# UNIVERSITY OF WASHINGTON FLIGHT SCENARIOS FOR THE CONVAIR-580 IN THE ARCTIC (15 MAY-26 JUNE 1998)*

Assembled

by

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# CONTENTS

## UNIVERSITY OF WASHINGTON FLIGHT SCENARIOS FOR THE CONVAIR-580 IN THE ARCTIC (15 MAY-26 JUNE 1998)

### GENERAL INFORMATION

The first field project for the University of Washington's (UW) new Convair-580 research aircraft will be in the Arctic. The aircraft will be based at Barrow, Alaska, in support of the FIRE Arctic Cloud Experiment (FIRE ACE) and SHEBA (**S**urface **H**eat **B**udget of the **A**rctic Ocean), with flying scheduled between 15 May through 26 June 1998.

The main research goals and tasks of the CARG are:

- To carry out coordinated flights beneath the NASA ER-2 aircraft for the purpose of providing in situ measurements of cloud microphysical structures and thicknesses simultaneously with remote sensing measurements from the ER-2. Of particular interest will be multi-cloud layer situations over highly reflecting ice surfaces (a scenario that provides a severe test for remote sensing of clouds).

- To obtain measurements of the absorption of solar radiation by layer clouds, using the Pilewskie (SSFR) radiometers and the CAR (for clouds thick enough to be in the "diffusion domain").

- To obtain measurements of surface spectral albedo and the bidirectional reflectance distribution function (BRDF) using the SSFR radiometers and the CAR.

- To explore radiative interactions between layer clouds (or highly reflecting surfaces) and overlying absorbing aerosol layers.

- To obtain statistical measurements of the microstructures of arctic stratus clouds over long path lengths (to test a number of hypotheses based on our previous measurements in the Arctic).

- To see whether anthropogenic pollutants (from either Barrow or long-range transport) affect the microstructures and radiative properties of arctic clouds.

- To do vertical profile flights over the SHEBA ship in the Beaufort Sea to provide in situ measurements (particularly of cloud-heights and cloud structural and radiation properties) for comparisons with the ground-based remote sensing measurements at those two sites. Also, surface albedo and BRDF measurements around the SHEBA ship.

  Similar profiles and measurements will be made over the ARM site at Barrow.

- To evaluate the utