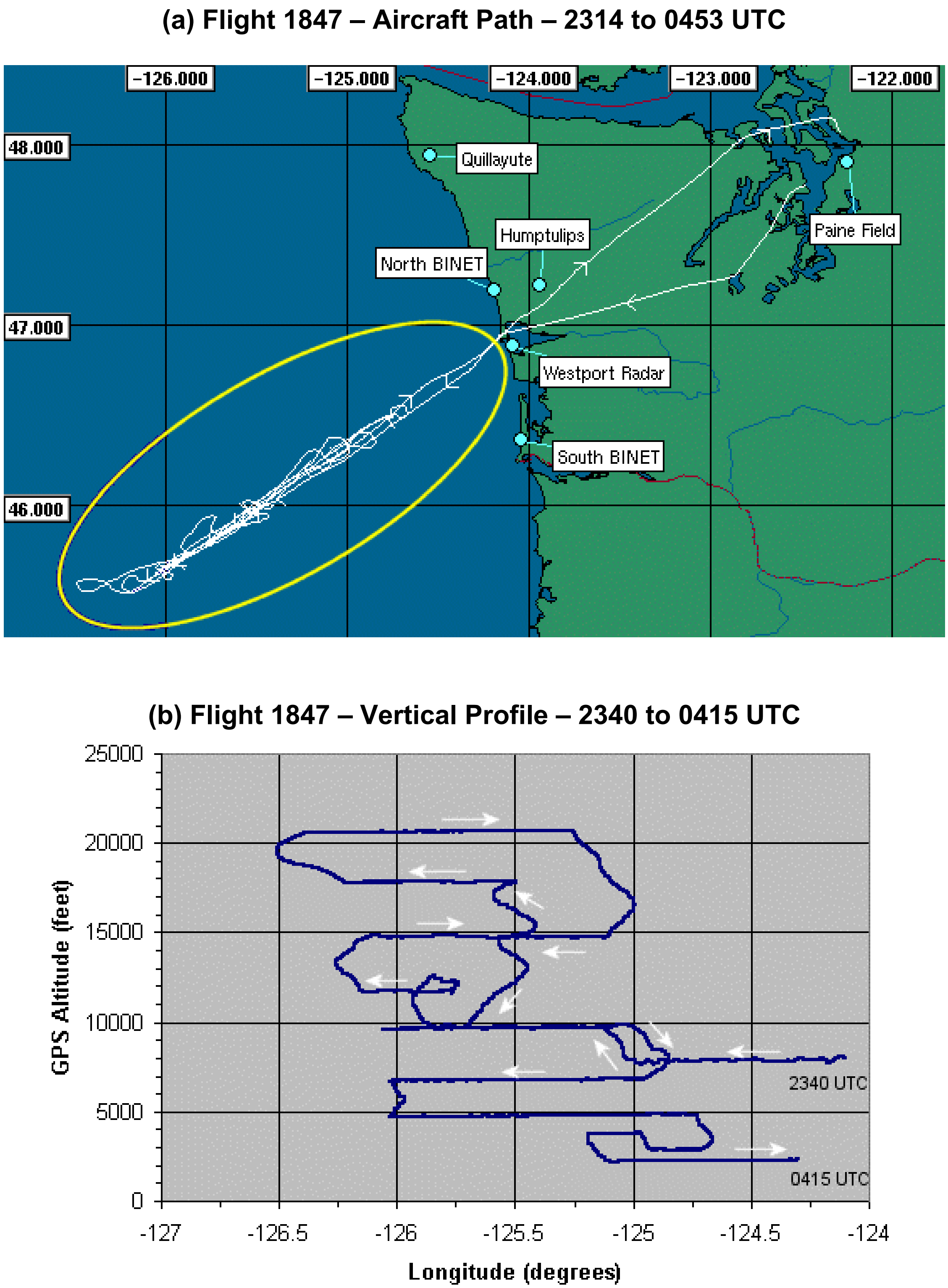
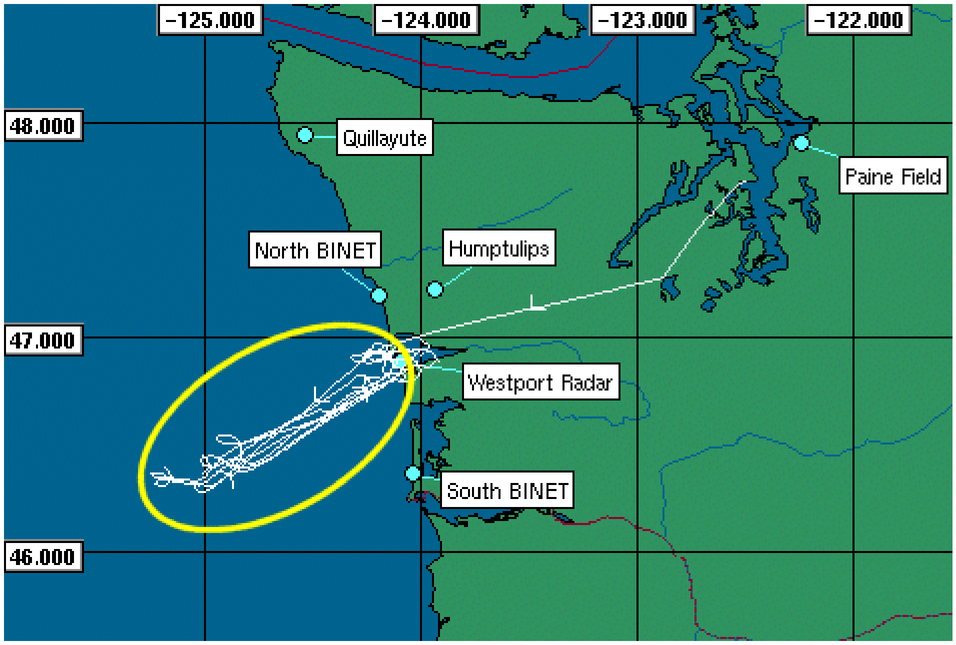


Figure 4.2. Flight track (white line) of the Convair-580 in IMPROVE-I on January 7-8, 2001 (UW flight 1847).

(a) Flight 1848 – Aircraft Path – 1744 to 2110 UTC



(b) Flight 1848 – Vertical Profile – 1817 to 2043 UTC

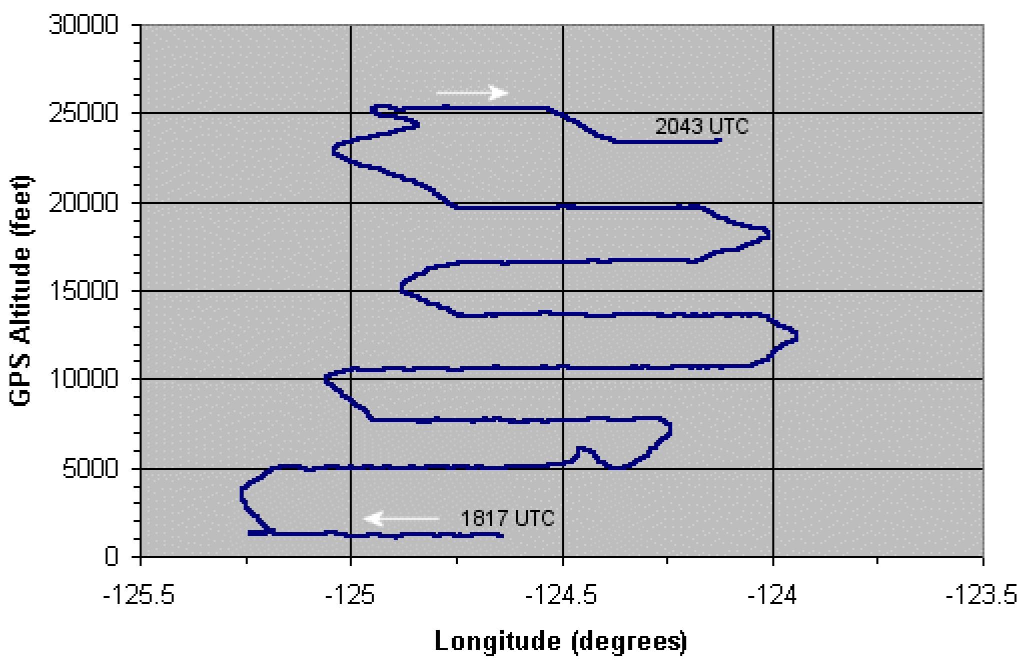
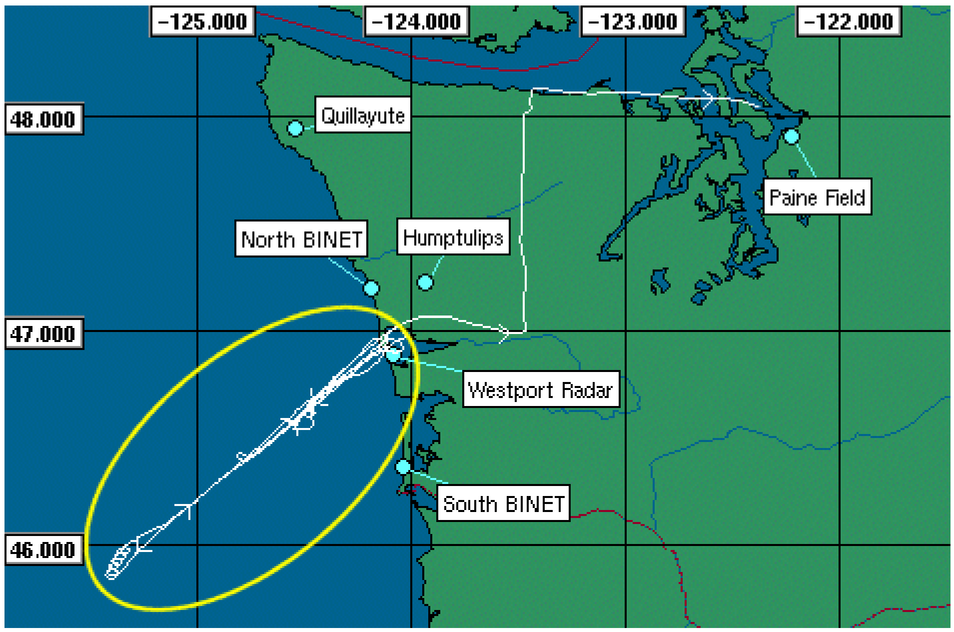


Figure 4.3. Flight track (white line) of the Convair-580 in IMPROVE-I on January 9, 2001 (UW flight 1848).

(a) Flight 1849 – Aircraft Path – 2246 to 0153 UTC



(b) Flight 1849 – Vertical Profile – 2247 to 0117 UTC

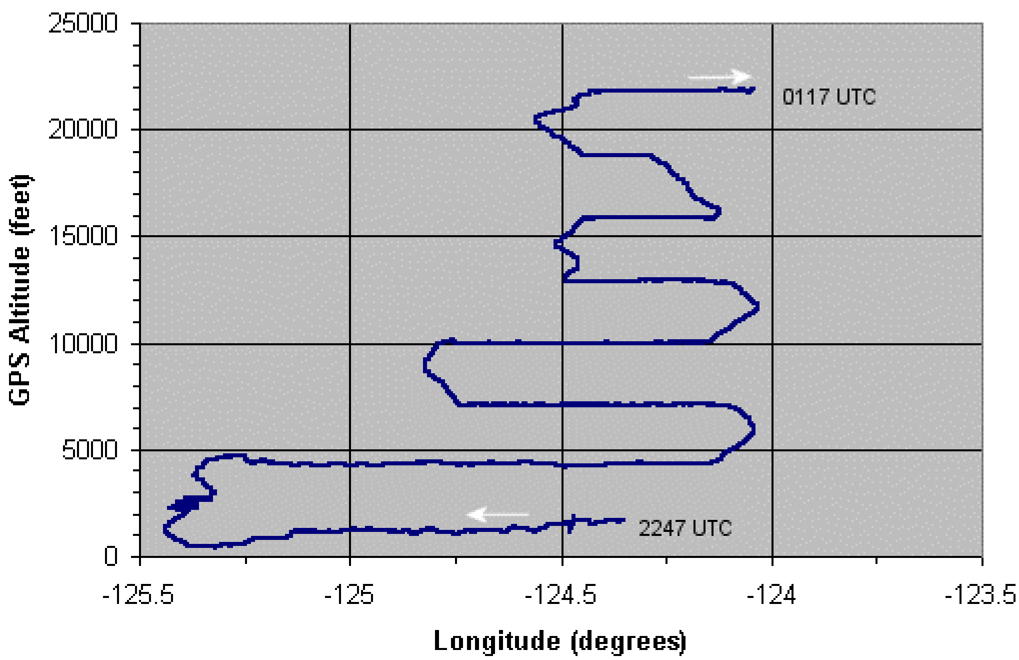
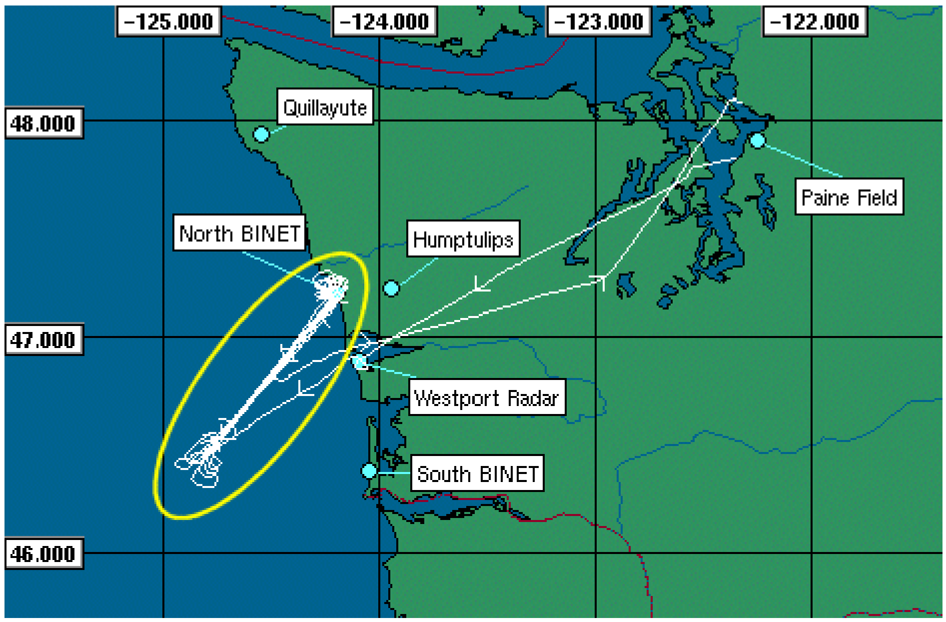


Figure 4.4. Flight track (white line) of the Convair-580 in IMPROVE-I on January 9-10, 2001 (UW flight 1849).

(a) Flight 1850 – Aircraft Path – 1516 to 2043 UTC



(b) Flight 1850 – Vertical Profile – 1600 to 1930 UTC

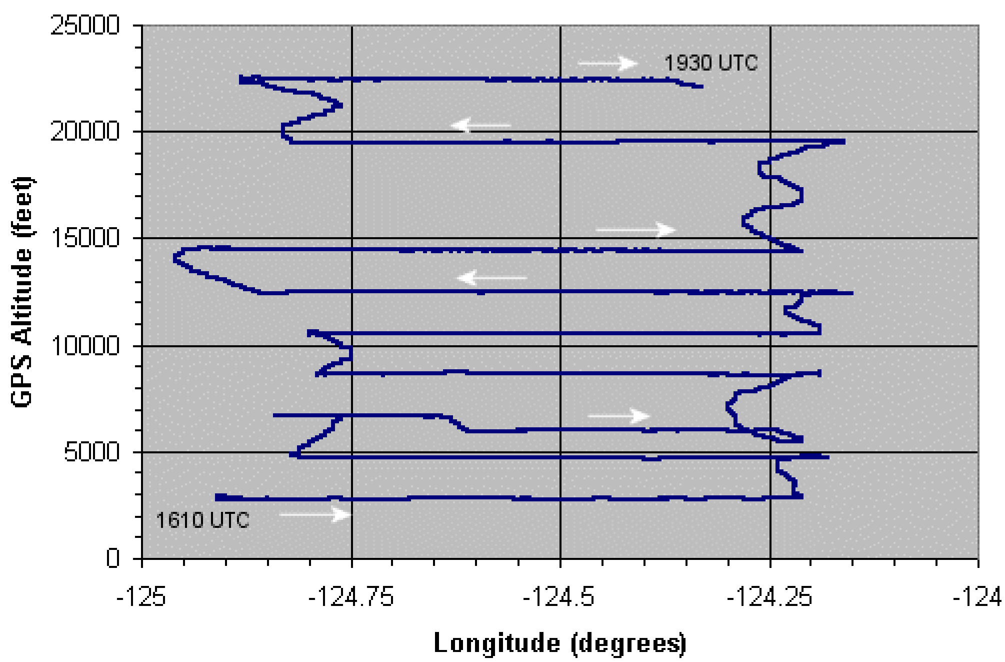
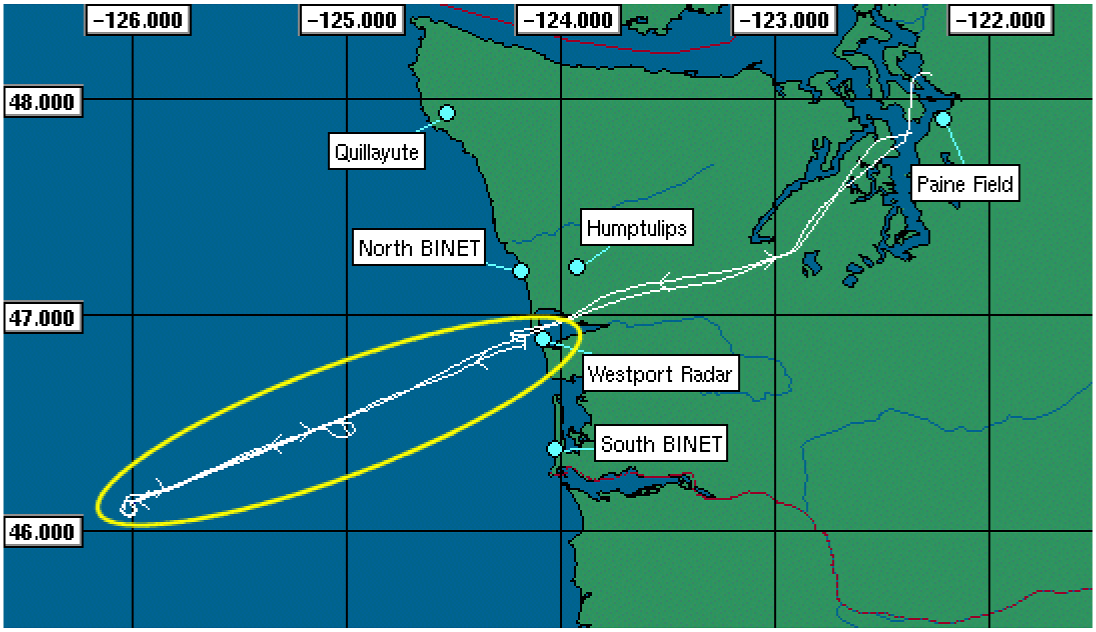


Figure 4.5. Flight track (white line) of the Convair-580 in IMPROVE-I on January 13, 2001 (UW flight 1850).

(a) Flight 1851 – Aircraft Path – 2029 to 2321 UTC



(b) Flight 1851 – Vertical Profile – 2054 to 2251 UTC

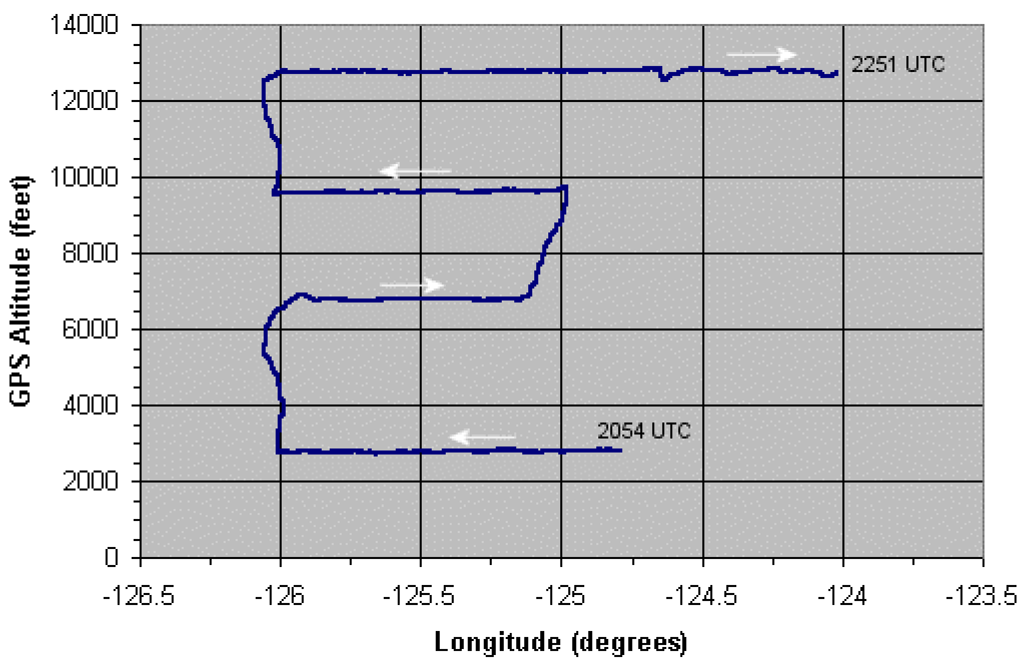
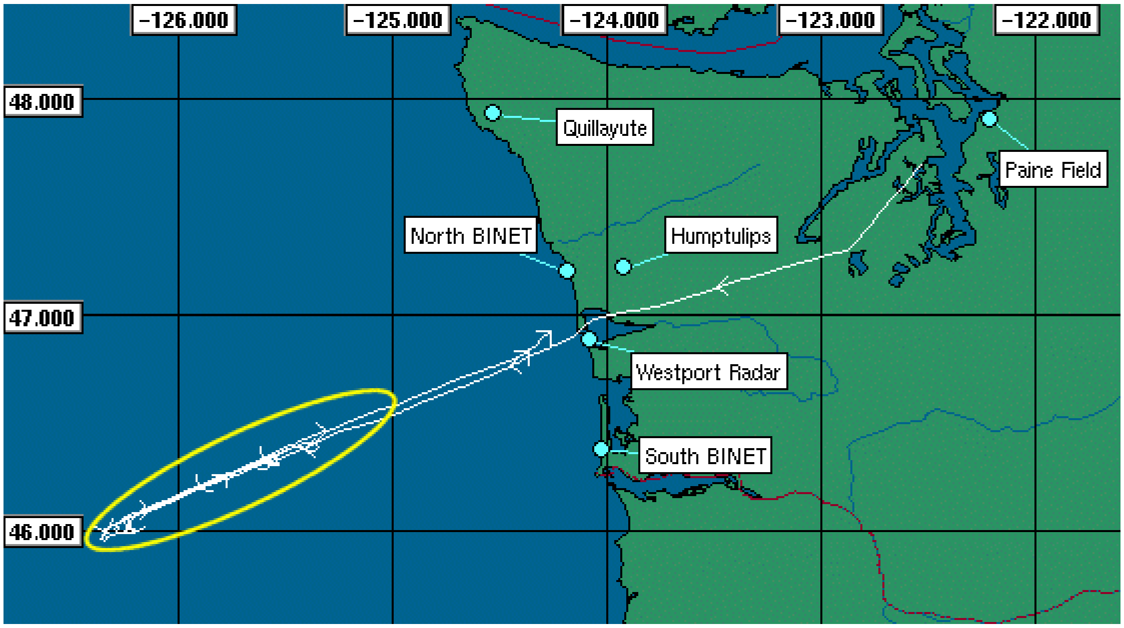


Figure 4.6. Flight track (white line) of the Convair-580 in IMPROVE-I on January 18, 2001 (UW flight 1851).

(a) Flight 1852 – Aircraft Path – 1652 to 2017 UTC



(b) Flight 1852 – Vertical Profile – 1745 to 1930 UTC

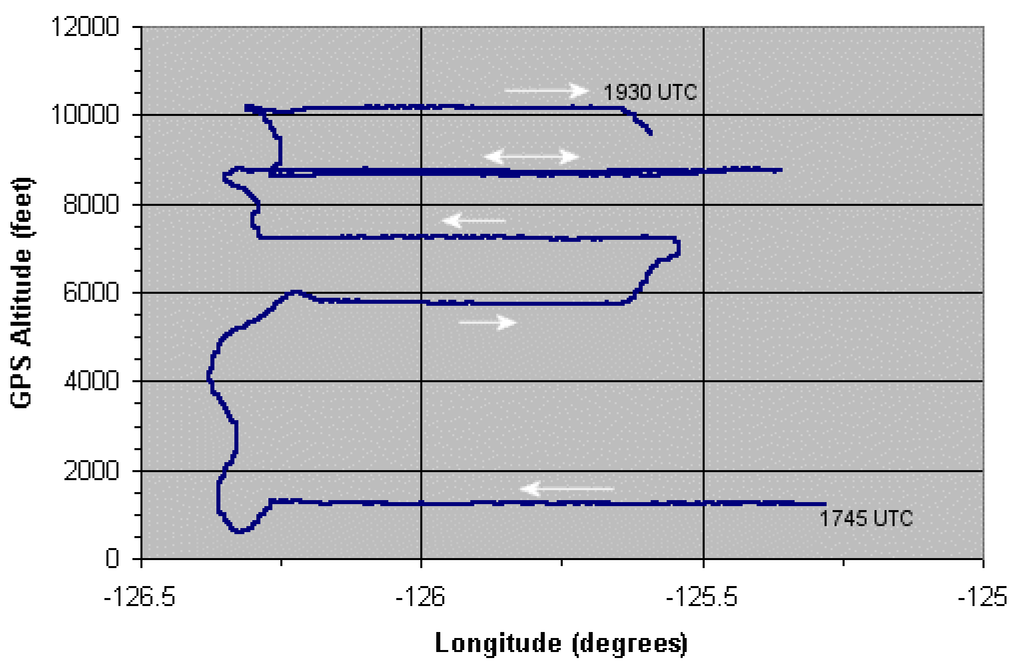


Figure 4.7. Flight track (white line) of the Convair-580 in IMPROVE-I on January 20, 2001 (UW flight 1852).

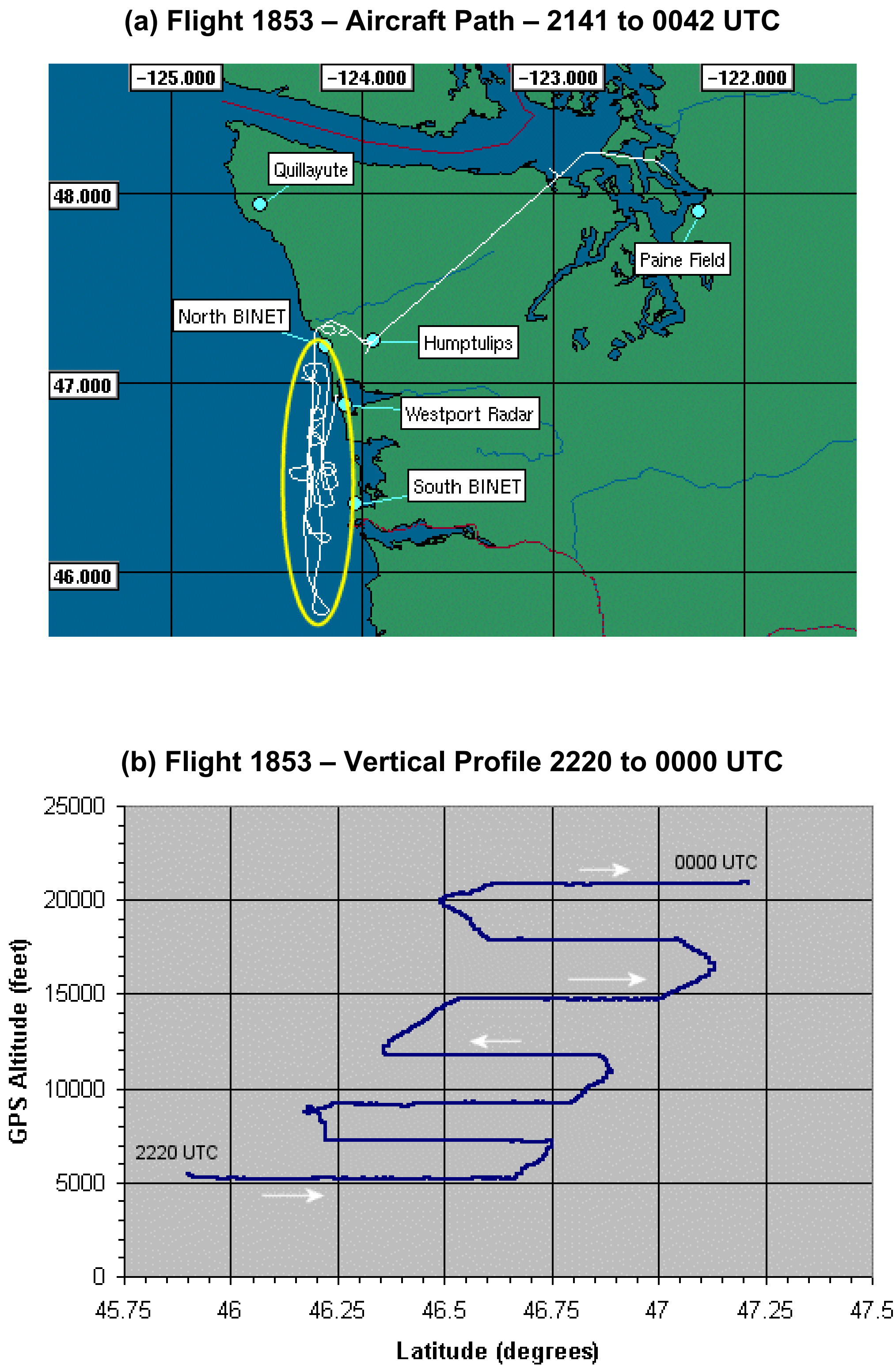


Figure 4.8. Flight track (white line) of the Convair-580 in IMPROVE-I on January 20-21, 2001 (UW flight 1853).

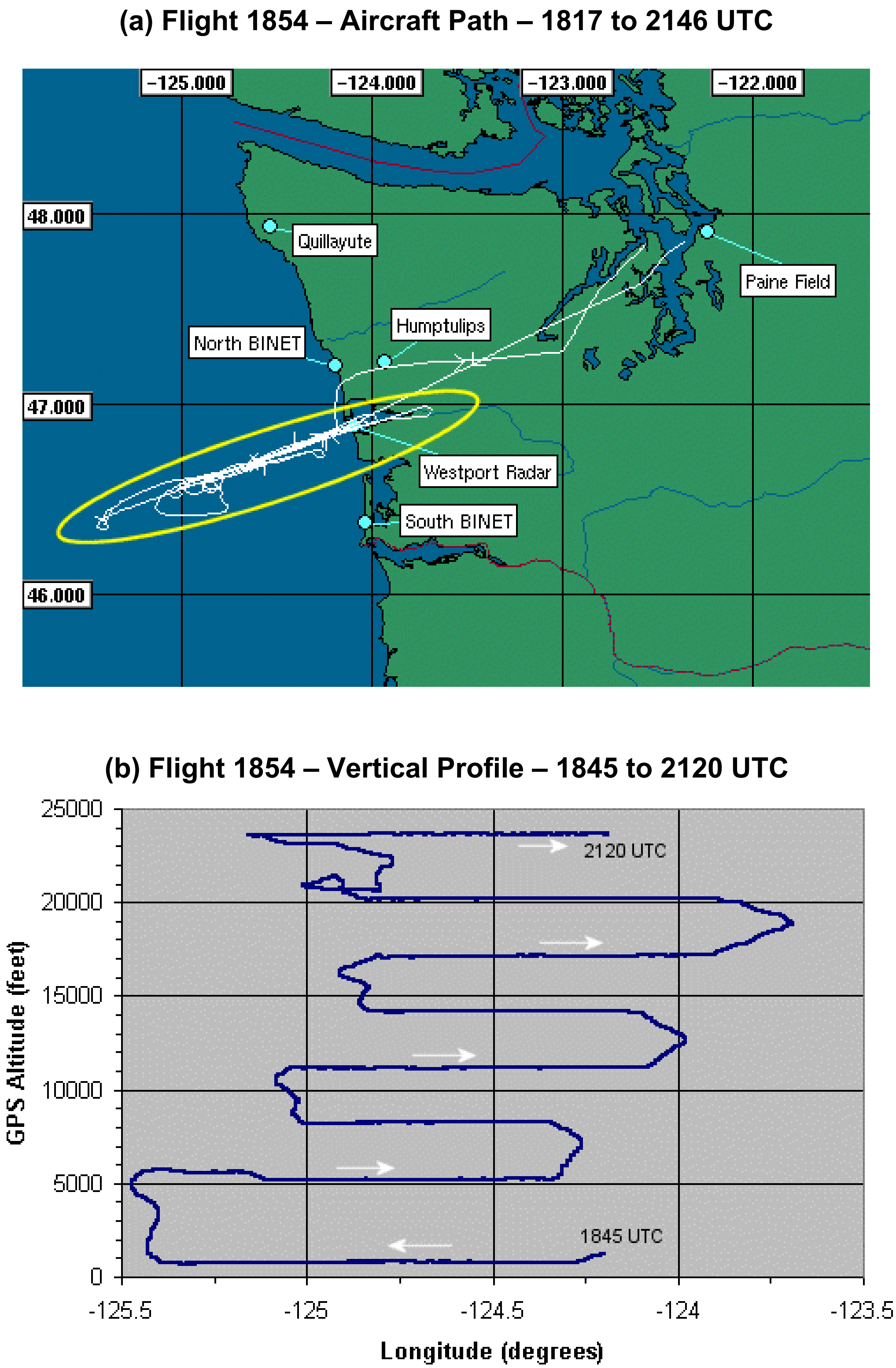
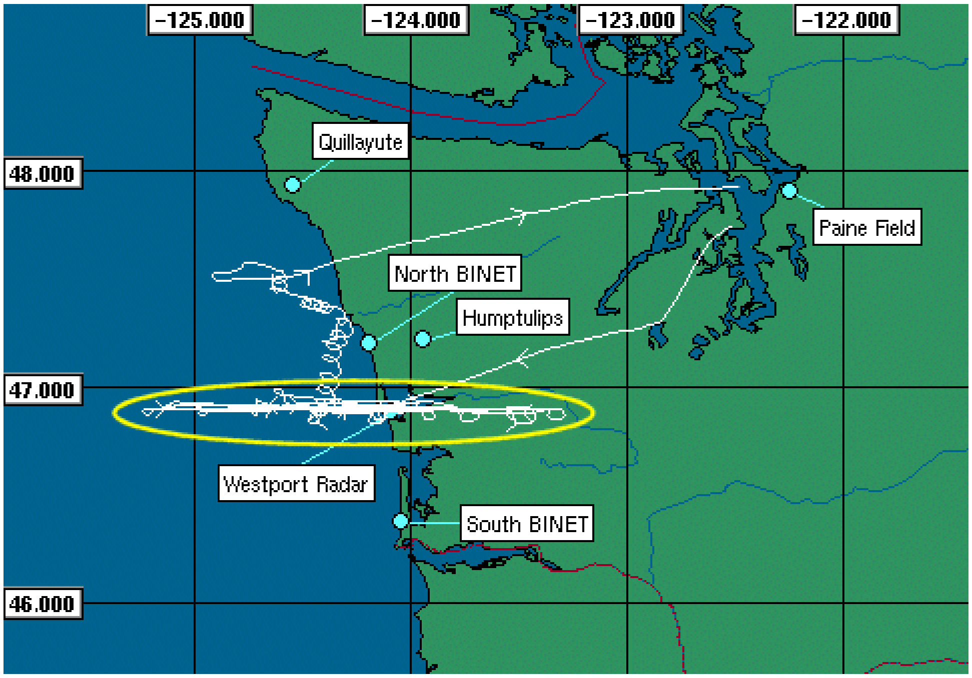


Figure 4.9. Flight track (white line) of the Convair-580 in IMPROVE-I on January 23, 2001 (UW flight 1854).

(a) Flight 1855 – Aircraft Path – 2315 to 0434 UTC



(b) Flight 1855 – Vertical Profile – 2347 to 0314 UTC

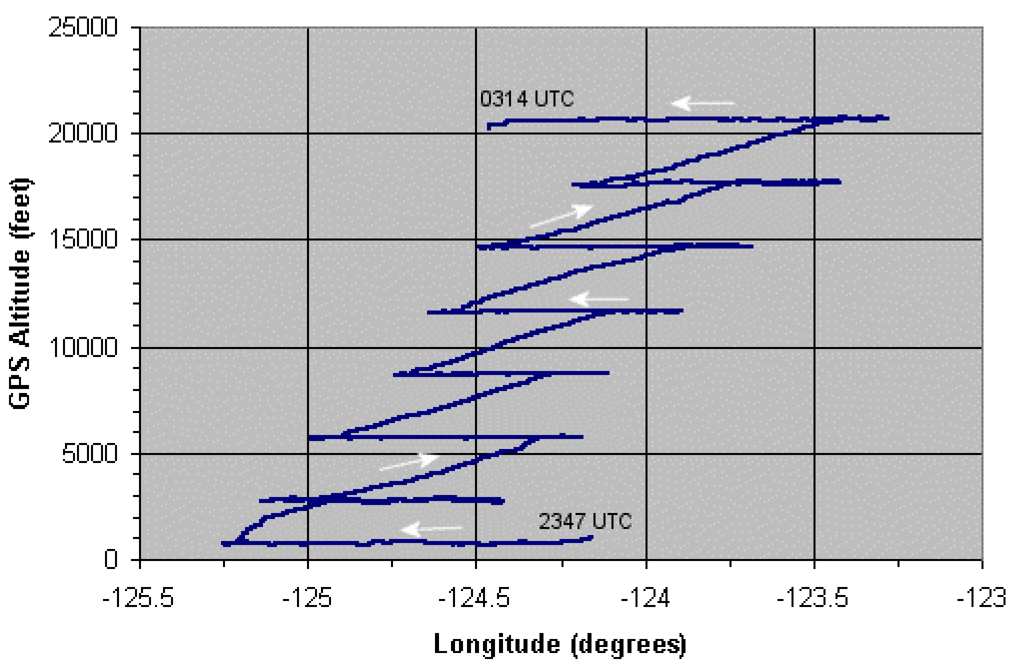
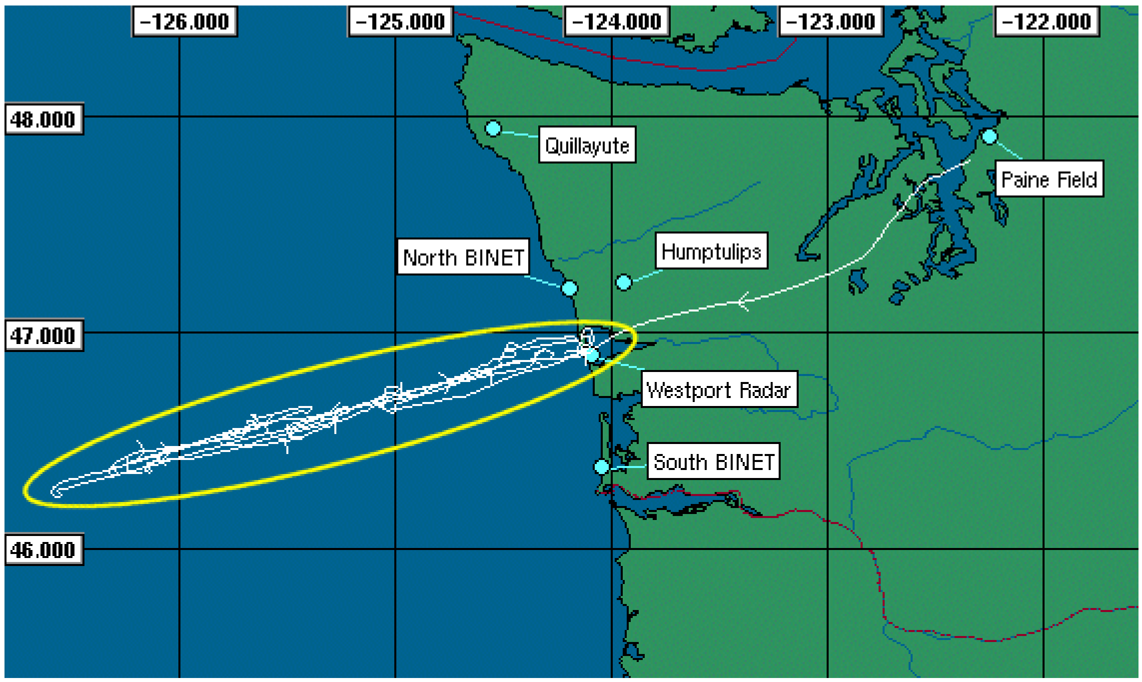


Figure 4.10. Flight track (white line) of the Convair-580 in IMPROVE-I on January 28-29, 2001 (UW flight 1855).

(a) Flight 1856 – Aircraft Path – 2248 to 0323 UTC



(b) Flight 1856 – Vertical Profile – 2321 to 0248 UTC

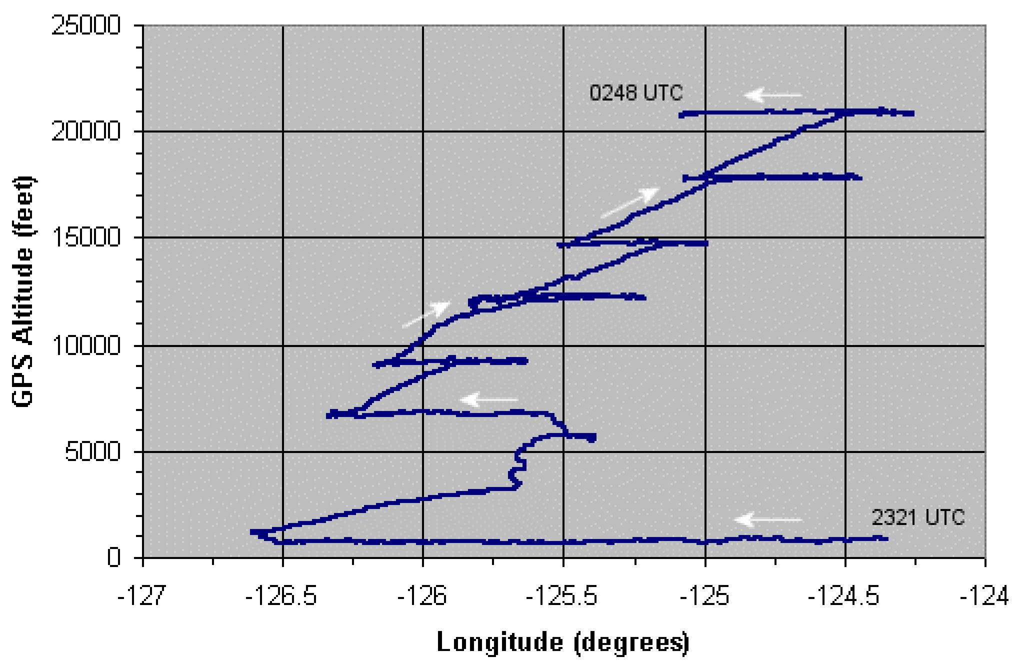
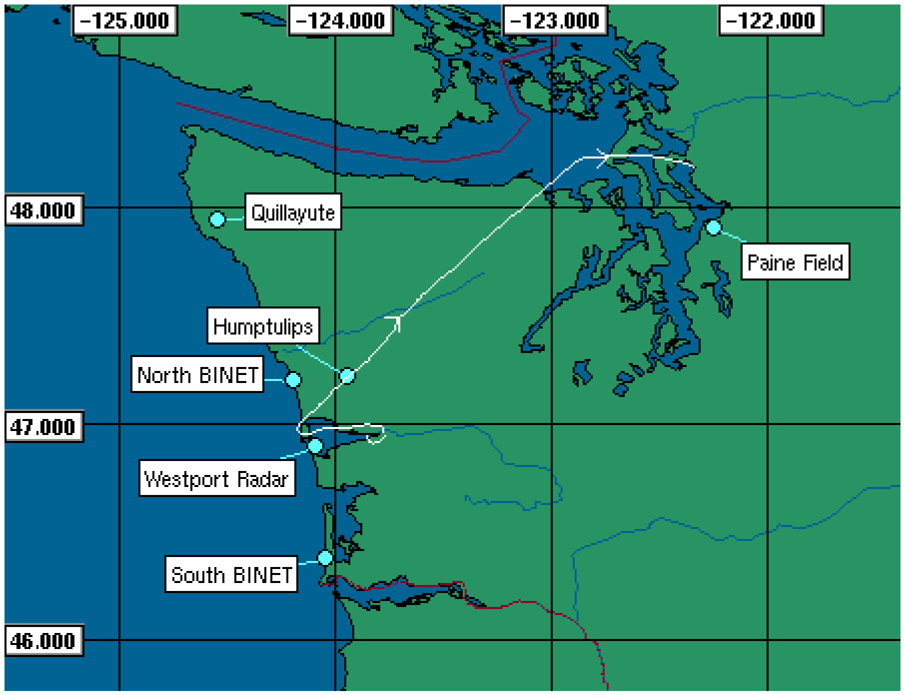


Figure 4.11. Flight track (white line) of the Convair-580 in IMPROVE-I on February 1, 2001 (UW flight 1856).

(a) Flight 1857 – Aircraft Path – 0500 to 0547 UTC



(b) Flight 1857 – Vertical Profile – 0500 to 0547 UTC

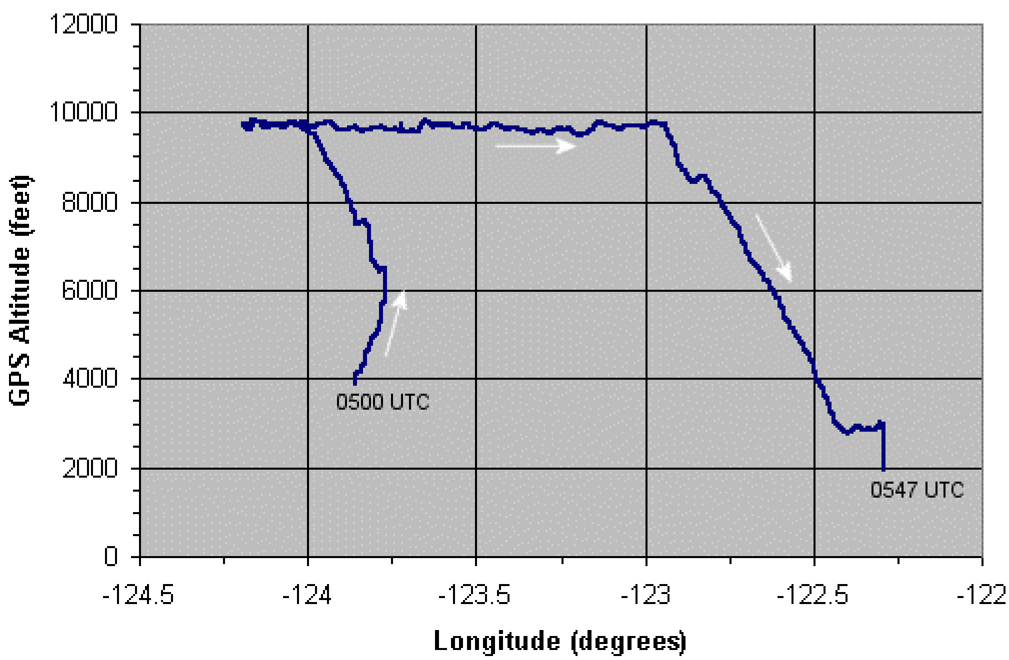
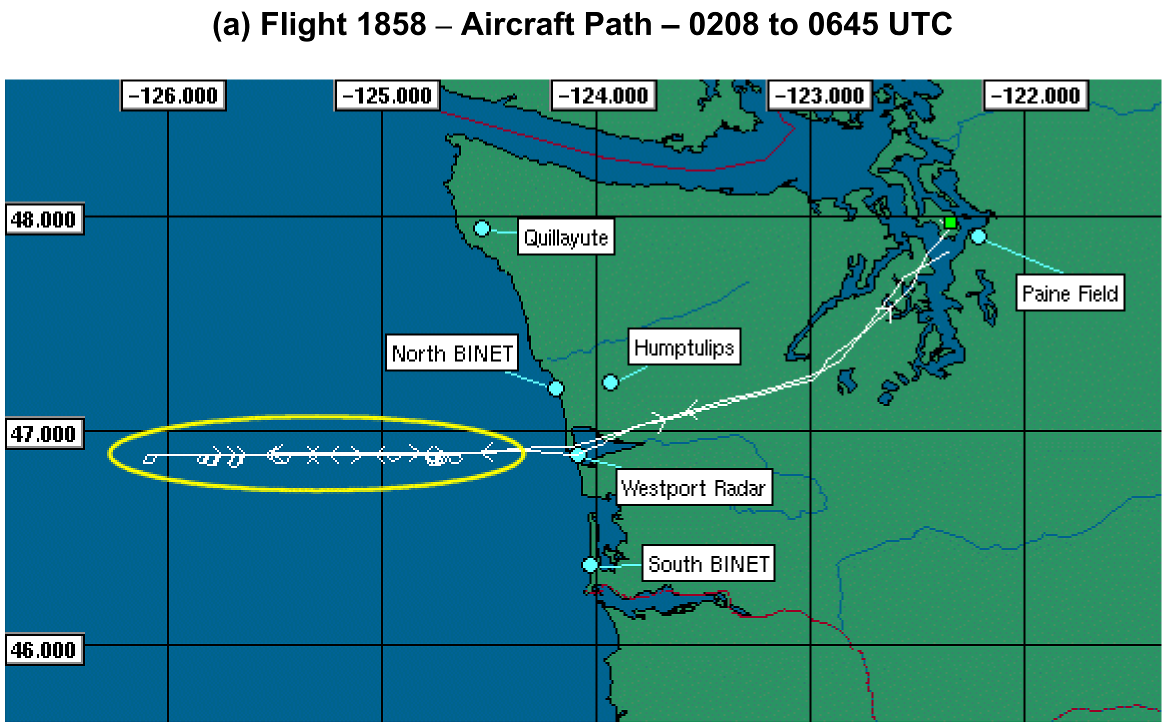


Figure 4.12. Flight track (white line) of the Convair-580 in IMPROVE-I on February 1, 2001 (UW flight 1857).



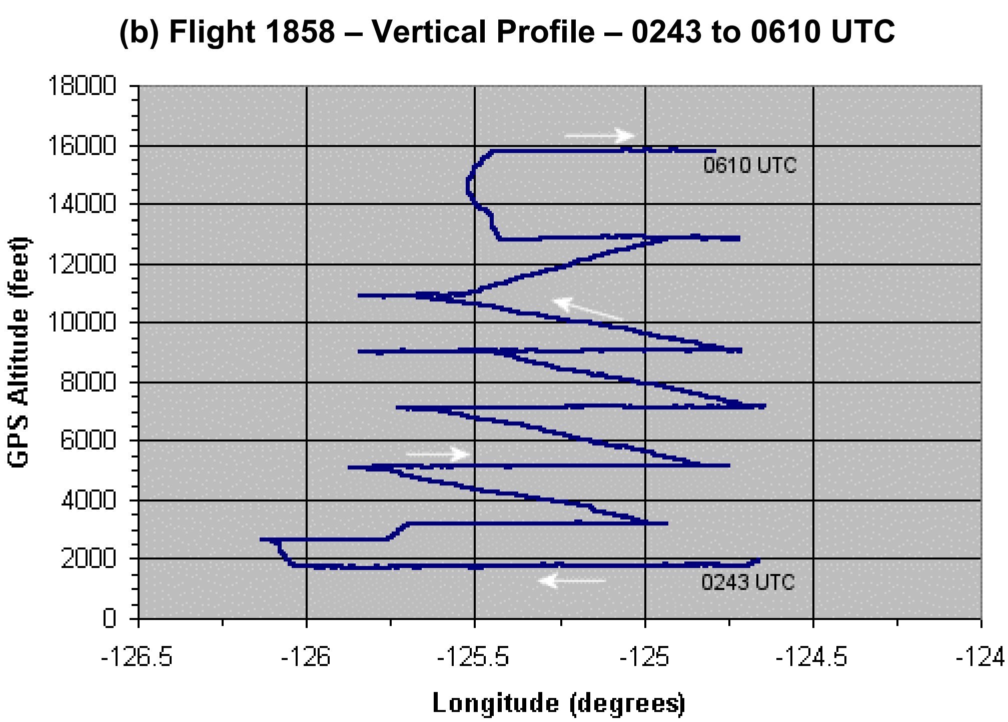
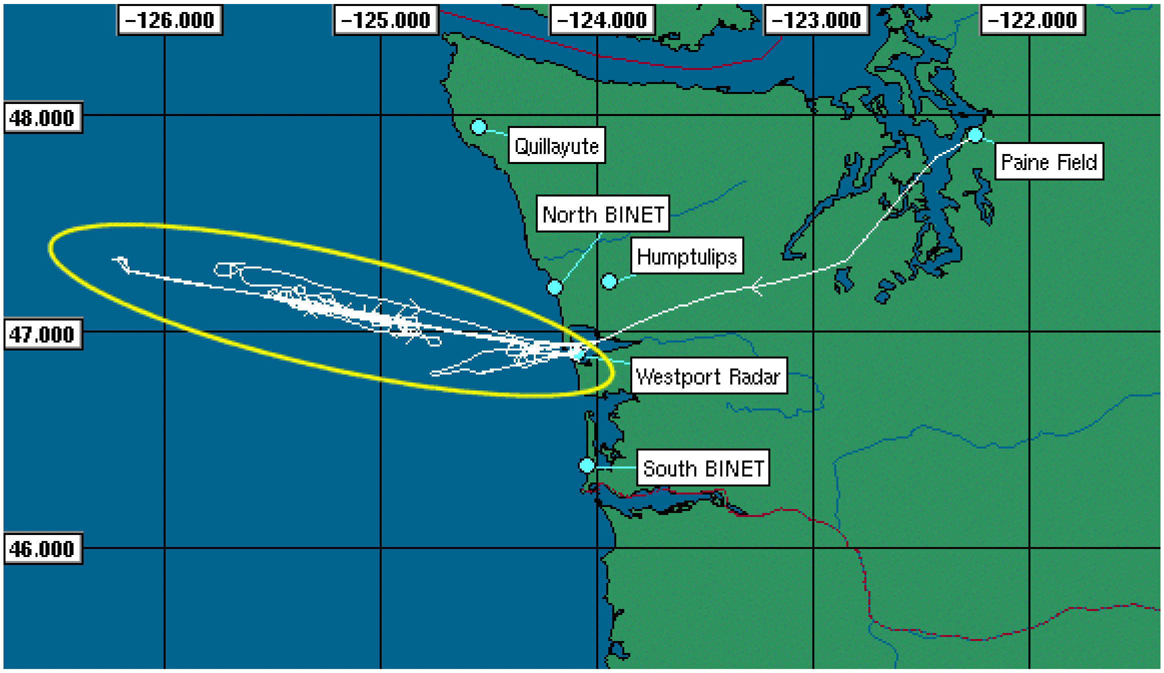


Figure 4.13. Flight track (white line) of the Convair-580 in IMPROVE-I on February 8, 2001 (UW flight 1858).

(a) Flight 1859 – Aircraft Path – 1435 to 2001 UTC



(b) Flight 1859 – Vertical Profile – 1503 to 1938 UTC

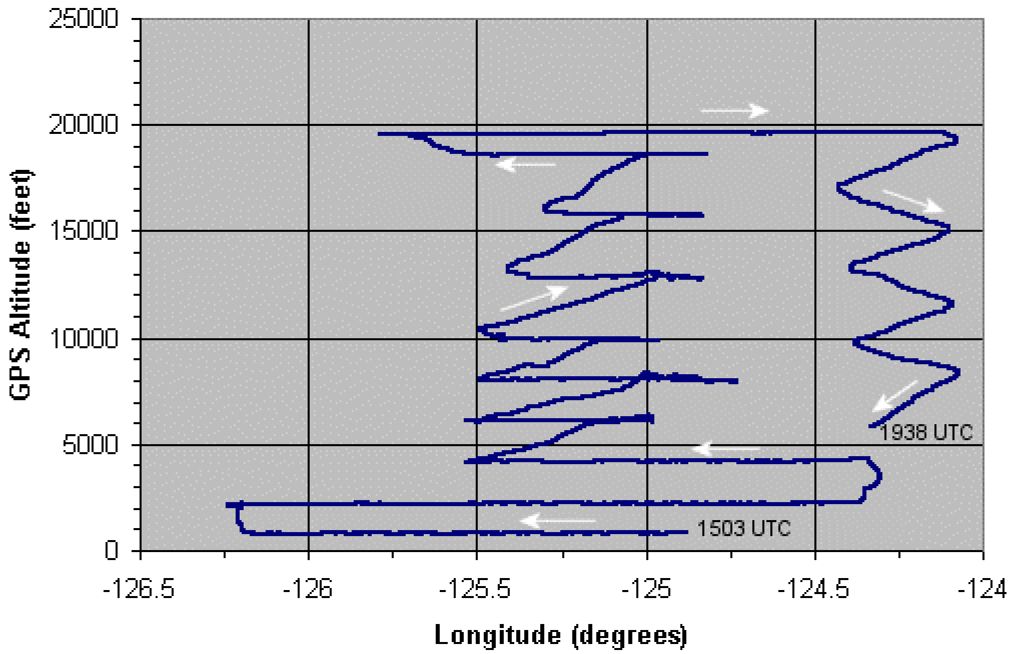


Figure 4.14. Flight track (white line) of the Convair-580 in IMPROVE-I on February 10, 2001 (UW flight 1859).

(a) Flight 1860 – Aircraft Path – 2154 to 0219 UTC

(b) Flight 1860 – Vertical Profile – 2208 to 0119 UTC

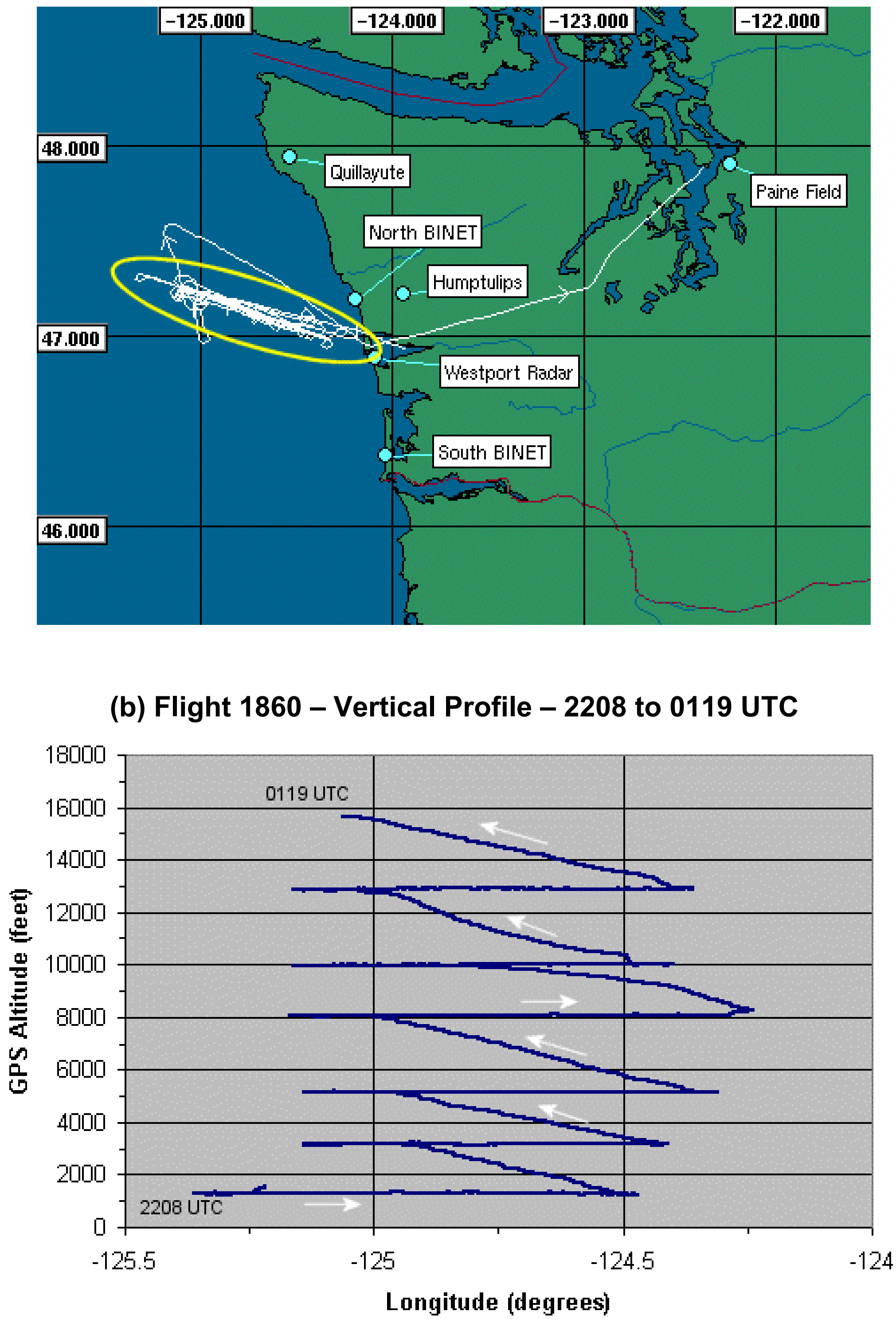


Figure 4.15. Flight track (white line) of the Convair-580 in IMPROVE-I on February 10-11, 2001 (UW flight 1860).

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

Two types of summaries for the Convair-580 flights in IMPROVE-I 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 information on the date and time period of each flight, the main accomplishments of the flight, weather conditions, 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-I. These "blow-by-blow" accounts provide detailed information on what transpired on each flight. However, because of their large bulk, these transcriptions are not reproduced here in their entirety.* Instead, Section 5.2 contains transcriptions of the verbal *summaries* that crew members recorded aboard the aircraft toward the end of each 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 1846 (4 January 2001)

Period of Flight (UTC): 1907-2138

* 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

Accomplishments of Flight:

Measurements in warm-sector rainbands producing light to moderate and steady precipitation.

Instrument Problems:

PMS 1-D and 2-D cloud probes and SPEC HVPS. SPEC CPI not aboard.

Flight Scientist: Nick Bond

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
1907	Engines on.
1916	Take off.
1932	Ferry to original point. In precipitation.
1942	Temporarily out of precipitation.
1950-1953	Communications with S-Pol.
1953	Spiraling down for first pass in precipitation.
2000	N. winds.
2003	Minor white capping.
2010	Low-level 300' run in light to moderate precipitation.
~2020	Spiraling up at west end.
2030-2040	Problems with 2D-C probe.
2040	Spoke with S-Pol. Tentatively planning cutting short due to equipment problems.
2048	Communications with S-Pol. Cutting flight short. Climbing to 15,000 ft for ferry back to Paine Field.
2059	Approaching tops near 15,000 ft. Descended due to cabin pressure to 13,000 ft.
2106	Still in light precipitation.
210644	A burst of 2D imagery. ~–5 TA, winds look okay, 230 at 31 ms^{-1}.
2112	Freezing level at ~8,000 ft.
2120	Drift angle looks suspicious. Winds 20-25 ms^{-1} at 4,000 ft then 36 ms^{-1}.
2130	Liquid H_2O probes off.
213130	Touch down.
2137	Engines off.

(b) University of Washington Flight 1847 (7-8 January 2001)

Period of Flight (UTC): 2300-0500

Accomplishments of Flight:

Measurements in light precipitation from a warm occlusion-type system.

Instrument Problems:

PMS 2-D cloud probe. SPEC CPI and PMS 1-D cloud probe not aboard.

Flight Scientist: Peter Hobbs

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
2300	Engines on.
2311	Take off.
2311-0025	Transit to Point A (about 100 nautical miles southwest of Westport).
0035-0045	A → B at 12,000 ft.
0045-0049	Climb to 15,000 ft at B.
0049-0058	B → A at 18,000 ft.
0058-0105	Climb to 18,000 ft at A.
0105-0120	A → B at 18,000 ft.
0120-0127	Climb to 21,000 ft at B.
0129-0140	B → A at 21,000 ft.
0140-0148	Descend to 15,000 ft at A.
0148-0200	A → B at 15,000 ft.
0200-0218	Descend to 10,000 ft at B then to new B location (45˚40'/126˚0').
0218-0234	B → A at 10,000 ft.
0234-0242	Descend to 7,000 ft at A.
0242-0307	A → B at 7,000 ft.
0307-0311	Descend to 5,000 ft at B.
0311-0335	B → A (46˚30'/124˚45') at 5,000 ft.
	(Lost radio contact with S-Pol radar between 7,000-5,000 ft at ~100 miles out from radar.)
0335-0340	Descend to 3,000 ft at A.
0340-0345	A → B at 3,000 ft.
0345-0348	Climb to 4,000 ft, still heading to B.
0348-0356	Continue toward B at 4,000 ft, but leg cut short due to fuel.
0356	Back toward Westport at 2,000 ft.

0416-0500	Return to Paine Field via Olympic Mountain transect (clouds east of Olympics).
0500	Engines off.

(c) University of Washington Flight 1848 (9 January 2001)

Period of Flight (UTC): 1734-2116

Accomplishments of Flight:

Vertical profile from near surface to top of pre-occluded front rainband.

Instrument Problems:

PMS 2-D cloud probe.
SPEC CPI not installed.

Flight Scientist: Nick Bond

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
1734	Engines on.
1742	Take off.
1746	Freezing level over Puget Sound ~800 mb.
1755	Low-level fog ins. Puget Sound Basin. Winds only 10 ms^{-1} from 190 at 700 mb.
1758	Checked in with S-Pol. Coordinates of first run okay.
1801	Winds picking up 15 ms^{-1} from 200.
1806	Over Grays Harbor. Precipitation in sight ahead.
1810	Numerous whitecaps. Starting Descent.
1813	800 mb, winds 180 at 18 ms^{-1}, light chop. Surface winds from south → southeast.
181445	850 mb 2˚C 200 at 20 ms^{-1}.
1816-1832	Low-level run.
181645	In precipitation. HVPS picking it up.
1820	46 20' 125 11 New point for end of run (from comms. with radar).
1828	Winds from sea state 140 at 20 ms^{-1}. 46 40' 124 30' new northeast point.
1834-1850	5,000 ft run.
1836	Good data from HVPS.

1843	Winds 170 33 ms^{-1} at 825 mb.
1850	46 20' 124 56' new southwest point.
1853	Starting run to southwest at ~8,000 ft.
1853-1912	8,000 ft run.
1856	HVPS temporarily down. Winds 170 at 30 ms^{-1}.
1858	HVPS back up.
1901	Light chop, winds 190 at 33-36 ms^{-1}.
1905	Temperature dropped from –3.3 to –4.1. Winds seem frozen at times.
1912	Beginning climb for 11,000 ft.
1914-1915	46 47' 124 11 new northeast point.
1918-1929	11,000 ft run.
1920	Lots of small particles on HVPS. Temperature –8˚C, winds suspicious. Fixed at 190˚ 33.4 or 36.0 ms^{-1}.
1930	46 26 124 44 southwest point for 14,000 ft.
1934-1952	14,000 ft run.
1934	Some flakiness in rev. temp; wind speed.
1937	Cabin pressure low O_2.
1942	Rev. temperature mostly bad –13 to –14.
1948	Cabin pressure back up.
1954	46 46' 124 13' near end point for 17,000 ft run.
1956-2007	17,000 ft. run.
2002	Correct temperature probably –17 also showing –19.8. Winds 170 at 38.6 ms^{-1}.
2009	Climbing to 20,000 ft. T –25.6, wind 180 at 36.
2010-2024	20,000 ft.
2015	Winds 180 at 33.4 ms^{-1}. Close to Progged.
2028	Spoke with radar planning possible landing at Hoquiam.
2034	Discussing second flight.
2041	Approaching cloud top last leg towards northeast never really got into clouds.
2048	Approach/descent into Hoquiam. Should provide good profile but HVPS not working.
2057	Getting good descent profile. Stable layer just above freezing level (isothermal). Mostly light some moderate chop. Freezing level about 3,100 ft.
2105-2109	Rough approach to Hoquiam below about 4,000 ft.

2111	Touch down at Hoquiam.
2115	Engines off.

(d) University of Washington Flight 1849 (9-10 January 2001)

Period of Flight (UTC): 2233-0202

Accomplishments of Flight:

Measurements in occluded front (same system as Flight 1848). Measurements across Olympic Mountains en route back to Paine field.

Instrument Problems:

PMS 2-D cloud probe.
SPEC CPI not installed.

Flight Scientist: Nick Bond

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
2233	Engines on.
2240	Take off from Hoquiam.
2245-2318	Heading for first point 46 25/124 45. Light-moderate turbulence, moderate visibility/mile. Wind 160 18-21 ms^{-1} at 1,500 ft. Temperature 1-4˚C.
2301	Winds picking up slightly. Temperature 3-4˚C.
2309	Still no sign of front except for perhaps lower cloud bases.
2311	Lower CIG & VIS.
2314	Probably through wind shift.
2318	Quite noticeable cloud band with front from west side.
2320	Southwest end point near 45 56/125 41.
2330	Heading back towards northeast, Temperature ~-2˚C.
2330-2352	4,000 ft run.
2336	Hitting bursts of liquid H_2O. Up to ~.8 g m^{-3}. New northeast point 46 54/124 09.
2342	Fairly large LWC ~.4 gm^{-3}.
2343	Pilots reporting some lift. Relatively cold ~–3.
2345	Temp. up, LWC down.

2351	Near or just above freezing level, low LWC.
2352	New southwest point 46 39/124 29.
2355-0016	7,000 ft run.
2357	Winds 230 21 ms^{-1}, T -4 → -6.
0006	Continuing course.
0016	Climbing to ~10,000 ft.
0018-0027	10,000 ft run.
0020	New northeast point 46 54/124 06.
0025	HVPS having problems.
0027	HVPS back doing okay. Climbing to ~13,000 ft. Slacker winds at 10,000 ft thru below.
0029	New southwest point 46 42/124 26.
0029-0040	13,000 ft. run.
0033	Winds 220 18 ms^{-1}. Temperature –14 → –16. 13,000 ft.
0035	Speed picking up ~26 ms^{-1}.
0041	Broke out starting climb.
0043-0052	16,000 ft run.
0047	Temperature –20 → –23. Wind 180 at 31 ms^{-1}. 16,000 ft.
0055-0101	19,000 ft run.
0057	Temperature –25 → –29. Wind 190 at 28 ms^{-1}. 19,000 ft. Still in precipitation.
0101	Climbing to 22,000 ft or higher.
0105-0114	22,000 ft run.
0113	Sou. 47 00/123 30. No. 48 13/123 30. Arranged for Olympic Transect.
0119	Lining up for Olympic Transect at 10,000 ft. Winds 190 at 18 ms^{-1}. HVPS back okay.
0119-0140	Olympic Transect.
0123-0125	Temporarily shut data system, but data probably being recorded.
0130	Bad temperature (–17→18). Winds bad.
0136	Data looks okay. No turbulence in lee of Olympics.
0140	Little or no precipitation.
0151	Shutting down data system. Nine legs.
0157	Touch down.
0202	Engines off.

(e) University of Washington Flight 1850 (13 January 2001)

Period of Flight (UTC): 1503-2050

Accomplishments of Flight:

Measurements in well defined but weak cold or warm-frontal rainband. Good measurements over Olympic Mountains on return and descent to Paine Field.

Instrument Problems:

No recording of 35 GHz radar data.

Flight Scientist: Peter Hobbs

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
1514	Take off.
1542	At A (46˚54'/124˚06')
1542-1602	A → B at 4,000 ft.
1602-1633	B (46˚26'/124˚50') → C (47˚12'/124˚12') at 3,000 ft (North BINET and PNNL site).
1633-1637	Climb to 5,000 ft over C.
1637-1656	C → B at 5,000 ft. Breaking out of cloud near B.
1656-1702	Climb to 7,000 ft at B in clear air.
1702-1721	B → C at 7,000 ft then 6,500 ft to get in cloud. Climb over C to get in cloud.
1721-1725	Climb to 9,000 ft over C.
1725-1742	C → B at 9,000 ft (–12˚C)
1742-1747	Climb too11,000 ft over B (about –15˚C over B at 11,000 ft).
1747-1804	B → C at 11,000 ft.
1804-1806	Climb to 13,000 ft over C.
1806-1825	C → B at 13,000 ft.
1825-1831	Climb to 15,000 ft over B.
1831-1849	B → C at 15,000 ft.
1849-1856	Climb to 20,000 ft over C.
1856-1910	C → B at 20,000 ft. Thin cirrus above, sampling crystals from cirrus above falling into main cloud deck just below.
1910-1917	Climb to 23,000 ft over B.
1917-1933	B → C at 23,000 ft near tops of cirrus.

1933-1953	Descent from 20,000 to 400 ft over C. (Rainband now between S-Pol radar and C and oriented east-west.)
1953-2000	C to southwest at 400 ft then 1,400 ft looking for precipitation (only a few drops).
2000-~2040	Back to Paine Field via Olympics—good cloud and precipitation.
2050	Engines off.

(f) University of Washington Flight 1851 (18 January 2001)

Period of Flight (UTC): 2016-2330

Accomplishments of Flight:

Profile of clouds and precipitation in advancing but weakening diffuse cold front.

Instrument Problems:

SPEC HVPS.
No recording of 35 GHz radar data.

Flight Scientist: Nick Bond

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
2016	Engines on.
2026	Take off. Ferry to operating area. Instruments working.
~2051	Beginning descent for low-level run.
2057	Past coastline.
2059	Start of low-level run at 3,000 ft.
2121	Back in precipitation.
2129	Out of precipitation.
2131	Back in precipitation.
2140	End of low-level leg.
2146	Beginning 7,000 ft run at ~–1˚C. HVPS malfunctioning.
2157	End of 7,000 ft run.
2201	Begin 10,000 ft run at ~–4 to –5˚C.
2213	Temporary break in precipitation.
2222	End of 10,000 ft fun.

2226	Start of 13,000 ft run. Near cloud top in and out (mostly out) of cloud. Temperature ~–9 → –10˚C.
2232	Hit patch of crystals. Wind 200 at 30 33 ms^{-1}.
2242	End of 13,000 ft run. Heading back to Paine Field.
2325	Touch down.
2330	Engines off.

(g) University of Washington Flight 1852 (20 January 2001)

Period of Flight (UTC): 1635-2028

Accomplishments of Flight:

Measurements in rainband along and to east of advancing occluded front.

Instrument Problems:

Some CPI computer shutdowns.

Flight Scientist: Nick Bond

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
1635	Engines on.
1648	Takeoff.
1655-1705	In moderate precipitation at 10,000 ft over south Puget Sound. Cloud radar shows down to 4,000-7,000 ft.
1721	Start of low-level leg (2,000 ft). No precipitation but OVC. All instruments okay.
1810	End of low-level leg to southwest.
1814	Start of leg at 6,000 ft.
1823	End of 6,000 ft.
1827	Start of 7,500 ft leg.
1840	End of 7,500 ft leg (southwest point).
1843	Start of 9,000 ft leg.
1847	System down.
1856	System back up.
1900	Repeat 9,000 ft leg heading southwest. By 1905 all instruments functional.
1916	End of 9,000 ft leg.

1919	Begin 10,500 ft leg. No precipitation initially.
1930	End 10,500 ft leg.
1933	Dropping from 9,000 ft to 3,500 ft.
1937	Leveling out at ~3,000 ft.
1945	Southwest end of 3,000 ft.
1948	Start at 500 ft at southwest end.
1951	End of 500 ft. Climbing to 6,000 ft (just above 0˚C lev).
1958	End of 6,000 ft (not much precipitation).
1959	Heading for Hoquiam.
2015	System taken down.
2022	Touch down at Hoquiam.
2028	Engines off.

(h) University of Washington Flight 1853 (20-21 January 2001)

Period of Flight (UTC): 2128-0050

Accomplishments of Flight:

Measurements in encroaching warm-frontal type rainband (same system as Flight 1852).

Flight Scientist: Nick Bond

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
2238	Begin run at 7,500 ft.
2249	End of 7,500 ft climb, turn.
2252	Begin run at 9,500 ft.
2304	End of 9,500 ft run climb & turn.
2310	Start 12,000 ft run.
2318	End of 12,000 ft run climb & turn.
2321	Start 15,000 ft run (at 14,000 ft at initial point).
2330	End of 15,000 ft run.
2336	Start 18,000 ft run.
2347	End 18,000 ft climb & turn.
2350	Start 21,000 ft.
0000	End 21,000 ft. Still in deep cloud. Spiraling down for Olympic Transect.
0015	Begin Olympic Transect at 10,000 ft. Enhanced winds. Precipitation near top TRB and weak winds in lee.

0031	End of Olympic Transect.
0045	Touch down.
0050	Engines off.

(i) University of Washington Flight 1854 (23 January 2001)

Period of Flight (UTC): 1805-2158

Accomplishments of Flight:

Measurements in a quasi-stationary rainband ahead of a low-level frontal (cold?) windshift line.

Instrument Problems:

Delayed start-up of SPEC CPI.

Flight Scientist: Art Rangno

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
1805	Engines on.
1817	Take off.
1835	Descending for low-level run. Freezing level ~6,000 ft.
1846	Begin low-level (1,000 ft) run. Temperature ~7˚C.
1853	Start of precipitation.
1905	End of low-level/climbing.
1909	Start of 6,000 ft run.
1914	Dropping to 5,500 ft. CPI out.
1927	End of 5,500-6,000 ft run.
1930	Start of 8,500 ft run.
1942	End of 8,500 ft/climb. Some CPI data.
1946	Start of 11,500 ft.
2000	End of 11,500 ft.
2003	Start of 14,500 ft. CPI okay.
2014	Out of precipitation for 1-2 min.
2017	End of 14,500 ft.
2022	Start of 17,500 ft.
2036	End of 17,500 ft.
2041	Start of 20,500 ft.
2054	End of 20,500 ft.
2056	Return at 21,000 ft.
2057	Checking for clearance to ascend.

2100	Ascending to 24,000 ft.
2106	Begin 24,000 ft.
2119	End of 24,000 ft.
2152	Touch down.
2158	Engines off.

(j) University of Washington Flight 1855 (28-29 January 2001)

Period of Flight (UTC): 2358-0445

Accomplishments of Flight:

Measurements in two rainbands ahead of strong cold front. Transect of Olympic Mountains on return to Paine Field.

Instrument Problems:

Lots of poor images on SPEC CPI.

Flight Scientist: Peter Hobbs

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
2258	Engines on.
2312	Take off.
2312-2344	Transit to Westport (ice crystal fallout—columns—at 9,700 ft). Freezing level ~4,000 ft.
RAINBAND #1	
2345-0005	Westbound from Westport at 1,000 ft to 46˚54'/125˚11' (B ← A).
0005-0020	Eastbound climb from 1,000 to 3,000 ft. Finish at 46˚54'/124˚28' (B → A).
0020-0035	Westbound at 3,000 ft to 46˚54'/125˚05' (B ← A).
0035-0049	Eastbound, climb from 3,000 to 6,000 ft, end at 46˚54'/124˚17' (B→ A).
0049-0102	Westbound at 6,000 ft (warming to west) to 46˚54'/124˚55' (B ← A).
0104→0114	Eastbound climbing from 6,000 to 9,000 ft to 46˚54'/124˚13' (B → A).
0114→0126	Westbound at 9,000 ft to 46˚54'/124˚42' (B ← A). (–6˚C at B.)
0128-0137	Eastbound, climbing from 9,000 to 12,000 ft, to 46˚54'/124˚00' (B → A).

0140-0150	Westbound at 12,000 ft to 46˚54'/124˚36' (B ← A).
0153-0204	Eastbound, climbing from 12,000 to 15,000 ft (–10˚C), to 46˚54'/123˚51' (B → A).
0209-0218	Westbound at 15,000 ft (–14˚C) to 46˚54'/124˚23' (B ← A).
0221-0231	Eastbound, climbing from 15,000 to 18,000 ft, to 46˚54'/123˚36' (B → A). Near cloud top at westerly point and 18,000 ft (–20˚C).
0235-0244	Westbound at 18,000 ft to 46˚54'/124˚07' (B ← A)
0248-0256	Eastbound, climbing from 18,000 to 21000 ft, to 46˚54'/123˚21' (B → A). –28˚ at 21,000 ft.
RAINBAND #2	
0306-0313	Head west at 21,000 ft to 46˚54'/124˚22' to Rainband #2.
0313-0402	Spiral down at 300 ft/min from 21,000 ft in Rainband #2. From 21,000 to 19,000 ft at fixed geographical location (46˚54'/124˚22'). Then from 19,000 to 3,000 ft drift to north with wind, until over coastline north of North BINET radar dish. Descend from 13,000 to 10,000 ft on coastline. Then moved west to allow descent to 2,000 ft.
0405	Start climb to east for return to Paine Field.
OLYMPIC MOUNTAIN TRANSECT	
	Passed over crest of Olympics (at ~9,000-10,000 ft) on return flight to Paine Field. Encountered considerable precipitation (Rainband #1?).
0440	Land Paine Field.
0445	Engines off.

(k) University of Washington Flight 1856 (1-2 February 2001)

Period of Flight (UTC): 2224-0333

Accomplishments of Flight:

Measurements from 1,000 to 21,000 ft in pre-frontal rainband in dual-Doppler area. Landed at Hoquiam in heavy rain.

Instrument Problems:

Poor images on SPEC CPI.

Flight Scientist: Peter Hobbs

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
2224	Engines on.
2245	Take off.
2245-2249	Climb to 8,000 ft.
2249-2315	Transit to Westport at 9,800 ft.
2315	Over S-Pol radar at Westport.
2315-0000	Westport → 46˚22'/126˚10' at 1,000 ft.
0006-0018	46˚22'/126˚10' to 48˚34'/125˚40'. Climbing steadily from 1,000 to 3,200 ft.
0018-0025	Spiral up to8˚34'/125˚40' to 6,700 ft (–2˚C).
0028-0047	Head southwest at 6,700 ft to 46˚20'/126˚20'.
0047-0058	Head northeast from 46˚20'/126˚20' to 46˚30'/125˚48'. Climbing steadily from 6,700 to 9,500 ft (–6˚C).
0059-0111	Head southwest at 9,500 ft.
0112-0123	Head northeast to 46˚34'/125˚20'. Climbing steadily from 9,500 to 12,500 ft (–9˚C).
0127-0135	Head southwest to 46˚30'/125˚45' at 12,500 ft.
0137-0145	Head northeast to 46˚40'/125˚07' climbing steadily to 15,000 ft.
0148-0155	Head southwest at 15,000 ft (–13˚C) to 46˚34'/125˚27'.
0200-0213	Head northeast to 46˚47'/124˚37' climbing to 18,000 ft (–18˚C).
0213-0222	Head southwest at 18,000 ft to 46˚40'/125˚00'.
0225-0232	Head northeast to 46˚50'/124˚25' climbing steadily to 21,000 ft (–24˚C).
0235-0247	Head southwest at 21,000 ft to 46˚40'/125˚00'.
0247-0307	Head northeast descending at ~1,500 ft/min to end up at low level over Westport.
0330	Land at Hoquiam (heavy rain).
0333	Engines off.

(l) University of Washington Flight 1857 (1 February 2001)

Period of Flight (UTC): 0449-0556

Accomplishments of Flight:

Return flight to Paine Field. Good measurements on west side of Olympics in rainband studied in UW Flight 1856.

Instrument Problems:

Some SPEC CPI dropouts.

Flight Scientist: Peter Hobbs

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
0449	Engines on.
0500	Take off from Hoquiam.
0514	Over Humptulips. Humptulips to Protection Island. Land Paine Field.
0556	Engines off.

(m) University of Washington Flight 1858 (8 February 2001)

Period of Flight (UTC): 0153-0655

Accomplishments of Flight:

Measurements in rainband associated with occluded front.

Instrument Problems:

Some SPEC HVPS dropouts.

Flight Scientist: Peter Hobbs

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
0153	Engines on.
0205	Take off. Ferry—instruments okay.
0234	Begin low-level leg. Initially 4,000 ft → 2,000 ft.
0252	Windshift and precipitation (heavy) onset.

0305	End of low-level.
0308	Start of 3,000 ft run (climbed to 3,500 ft early).
0327	End of 3,000-3,500 ft.
0329	Start of slow ascent 3,500→5,500 ft.
0342	End of ascent 3,500→5,500 ft.
0343	Start of 5,500 ft.
0400	End of 5,500 ft.
0403	Start of 5,500→7,500 ft ramp.
0415	End of 5,500→7,500 ft ramp.
0419	Start of 7,500 ft.
0435	End of 7,500 ft.
0437	Start of 7,500-9,500 ft.
0452	End of 7,500-9,500 ft.
0455	Start of 9,500 ft.
0510	End of 9,500 ft.
0513	Start of 9,500-11,500 ft.
0527	End of 9,500-11,500 ft.
0531	Start of 11,500 ft.
0535	Begin climb at 200 ft/min (as part of eastbound run).
0545	End.
0549	Start of 13,500 ft.
0557	End.
0601	True air speed malfunction.
0602	Start of 16,500 ft.
0610	End of 16,500 ft.
0648	Touch down.
0655	Engines off.

(n) University of Washington Flight 1859 (10 February 2001)

Period of Flight (UTC): 1430-2005

Accomplishments of Flight:

Measurements from 2,000-20,000 ft in wide cold-frontal (?) rainband.

Instrument Problems:

Electrical discharge to aircraft at 1703 UTC caused permanent failure of Johnson-Williams LW meter and temporary failure of SPEC CPI.

Flight Scientist: Peter Hobbs

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
1430	Engines on.
1437	Take off from Paine Field.
1437-1447	Climb to 9,500 ft (–14˚C) (FL at 2,200 ft).
1500-1507	Descend to 2,000 ft near Washington coast.
1507-1540	Head to west point (47˚10'/125˚56') at 2,000 ft. Some precipitation.
1540-1543	Turn at west point.
1543-1612	Head east at –2˚C level in cloud. Turn back west to 47˚11'/125˚37', climb to 4,500 ft.
1617-1633	Head west at 4,500 ft (–6˚C).
1633-1636	Turn.
1636-1642	Head east, climbing to 6,500 ft.
1642-1645	Turn.
1645-1654	Head west at 6,500 ft (–8˚C).
1654-1656	Turn.
1656-1708	Head east climbing to 8,500 ft.
170310	Electrical discharge from aircraft. Lost CPI temporarily and J-W permanently.
1708	Turn at easterly point.
1710-1720	Head west at 8,500 ft. (–13˚C).
1720-1723	Turn.
1723-1731	Head east climbing to 10,500 ft.
1731-1732	Turn.
1732-1739	Head west at 10,500 ft (–16˚C).
1739-1749	Turn and head east climbing to 13,500 ft (–22˚C).
1749-1750	Turn at easterly point.
1750-1759	Head west at 13,500 ft.
1800	Turn.
1802-1809	Head east climbing to 16,500 ft.
1809-1817	Head west at 16,500 ft (–30˚C).
1817-1819	Turn.
1819-1824	Head east climbing to 19,500 ft (–38˚C). Breaking out of top of band clouds to east.
1824-1826 (?)	Turn.
1826 (?)-1834?	Head west at 19,500 ft.
1834 (?)	Turn and climb.
1942-1903	Head east to Westport at 20,700 ft (–40˚C).
1905-1945	Spiral descent on coast at 500 ft/min then 1,000 ft/min to 2,000 ft <u>ahead</u> of rainband but in "interesting precip" (S-Pol operator).
~2000	Land at Hoquiam.

(o) University of Washington Flight 1860 (10-11 February 2001)

Period of Flight (UTC): 2148-0225

Accomplishments of Flight:

Continued to sample same (almost stationary) rainband as on Flight 1859.

Instrument Problems:

Some poor images on SPEC CPI. Could not switch 35 GHz radar from up to down at low temperatures.

Flight Scientist: Peter Hobbs

Approximate UTC Time (Local time = UTC – 8 hours)	Activity
2148	Engines on.
2153	Take off from Hoquiam.
2153-2213	Head west to 47˚15'/125˚02' at 7,000 ft.
2215-2232	Head east at 1,500 ft (1˚C).
2233	Turn at easterly point.
2134-?	Head west climbing at 300 ft/min to 3,500 ft too47˚15'/125˚02'.
?-2258	Head east at 3,500 ft (–2.5˚C).
2300-?	Head west climbing to 5,500 ft.
2310	Turn.
2313-2327	Head east at 5,500 ft (–6˚C).
2327-2329	Turn.
2330-2341	Head west climbing to 8,500 ft.
2341	Turn.
2345-2358	Head east at 8,500 ft (–12˚C).
2358-0002	Turn.
0002-0013	Head west climbing to 10,500 ft.
0014-0016	Turn.
0017-0026	Head east at 10,500 ft. (–15˚C).
0026-0029	Turn.
0030-0039	Head west climbing to 13,500 ft.
0040-0055	Headed south to (wrong) coordinate from radar. Returned to original west point location.
0056-0108	Head east at 13,500 ft (–22˚C). Cirrus fallstreaks.
0108-0111	Turn.

0111-0121	Head west climbing to 16,500 ft (–29˚C).
0122-0139	Sampled cirrus near westerly point at 18,000 ft (–33˚C). This cirrus was seeding lower cloud earlier in flight but had drifted to north.
0139	Head back to Paine Field.
0222	Land at Paine Field.
0225	Engines off.

*5.2. Transcriptions of In-Flight Summaries**

(a) University of Washington Flight 1846 (4 January 2001)

No summary given on tape.

(b) University of Washington Flight 1847 (7-8 January 2001)

PH: I'm going to give a short summary here. This was a pretty good case according to the radar people, synoptic situation and so on. It was a warm front. One of the situations we're interested in. We crossed the warm front several times. We got into some precip. In the early part of the flight, we climbed up to about 21,000 ft. In the later part of the flight, we went down to our lowest level, which is our present level of 2,000 ft. So all that worked out fairly well. Unfortunately, the PMS 2-D cloud probe did not work. The PMS 1-DC was not on board. We didn't have the CPI. On the good side, however, the HVPS should have provided some data, and the FSSP and the liquid water meters. So that's my summary of this flight. Anyone else want to summarize? Art?

AR: I'll just say that the radar worked real well as far as we could tell except in the downward direction there is some question whether we were looking at all the precip that was below us, but in the upward direction it looked fabulous. So I think we should be pretty pleased about that.

PH: But the radar wasn't recorded.

AR: It wasn't recorded, but at least there are some verbal notes here and there. Back to the black glove technique as far as aircraft measurements. Other than that, the system we flew through you could see on the satellite imagery. They were northwest to southeast-banded structures coming around a large cyclone whose main center was in the Gulf of Alaska. A secondary center developing off southern Oregon and that actually caused some problems

* Speakers: AR = Art Rangno, DL = David Laskin, DS = Don Spurgeon, EC = Eric Cooper (pilot), EG = Eric Grimit, GG = Grant Gray, JR = Jerry Rhode (pilot), JS = Justin Sharp, KM = Ken McMillen (pilot), LS = Larry Sutherland (pilot), MG = Matt Garvert, MS = Mark Stoelinga, NB = Nick Bond, PH = Peter Hobbs, SR = Stan Rose, TW = Tom Wilson, ZS = Zan Sutherland (pilot)

for us because as it redeveloped down to the south this particular band approaching the Washington coast was weakening. We past through a couple of bands on the way out that had really mutated to nothing more than altostratus with virga. Then our main frontal system that we sampled I thought we did a pretty job of centering that pretty well. Either the whole thing or one of the main bands with that warm front because at each end of the turnaround points the moon came out or at least was visible. The moon was not visible through the middle of our track, which is a pretty good indication that we under flew the thickest clouds anyway. The lack of liquid water generally, with the exception of that at the frontal surface around 7,000 ft, was kind of indicative of weak synoptic lifting in this whole thing. As a result we didn't see big aggregates, big ice crystals, rimming, or big clumpy ice crystals associated with rimming and that sort of thing. So it was kind of an inert system, which would produce very, very light precipitation when it makes landfall. That's for sure. Let's see. Can I think of anything else? We sampled at a couple of interesting temperature levels, –21˚, –22˚. We looked for plates and short columns and that kind of thing. Then our next pass after that highest pass was at the bottom of the dendritic temperature zone looking for change of crystal types and contributions of fragmentation and crystal growth in the dendritic and stellar regions, but of course they're difficult to make out with the HVPS. Then we flew again around 10,000 ft, which happened to be near the peak of the rimming/splintering process. There wasn't any liquid water there and, of course, we didn't see any evidence of splinters being produced. But the time that we had out here, we had a pretty good sampling strategy, I think, by targeting those temperatures because those are temperatures of interest in the cloud microstructure for these models. Then, of course, wrapping it up with the lower legs where we might have had a seeder-feeder type cloud. In fact, we did have one kind of a frontal over running stratocumulus that had liquid water up to half a gram, which is pretty significant. But that was the only place we really saw liquid water was in that stratocumulus layer that we transected at 7,000 ft. I think we touched a little bit maybe at 5,000 ft. Off four flow generally today and that was represented by the lower clouds around 2,000 ft having humungous droplet concentrations for a maritime environment. The highest I saw was over 500/cc, whereas in the meantime our droplet concentrations in the over running maritime cloud were in the 10s per cc. So with our FSSP looking real good and getting some measurements there, we're looking at kind of a continental maritime interaction in the seeder-feeder area of the storm. I guess that's about it. I'm getting too windy.

8:16 PM

PH: Do the engineers have anything they want to add to the tape recording? Tom?

TW: Nope.

PH: Do you want to say anything about the HVPS?

TW: It looks like it was working. A lot of times it gets precipitation on the lens and then it cross-triggers and overloads for a period of time. That usually happened when the plane was climbing or descending. So nothing you can do about that. Like right now it's doing it.

PH: It's doing its job.

8:19 PM

PH: Grant, do you want to put anything on the tape for summary?

GG: I basically just did. The noise problem with the PVM turned out partly at least to be a ground that has come loose or something. We got around that. Otherwise most everything was working okay except that we don't have the 1-D and the 2-D, but we'll have to work on that. It appears with the radar that we're getting some decent signals looking upward. Looking downward it appears we do get some signal through because we can see the ground, however, the precipitation, which we should see when we're in the middle of a cloud, doesn't show up. So I suspect that we have something attenuating the signal. It might be the antenna. It could be something beyond the wave-guides switch. It has to be beyond the switch because we're getting good response out of the upward looking antenna. We'll have recording capability within a week on the radar also. I can't think of anything else pertinent right now.

PH: Have you fixed the PVM now because there's still noise coming in?

GG: Well there's occasional noise, but it's much reduced over what it was. Earlier it was just painting the whole screen on the strip charts. Let me go take a look over here.

8:20 PM

GG: Well, I guess we've had quite a few noise spikes on it. Maybe we're not out of the woods yet.

PH: Yes and on the J-W as well.

GG: The J-W has been really acting up this trip.

8:21 PM

(c) University of Washington Flight 1848 (9 January 2001)

No summary given on tape.

(d) University of Washington Flight 1849 (9-10 January 2001)

AR: I was going to squeeze in a little summary here but on the record of what worked and what didn't work and a few weather words. Nick, it's kind of a tradition on the flight to say what you thought of it in a paragraph or so.

NB: So Art, do you want me to do one too?

AR: Yes. Peter will be looking for it. If you want to start out and say how you thought the flight went in general, what essentially we did, how many legs and so forth if you have that there. If you don't, we're pretty close to landing.

NB: I don't know exactly how many legs we did. I could count them up. Yes, I'm willing to do it. So why don't you go ahead and let me know when you're done.

AR: Okay. Today's flight we had two flight actually, one in a pre-frontal band. Well I'll let Nick cover that kind of stuff because I might get the jargon mixed up. Anyway I'll talk about what did work.

We had some improvement in our 1-D probe, which did not work in the last few flights. It was fixed by Don and maybe Grant. (crosstalk) …have good spectra the whole flight. So that filled an important gap in our precip spectra, the small end anyway. The HVPS was generally going through its periodic outages. They seemed to be particularly when we were changing elevations. So maybe temperature changes, pressure changes were altering some electronics in some way or condensation on the lens possibly when we were descending. It's hard to say, but most of the time it was good. We had good winds again. The temperature looked good. t-statr seemed to be solid most of the time. There was one period when we had some glitches and the temperatures were not accurate for maybe 5 to 10 min. Other than that I thought the liquid water measurements were good. The other thing we really lack is a CPI, which is being repaired, and the 2-DC, which has still got some tough problems to solve. They maybe intermittent or something. That's about it.

Cloud-wise the first system I'll mention was one in which we approached and had largely virga as we entered the precip. In the lower cloud was falling precip. Then as we got into it we sampled a few brief little cloudlets here and there, but generally it did not have significant liquid water.

In the second flight we were back in the richer liquid water content near the ground wind shift. We had water contents up to about 0.7 in some of the stratocumulus clouds around I think it was 5,000 ft. All these clouds did not extend much above 5,000 ft. At 7,000 ft we didn't hit nor did I see any top of that wind shift line forced heavier stratocumulus/cumulus mediocris line and, in fact, that was kind of tattered. It really wasn't in a good line, but in several clumps of clouds over maybe a 5 to 7-min period over which time the wind was shifting gradually. Not much in the way of temperature discontinuity either. The water on the bottom of the broad spectrum good for riming accretion, so it was doing it's part even if it wasn't much to add a little bit to the precip. Aloft mainly glaciated. We didn't see any embedded altocumulus that we sometimes see in the more active systems. Cloud tops were as a rule above 20,000 ft and they were glaciated.

I think that's about all I'm going to say. We're almost going to land anyway.

NB: Right. All I need to add to that is that there were a total of 7 legs flown on the first phase through the pre-frontal rainband probably associated with the cold front aloft. We had precip up to 17,000 ft on that one. The second one was a rainband probably associated with an occluded front and a wind shift at the surface. It had 9 legs in that one with precip up to 22,000 ft. That one it was either asking to see the cooler plumes of boundary layer moisture up to the 4,000 ft level but not up to the 7,000 ft level. So there was a lot at 4,000 ft. Quite a bit of horizontal gradients in liquid water content. So that will be something interesting to look at perhaps. For the Olympic transect, definitely precip on the windward side and very little on the leeward side and almost no turbulence to my surprise. That's all.

GG: This is Grant. I just wanted to add that our faithful little KA-band radar, which was working great yesterday and on our last flight, apparently suffered some damage maybe in a heavy landing or maybe there's water in the wave guide. But it gave a serious arc and we shut it down. So we need to trouble shoot that.

(e) University of Washington Flight 1850 (13 January 2001)

12:03 PM

PH: I'm going to start the summary. We've been working a fairly weak rainband but well defined on the radar. Initially situated fairly stationary southwest of the S-Pol radar. As the flight went on it moved a bit toward the northeast and ended up mainly between the radar and the north Binet site. It was well defined but weak rainband associated with an occluded system. I'm not quite sure whether it was a cold frontal rainband or warm frontal. But we worked it pretty well at many different levels, starting off at 4,000 ft, then 3,000, 5,000, 7,000, 9,000, 11,000, 13,000 15,000 and then 20,000 ft. Then at 23,000 ft as we went backward and forward between our southwesterly point, which was about 40 miles southwest of Westport. Our northeasterly point, which ended up being pretty much the same for all those legs, was the north Binet site where Battelle NW was also operating their microwave radiometer. The big news on this flight was that all our imagery was up most of the time. That was the CPI and the HVPS, as well as the 2-DC and 1-DC. That's the first IMPROVE IOP where all the things we really need were working. So that was very good work by Don, Grant and Tom to get all that finally up. We're now heading back. Art, do you want to jump in?

AR: Roger. The synoptic situation was a very weak low-pressure center located offshore of Astoria and light offshore flow and the trough moving into the coast was actually moving into the coast as an upper-level ridge was building along the coast. So it wasn't much of anything that's for sure. Our passes today, as far as the clouds go, are the first pass started out at about 4,000 ft. We dropped down to 3,000 ft to get into some clouds that along the coast had very minimal droplet cloud much like we have right now, scattered cumulus fractus, stratus fractus. Then as we penetrated further offshore as is the case now, we intercepted increasing amounts of stratocumulus that virtually reached our flight level at 3,000 to 4,000, 5,000 ft. In that we saw, I'm going to have to back up here a little bit. We intercepted a layer at about 4,000 to 6,000 ft that was located (this was on our first pass to the southwest I believe it was) in the Hallet-Mossop rimming-splintering zone at very, very low droplet concentrations in the 10s per cc. It was providing a target for the aggregates that were falling from the deep altostratus/nimbostratus layers piled up over this to apparently cause rimming and splintering. Not only did that occur, but in that –3˚ to –8˚ temperature zone, but there were also times when there was supercooled drizzle and supercooled small drizzle drops of the 100-micron variety. So that broad spectrum provided in that cloud provided an interesting aspect to precipitation development in this system, which otherwise would be on the minimal side. Above that layer, we intercepted no liquid water and it was all just a matter of depositional graupel as near as I could see on the crystal types. That continued up to the 20,000 ft level when then we saw that perhaps we could tweak cloud top level a little bit. Then there was a larger drop-off in size from the 20,000 to 23,000 ft level suggesting that that near cloud top region was an area for very rapid growth of ice crystals. Then, if my memory serves me right, a slower growth all the way down until that interesting interaction with the Hallet-Mossop stratus/stratocumulus cloud located I think it was 4,000 to 5,000 or 6,000 ft that we intercepted on one of our first legs in the southwest track.

PH: Art, let me interrupt you here. As we head back home, and as we climb through 6,000/7,000 ft just to the north of Westport radar, we're going through probably the strongest part of this rainband. We're getting good images on the 2-D and on the CPI. The rainband is actually strongest now over the land, as it has moved toward the northeast during the course of this flight. So the climb we're doing now up and over the Olympics should document the rainband as it moves over the land.

AR: I wanted to finish up by saying that there also are some embedded altocumulus clouds. We didn't actually sample them, but some can be seen off the right wing now up in that –25˚ to –35˚C temperature zone. We just didn't happen to hit any. The other thing our experience at cloud top was very reminiscent of what we saw in the Arctic kind of an amorphous fog-like cloud with crystals gradually diminishing in size with height. Then above that we have this very complicated structure of lowering and striations in an often completely separate cirrus cloud. That would have been located in the 25,000 to say 30,000-ft range. That would have been like fibratus and uncinus-types of cirrus.

12:11 PM

AR: Along with that I just remembered to mention the risings and the saddle, the humps and saddles, in the cloud top in these banded structures that we saw. That was in the lower amorphous fog-type ice cloud.

12:12 PM

PH: I just asked John at the S-Pol radar site to do an RHI out toward the northeast from the Westport radar since we're getting good measurements here as we head back home in that direction. Any more summaries from the engineers? Anyone want to say anything?

12:13 PM

AR: I can mention that the radar worked really well for the first time on the downward position.

GG: The radar had the antenna cross guided. That's why we weren't getting anything out at the bottom. Now it's operating well enough that we can actually see the airplane on the second return.

PH: So the radar is working well both looking upward and downward, but we're still not recording. Art's made some comments on the tape of what he's been seeing on the radar. You're going to draw those sketches of the cloudscape, Art.

AR: Right.

PH: Go ahead Grant. Any more?

GG: We also noticed in the ever none ending chase for this noise problem that when we got up to altitude around 20,000 to 23,000 ft all A-to-Ds, except for a couple that I think we know where the problem is back at the instrument, they all quieted down. So there's something very strange going on here. It can even be as odd as electrostatic discharge from the aircraft or something like that.

PH: Don, anything?

DS: Well, Art's probably already said it but all the probes that Grant and I worked on, the 2-DC, HVPS, CPI and 1-DC, and the radar all worked this flight.

PH: Does Tom have anything to say?

TW: Not really.

PH: As I said in my e-mail to you, now that we're much better off in terms of having things up at least for a while, the three of you can sort of trade off so that we only need two onboard probably.

TW: I do have a new map available that I'll probably put on for the next flight. It's a little cleaner than the last one. A little better colors than yellow and blue.

PH: Actually this map is pretty good. The only thing that I suggested on an earlier flight is that you extent it a bit further down toward the southwest.

TW: Yes. That's what this one does actually.

GG: Also, Tom, I'd just like to say that all your effort on the HVPS and the 2-D have really paid off. It's pretty darn clean.

DS: Yes. We're into the third or fourth rendition of the 2-D software as we eliminated hardware glitches and allowed Tom to eliminate software glitches.

TW: Yes. There's just a couple little blips left and I think we'll figure those out real soon.

PH: Something you could add to the 2-DC imagery is a digital readout of the concentration.

TW: Okay.

PH: The number of particles per liter would be a good number to have.

TW: Yes. I'll have to go over with Art on how to compute that.

PH: Okay. All the displays are looking good.

12:17 PM

PH: I think all the liquid water probes are okay except for the DMT as usual that's very noisy. We're not getting any signals. So it's just doing its noisy business.

(f) University of Washington Flight 1851 (18 January 2001)

NB: So this is Nick Bond, flight scientist, for the flight 1851 on 18 January. The weather was what we thought was a pre-cold frontal precipitation band. It turned out it had tops of something like 10,000-13,000 ft. In terms of the weather, it looked like it was about 5°-6°C at 3,000 ft with winds from 210 at 18 to 20 meters per second. Those were a bit stronger than prog. The winds at the top of our stack, which was at 13,000 ft, were from 170 to 180 at 30-33 meters per second. That was almost twice as strong as prog and not as much of a westerly component. That implies that wind profiling implies cold advection and I don't think the models really had this to any degree and that perhaps was why we didn't get quite as much synoptic life as anticipated and, therefore, maybe not as deep a precip band as we originally anticipated. Basically the instruments, the CPI worked very well. The 2-DC worked very well. There was a hiccup or two, but that's about it. The HVPS had a few problems at times, but was basically functioning itself. So it was a fairly complete data set on a run of the mill rainband with some corrugations to it, but certainly nothing that distinctive. Now I'll turn it over to Art.

AR: Roger. I thought the corrugations really fit this well because I was beginning to call this the slop flight because there are so many undulations, thickening and thinning of the clouds both aloft and in the number of bands that we did run into out there. For me, this was clearly the best of all the IMPROVE flights because we got to cloud top and we actually could see what was going on out there. But down low, I felt there was an extremely interesting feature. A bit of a puzzle right now because after trucking through the precip on the way out there, we dropped down into the boundary layer. As we hit the first area of liquid water, which was sustained for probably 5 to 10 kilometers, at least a good minute or so, the droplet concentrations offshore were phenomenal for the marine environment, 250/cm^3 pretty regularly and a couple up to 300/cm^3, which you just do not see. That's a dead give away that the flows that were due to offshore air. The fact that we were seeing liquid water contents of 0.5 g/m^3 and even a little greater at 2,700 ft indicated the cloud base must have been right on the deck in order to produce that much liquid water at 2,700 ft. So clearly it was being sucked up there for some reason and I thought I saw also at that level a temperature drop of about 2˚ to 3˚C over about a 1 to 3 min period. There was some question about whether that was a true frontal major. But clearly between that zone and further offshore, there was certainly an air mass contrast in terms of aerosol content because further out when we got into the subsequent series of bands (and there were at least two or three). But out there the droplet concentrations were more typical of long-fetch maritime air being in the 10s per cc and sometimes even in the low 10s in some of the altocumulus out there and also equally high liquid water. In fact even higher liquid water, at up around a gram per m^3 or so, between 0.5 and a gram, in some of the more active lift regions of the band. So that air was being lifted and any CCN was certainly activated by a pretty good updraft. So again it's a good sign that the difference was real and not due to different updraft velocities out there. That to me raises a question of where the front really was. Then going on these legs on up to 10,000-13,000 ft, there was a tremendous variation in the differences in the precip mechanisms going on in those clouds. At times we saw at the freezing level, supercool drizzle indicating an all-liquid process. At other times it was at lower temperatures. We saw in the Hallet-Mossop temperature zone, jillians of ice needles and columns possibly being produced in situ there by either well probably not crystals falling from higher levels in some areas, but certainly in other areas where the tops were actually a little colder. I don't think any crystals fell from the higher layer, but certainly when we did our last pass at 13,000 ft there were tops and some of the highest tops probably reached 15,000 ft actually I would say and probably were certainly no. I doubt they were any colder than –15˚C. So from the standpoint of precip and model ice, it's a very interesting case because of all the ice multiplication going on and the fact that the tops in these bands were, as you were pointing out, 10,000 to 13,000 to 15,000 ft maybe. But those temperatures were only maybe –5˚ to –15˚C for the overall tops considering the saddle areas and enhanced cloud tops. Just to emphasize that at no time out in those areas did I see any virga reaching the ground from the overlying altocumulus/altostratus and banded clouds above the clouds that we sampled. Over and out.

(g) University of Washington Flight 1852 (20 January 2001)

12:04 PM

AR: We got a computer outage for about 7 min causing us to repeat the leg at –6˚C. Lots of changes in time. We were flying a set ground pattern and it was clear that a lot of different microstructures past over that site on the different legs.

12:05 PM

AR: That's my summary.

AR: I will enhance my summary by saying that, of the different microstructures, we saw supercooled drizzle, rain produced by the collision coalescence process, ice multiplication, ice dropping from cold clouds into separate warmer clouds, and a lot of change in time, as I mentioned, as we flew over the same ground track.

12:08 PM

NB: This is Nick Bond, flight scientist for UW flight 1852, on 20 January 2001. The goals of this flight were to profile a rainband in an inverted trough or an occluded front north of a developing low-pressure center along a frontal boundary. The maneuvers included heading out to the Westport radar and then a low-level run to the southwest at 1,500 to 500 ft. We did not hit the surface wind shift, but did see a shift from south-southeasterly winds to perhaps south-southwesterly winds. After that low-level leg, we climbed above the freezing level to 6,000 ft and did a profile stack 6,000 ft, 7,500 ft, and 9,000 ft. We had a temporary breakdown of the data system and repeated the leg at 9,000 ft. Then finally the top point at 10,500 ft, which was near the cloud tops. Then we dropped back down heading to the southwest point again at 3,500 ft. We went down and investigated whether the wind shift was at the southwest end of our track at 500 ft and finally climbed to 6,000 ft before returning to Hoquiam. This track that we did was along the 240 radial out of the Westport radar. There was drizzle on the northeast end of the section that we were working and definitely rain on the southwest end. Again, it's going to be a somewhat complicated situation to investigate in that there were some multiple cloud decks. But for the most part, the instrumentation worked successfully. Now we're heading into Hoquiam and perhaps we'll do a flight right after this in the warm front of the developing low to the south. For what it's worth, the winds at low levels were considerably stronger than forecast by the MM5 in its 0 Z front from the day before.

(h) University of Washington Flight 1853 (20-21 January 2001)

AR: On this flight we flew southbound to intercept what was perceived as a east-west more or less oriented band and I'll concentrate from here on on the microstructure. We flew below cloud base. All we had at cloud base was a few ragged stratus fractus clouds, no real seeder-feeder going on until a little bit toward the middle of this band when we intercepted and flew under a bunch of heavier precip. It was almost coming from a soft or what I would sometimes call a soft cumulonimbus where there is embedded convection and there is kind of a rain shaft-look to the precip as you come up to it. A cumuliform-looking cloud base, dark cloud base, amid the sort of diffuse stratiform nimbostratus base and indeed when we went back northbound and intercepted that at 5,000 ft we entered a lot of liquid water and that was just above the freezing level, lots of large snowflakes, heavy precipitation. It was probably light to moderate precipitation down at the ground. Anyway moderate to even heavy snow aloft and probably the biggest flakes we've seen imaged by the HVPS. Then we continued to do legs after that, but because we were flying legs that were geographically anchored at that particular cell feature moved away and then the whole rest of the flight was simply what appeared to me to be unrimmed aggregates, single crystals fragments and so forth. These habit kind of mutated with the temperature. Lots of dendritic-type aggregates in the –15˚ I think it was or –17˚. Then just above that we started seeing bullet rosettes, which actually were crystals falling down from cirrus levels at the –30˚ and lower temperatures. Going along with that when we got to our highest flight level of 21,000 ft, the disc of the sun was not visible, which in the daytime means that that cloud is at least 2 kilometers above the aircraft and probably more like 3 kilometer. I'll just cut it right there.

NB: From the met side like Art said, it was a warm frontal perhaps a deformation zone rainband that we were flying through. What we did was the moving stack pattern oriented north-south. Our legs included a low-level leg at 1,000 ft and then the legs above the freezing level at 5.5, 7.5, 9.5, 12, 15, 18 and 21,000 ft. On the south side of that zone, the winds tended to be stronger from 200 at 15 to 20 meters per second or even a little higher. Quite a bit weaker winds on the north side of the band something like 6 or 10 meters per second and a little bit more of a westerly component. There was some noticeable turbulence on the north side of that band at a relatively abrupt shift in the winds. After doing that moving stack pattern we lined up for the Olympic transect from Humptulips to Protection Point and ran that at 10,000 ft. We had winds from 210 at roughly 12 meters per second initially speeding up to something like 16 or 18 meters per second just on the windward side or at the top of the terrain. Then weakening dramatically to something like 5 to 8 meters per second in the lee. There was pretty steady precip and both substantial cloud liquid points and supercooled liquid droplets along most of the way. There wasn't that noticeable of a clearing in the lee except for at low levels. Over.

AR: Grant, do you want to say anything about the radar.

GG: Yes. We finally got the digitizer card installed for the 35 GHz radar and we're using some rather crude software supplied by the vendor. We'll replace that with some QNX software later on so we can integrate the whole thing into our data system. We were recording some data upward and downward looking and various resolutions up to 5 MHz, usually at 1 MHz. It seemed to working fairly well. The digitizer by Gage does a superb job of digitizing. It's just a little difficult to control because it wasn't really built for this application. However, I'm sure we can work out the difficulties and it will work better in the future.

(i) University of Washington Flight 1854 (23 January 2001)

AR: I'll just say I thought this case turned out to be pretty decent case considering I was a little bit of a skeptic on whether it would hold together. But by golly, there was precip just offshore and it was a multi-layered quasi-steady state system, although it was very complicated. I say that because there were undulations in the tops of the altostratus cirroform top of the storm as evidenced by the sun dimming and brightening as we flew at constant levels. Then in the levels below 20,000 ft why we had at least four droplet cloud layers, these are the mid-level embedded altocumulus-like layers toward the southwest end, which provided possibly rimming targets. That's something that will have to be looked at in the data before to see if the ice crystals dropping down from the glaciated upper part of the storm actually did rim. But at least they were down there and if nothing else those droplet clouds were signposts for water supersaturation in this otherwise glaciated cloud mass. Which we can't always tell, as I should point out, what the degree of ice supersaturation is because our dew point measurements just do not work that well in precip and at low temperatures. But the intercept of droplet clouds is an absolute sign that you're at water saturation, of course, and an appropriate level of ice supersaturation depending on the temperature. So they are very important to know about in these precipitating systems from both the rimming standpoint and the other you're experiencing water saturation in all this stuff. So I thought it was a pretty neat day all in all with the quasi-steady state conditions and those droplet clouds out there embedded in this stuff.

NB: Just to summarize what we did. We flew an eight-level stack through a pre-frontal rainband. I believe it was probably a cold rather than an occluded front, but that remains to be seen. This eight-level stack was at the levels of 1,000, 5,500-6,000 and then 8,500, 11,500, 14,500, 17,500, 20,500 and finally 24,000 ft. The instrumentation largely worked pretty well except for the CPI, which on the legs below 11,500 ft was basically non-functional. One thing highly encouraging was that the cloud radar for the plane at least was grossly consistent with the reports from the S-Pol radar. Finally, regarding some of the meteorology, I saw a low-level convergence or the convergence seen not just at low levels, but up to as high as 11,500 ft. That was probably providing some of the lift for the liquid water clouds that Art just mentioned. Finally in comparing with the MM5 prog, the low-level winds were a bit stronger than prog, but otherwise the model seemed to have a pretty good handle on the overall flow. By way of comparing with previous flights at least the ones I've been on, we I believe were at the coldest temperatures where we were collecting ice crystal data of the program so far. At the 24,000 ft, we were at –37˚C approximately. Over.

AR: Grant, do you want to add anything about the radar or anything like that? He's not on the headset. Tom, do you want to say anything? He's on "chat." I think Tom was busy programming the whole flight.

NB: Yes. Grant's going to say something about his bailiwick here.

GG: We had a lot of trouble with the J-W. It seemed to be drifting badly in zero. One problem is that the zeroing potentiometer is shot. It's been zeroed right around that point for a long time. We need to replace it. Also, I noticed that when the de-ice was in auto position, where the light flickers a little bit, it seemed to put a lot of noise on the line. That propagates over into the J-W, so that maybe one of the noise sources on some of the instruments. The radar performed well except we ran out of disk space someplace along the way after 5,000 s of operation. Otherwise we do have data recorded.

1:36 PM

GG: I need to put in one more little remark here. We need the heat source for the radar antenna transfer switch because the thing freezes up when it gets down below about –10˚C.

(j) University of Washington Flight 1855 (28-29 January 2001)

PH: A brief summary of this IMPROVE flight. We worked two rainbands close into the coast and both I believe within the Dual Doppler area and both fairly nice moderate strength rainbands somewhat stronger than we've looked at previously.

The first rainband, which started off at 1,000 ft, and worked it going east-west climbing by 2,000 ft increments. Then with horizontal runs at each level moving in progressively in toward the radar site as the rainband moved eastward. Eventually ended up working the rainband from about the radar site to a point some 20 miles east of the radar site. We worked it from 1,000 ft up to 21,000 ft, which was near cloud top. There maybe some cirrus above.

Then the last part of the flight we went off the coast again to a location given to us by the radar to get into rainband #2. We did a spiral descent in rainband #2 from 21,000 ft down to 2,000 ft at 300 ft/min, so it should be a good set of measurements there.

Most of the instruments seemed to be working today as far as I could see except we had some problems with the CPI not getting us a nice clear background, but there maybe some usable data on there. That's about it.

I'll just add that this was supposedly a cold frontal situation, although it wasn't very clear from our measurements or apparently from the radar that there was a strong cold front there, but synoptically a cold front that was moving into the coast.

Art, do you have a summary?

AR: Right. I'm just guessing that we probably just didn't get all the way to the west side of it, but we must have been awfully darn close in that last pass partially judging from the turbulence point it picked up down there.

I'm going to start from the back here and I'm going to stick to the cloud microstructure in these two north-south oriented bands associated with what was termed a cold front. The last pass was marked by glaciated conditions at the highest point that we past, although there is some question about what was above us. There appeared to be some droplet cloud yet above 21,000 ft.

PH: Art, you're talking about the last pass in the first rainband, are you?

AR: Actually what I meant was the spiral in the last rainband that started with glaciated conditions at the top.

PH: What we're calling the second rainband.

AR: Right. In the last rainband that we sampled, the second one of the cold front, started with glaciated conditions at cloud top, but it appeared that there was still droplet cloud above us.

In that we circled down in that about 10 to 15 miles west of the coast. That structure was quite a bit different in there than we saw earlier, which I'll sort of back through it. Because of the lack of liquid water cloud in that downward spiral until we got down to right around 17,000 ft and down to about 14,500 ft, we had about a kilometer of liquid cloud. There was no liquid cloud again until about 6,800 ft and then it was liquid water all the way down pretty much to 2,000 ft. That was probably representing some orographic enhancement due to the nearness of the Olympic Mountains. In contrast, the first rainband (the one that was to the east of the rainband I just mentioned) had liquid water in the main part of the band. Pretty well from the bottom just over the cloud bases running just above 1,000 ft (our first pass level) all the way up through 21,000 ft, we were still getting indications of droplet clouds here and there in this particular cloud layer. They weren't contiguous layers, but more like embedded shin shallow layers and that from the liquid water content in these things rarely was it over a tenth of so indicating very thin embedded altocumulus-like clouds. At one point we were topping the storm as evidenced by the many stars and the moon while flying in altocumulus clouds. However, that was kind of a saddle region of the first band and rather temporary because most of the time ice crystals were falling from what was probably a cirroform layer in the 20,000 to 25,000 ft height range that I'm estimating from the radar depiction. So we had again the type of undulating tops, a saddle region marked by total liquid water and ice crystals falling in it and dropping out. Then other regions where the tops either merged together with an ice crystal fall out from the cirroform layer or rose up into that cirroform layer. It's kind of hard to tell at night here. Anyway a very interesting situation because of the great number of layers. I counted 11 separate altocumulus-like layers and stratocumulus down below those levels in this particular first rainband in the middle or west in the most intense region, the west end of the first rainband. I think I'll just end it right there. It's pretty long.

PH: Okay. Good Art. Do you just want to add a few sentences about what you saw on the radar?

AR: Roger. The radar was in the up position for most of the flight here trying to get a handle on the cloud tops and whether we cloud get to them or not. They did show pretty much what I was describing. They were near top anyway in terms of rising up toward the west end of this particular first rainband. Indicating that the tops were just barely above the flight level at the east end of the first rainband or at least in that saddle region. Actually at the very, very east end on our last pass the tops were up again. During the last rainband, or the second rainband, we had indicated glaciated tops that went up to probably over 25,000 ft at there deepest point. That would be about the point where we started our downward spiral.

AR: I was just going to finish up. As far as the crystal types go, we did see bullet rosettes falling from the temperatures below –20˚C indicating that the tops of those cirrus clouds were well below –30˚C. I think the lowest temperature we actually got to was –28˚C. The other thing that I thought was interesting was there were a lot of columns and needles in the usual Hallet-Mossop rimming-splintering zone, but in many occasions there didn't seem to be any liquid water at those levels that we were sampling. Even though there was liquid water in many, many locations, there were times when an awful lot of needles and columns were without liquid water indicating either that it had been dissipated or maybe the crystals were forming there as a result of ____ shards from colder regimes.

AR: And I could, of course, go on in the lower levels of the first pass. We did seem to intercept the stable layer essentially with some kind of over running type of phenomenon, warm frontal-type inversion or stable layer. There was a wind shift along with that from more south-southeast to south-southwest as we went through that. I believe that was at 6,000 ft.

8:19 PM

PH: Grant.

GG: Go ahead.

PH: Do you have anything for the tape by way of summary?

GG: Just about the radar. The radar worked fine during the entire operation. The one problem we had with this scheme is that it takes about a half an hour in the middle of the flight to get the data transferred out of the DOS partition and into the QNX partition so we can record more data. Hopefully, once we get into full QNX operation, we won't have that problem.

8:30 PM

AR: Another little piece of my summary that I meant to mention even as long as it was I left it out was the continentality of the low clouds in the first rainband. This is something that we've seen quite a few times the south-southwest wind being an offshore wind and finding those maritimey clouds out there not so maritime because of the offshore CCN continental aerosols that are being ingested into those low clouds. They were running something like 150 to 250/cc, which is about maybe three times above a normal background. We're starting to get some light turbulence here as we descend into Paine Field. So I'm going to get out of here and buckle up.

PH: Don, did you want to say anything about instrument problems?

DS: There was really not any serious instrument problems just fogging of optics. Particularly in this last bit we've gone up and down quite a bit.

(k) University of Washington Flight 1856 (1-2 February 2001)

6:44 PM

PH: I'm going to summarize this flight. It's been pretty straightforward. It's been a track through backward and forward, southwest to northeast, through a rainband ahead of a cold front offshore. We've been profiling it from 1,000 ft up to 21,000 ft stepping up in 3,000 ft increments with level tracks every 3,000 ft and then on the reverse track climbing 3,000 ft. We've been doing that for the whole flight. We're just at our final southwest point.

PH: Just doing our final leg for the northeast descending fairly rapidly to take us from 21,000 ft down to 1,000 ft over the radar. Then we'll heading into land. Art, do you want to do a summary?

AR: Sure. Microstructurally this wasn't as interesting as I thought it was going to be. No liquid water except for a little patch of embedded altocumulus up around 21,000 ft just a couple of minutes ago. Other than that, mostly unrimed aggregates all the way down to the level that we did see liquid water and that was around 7,000 ft. Both clouds were situated in an inversion layer of warm over running situation that the base of that was near the surface actually out there and then topped out around 6,000-7,000 ft as I recall. I note that over running inversion was crammed with stratocumulus clouds, liquid water contents up to 0.3-0.4 at the most and had a little bit of a cumuliform aspect to it. Then the only other liquid droplet clouds that we found were really kind of shred clouds at our most southwestern point. That was a little unusual because we've seen those low stratus fractus and stratocumulus clouds much more plentiful out in the area of the rain compared with today where those kind of clouds were restricted only to about the last 10 nautical miles maybe 20 nautical miles of our southwesterly first run at this prefrontal rainband. So that was a little different than the last band we sampled where there was lots of liquid water all the way up to the highest level flown also at 21,000 ft. That fits with a lot of the earlier studies that I think this group has done where these prefrontal bands are mostly glaciated in the regions ahead of the front and then if we do fly in that frontal band I would expect we'd see a lot more liquid water and a more interesting situation.

(l) University of Washington Flight 1857 (1 February 2001)

No summary on tape.

(m) University of Washington Flight 1858 (8 February 2001)

AR: I guess I'll just mention what I found interesting today. This band resembles some of the other bands that we've sampled that had the many embedded droplet layers. There must have been three or four above the flight level of 9,000 ft, most of which we did sample, and those were primarily located on the east side of the band. I won't go into all the details. The band itself seemed to be comprised of, at least where the highest cloud tops where, the glaciated core. I judge that from looking at the moon when we were in those deeper parts and all you could see were no sign of any droplet clouds between the aircraft and the moon. On the sides of this deeper cloud there were shelves of droplet clouds out there. The one of the other characteristics that we've seen before is the boundary layer cloud on the east side having very continental characteristics. I saw one droplet concentration in that heavier liquid water content region that sort of floated the main part of that frontal band there and having over 300/cc. That's as high as we've seen in any offshore cloud in this project so that really shows that that was the continental origin air that was feeding in. I think Nick talked about some substructure of that air feeding into the band out there that he could deduce from the winds. So I thought that was pretty interesting and that particularly east side high liquid water zone did extend up to about 9,000 ft, but we didn't hit it on every pass. We did miss it on one pass. Evidently some of the cellular structure was translating off to the north when we were flying our constant east to west route. I'll just finish up by saying that again we saw a tremendous complexity in the cloud microstructure from drizzle drops being observed at –15˚C. Some altocumulus clouds momentary in a saddle region of one of our legs. Drizzle drops down around the –3˚C level in shallow clouds down there that of themselves were precipitating needing no help from above. This was one of the liquid layers out in the east side of that the stratocumulus deck. Drizzling and then later apparently as the tops of that deepened up tremendous amounts of ice multiplication. Huge needle aggregates there and that was on our first pass on the way descending out and passing just west of Westport as we were about to begin our first leg. Again lots of ice multiplication here and there and then in other places of course the deeper of course the lower temperature crystals feeding into these lower clouds from those higher tops. So all in all pretty complicated for a band that's really kind of sitting there and fairly steady state, lots of complications in the cloud microstructure.

NB: Okay. Thanks. Just to summarize what we did on the flight, we went directly to the Westport radar and did a series of runs along a latitude line of 46'-54' due west from the Westport radar. It was sort of a modified "Z" pattern in the vertical, again 12 runs total. The first outbound started at 4,000 ft and then fairly quickly descend down to 2,000 ft. We were at temperatures of 1˚-2˚C at the west end of that leg. That was followed by the inbound leg at 3,500 ft and then a series of slow ramps and then level legs. So the next outbound was a ramp from 3,500 to 5,500 ft followed by a level leg at 5,500 ft. Then another outbound ramp from 5,500 ft to 7,500 ft followed by an inbound at 7,500 ft. A ramp at 7,500 ft to 9,500 ft followed by an inbound at 9,500 ft. Finally on our last outbound ramp at 9,500 ft to 11,500 ft, at that point, we were at the west part of the precip band. It was clear that there was some more echo above us, so on the inbound here we went at a ramp on that part from 11,500 ft to 13,500 ft and then finally the last two legs were level at 13,500 ft and 16,500 ft. These legs were approximately 35 nautical miles wide. The weather that we encountered this was probably an occluded front with a low-level wind shift of about 40˚ at the lowest few thousand feet and basically convergence up to about 7,000 ft or so with weak divergence above that. In the central eastern part of the band where the echo was stronger and the crystals were bigger and all that sort of good stuff, we could see up to about 7,500 ft. The signature of low-level boundary layer air being sort of ascending upward in a plume with enhanced easterly wind components in there. That kind of boundary layer plume also included a little bit of enhanced turbulence and then enhanced liquid with water contents. This whole flight was in very cold conditions. The freezing level something like around 2,000-3,000 ft. For example, at 700 mb, the temperature was –12˚C or so. All the instruments seemed to work very well through the entirety of the flight. One last thing though, getting back to the meteorology is that the band made very little progress toward the east. We had the impression, both from our measurements and from discussions with the radar, that it was getting eroded on its east edge. That there were fresh elements moving along the band from south to north that were kind of tended to replenish more on the west side or as kind of filling in on the west. So that's the summary of the flight.

(n) University of Washington Flight 1859 (10 February 2001)

PH: We've spent must of this flight looking at a wide cold frontal rainband. That's what we think it is. We've profiled it from about 1,000 ft up to 21,000 ft. We got pretty good measurements for most of the flight. At the end of the flight, we did a spiral down over the Westport radar, S-Pol radar, from 21,000 ft down to 2,000 ft. We're now heading into land at Hoquiam to refuel and prepare for a possible second flight. Art, summary. Someone put Art on the headset.

11:56 AM

PH: Art, do a quick summary.

AR: This rainband was almost like the last rainband and there were several now that kind of fit this pattern. All water confined to below about 7,000 ft. The substructure of this band was such that at the lowest level we detected I think it was three slight wind shifts and they were each one accompanied by enhanced stratocumulus/cumulus clouds that we under flew on the way out there. These areas had between them higher cloud bases with more like stratocumulus with the wind shifting being associated with lower cloud bases. After that pass we did our vertical increments and I'll let you describe those. The last liquid water we hit tended to be toward the east end where there was some heavy convection. We reached the peak of this project by exceeding 1 gram per cubic meter at one point and I think that might have even been in the area where we had that lightning strike. At that same time, we saw more graupel on this particular flight than any other flight. It was a little rougher at least in that one area than anything we've seen before. As far as the ice crystals above, say 10,000 ft it was just pretty much lineated growth that seemed to me in mottle size. I didn't see any rimed crystals above 10,000 ft. They were all dry looking aggregates or single crystals above that level. I think beginning around 12,000 ft we started to pick up the cirroform type crystal. Bullet rosettes were starting to show up here and there. Then, of course, as we got higher up to around 20,000 ft, mostly composed of bullet rosettes and plates and short columns.

PH: I should mention that there was a convective rainband that was closer into the shore while we were looking at the wide cold frontal rainband and we intercepted that on some of our easterly traverses. It was in that that we got discharged that knocked out the CPI for awhile. We got it back up again. Then we tended to try to keep clear of that rainband. Eventually that convective rainband merged with our wide cold frontal rainband as the flight went on.

(o) University of Washington Flight 1860 (10-11 February 2001)

5:48 PM

PH: I might as well give a quick summary here of this flight. After taking off from Hoquiam, we've been doing a profile through the same rainband that we worked earlier this morning. This rainband moving very slowly, almost stationary off the coast, about 40 miles wide. We profiled it from 2,000 ft up to 18,000 ft. The temperatures were –33˚C. Got good measurements. Microphysical measurements the main structural change was compared with this morning when the rainband had liquid water in and it was probably precipitating harder than it is this afternoon. So this afternoon we've be looking more at the aging-dying rainband, but still producing some showers on the ground no doubt.

5:52 PM

PH: Is Art on the headset?

GG: Not at the moment.

PH: I'll get him. Just passing over Hoquiam now heading northeast back to Seattle. There's no precip over the Olympics according to the radar so we're not doing the official Olympic Mountain transect, but of course we will be flying roughly on that transect anyway on the way back to Paine Field.

5:53 PM

AR: Peter, did you call?

PH: Do you want to do a quick summary of this flight?

AR: I was just checking the audiotape to make sure there was enough. Actually I did check with Grant and there is enough if I speak just a few words here.

This second flight was sampling essentially the same rainband. That rainband had a number of the same features at least in the lowest 2,000 ft and that is a large liquid water content on the east end. I think that it got over 0.5. That would be almost a gram and that occurring in high droplet concentration clouds. They're indicating a continental aerosol rising up to 3,000-5,000 ft levels.

PH: Art, I think that was the convective cloud that was moving in from the south and intercepting our rainband on the east side.

AR: Right and we had that again on the second flight. That is one little red cloud. We went through it twice as we turned around. I don't remember whether it was at the east end or the center, but I did notice that it did happen again much like we saw in the first flight where we had the lightning strike. It was kind of a separate cloud situation, high droplet concentrations, very high liquid water content and it was confined pretty much this time below 7,000 ft because I know we went through it at 8,000 ft and again I think at 5,000 ft on those level passes. It was a ramp pass I guess it was on one of them. Even at that it was much more chaotic than we saw on the first rainband. The first rainband being homogeneous pretty much all the way up above about 10,000 ft. That is was like flying in an ice fog with a little gradation in the thickness of that ice fog, not much structure to it. On the second rainband this afternoon, a lot of structure in the way of fall streaks from very complicated appearing cirrus that were impacting our various level runs. In fact, the rainband was topped by a particularly complicated cirrus band but actually drifted away from our lower sampling levels such as at 12 K. So we went back and tried to resample that cirrus at the higher level that would have been the radar had been pointed at crystals we sampled at 12 K, which I thought was a good thing to do. I guess that's about it. I won't say any more.

PH: Okay. Just note that it's the same rainband that we were looking at this morning. Does anyone else, either of the two students or the engineers, want to add something to the tape?

6:15 PM

GG: A little summary of the various problems. Most everything worked fine except that after the lightning strike we lost the J-W. It is putting out absolutely nothing and the CPI seems to have been affected somewhat. Maybe the heaters inside the interior temperature of the device was very low when we were at high altitude down below –20˚C. So that bears looking into. We had a few problems with the 2-D, but otherwise it behaved very well. I think we got some very good data.

PH: Did you mention the J-W?

GG: Yes I did. One other thing, the radar antenna transfer switch something has to be done about that if we are every to use the radar again because it utterly fails at low temperatures. I will not switch.
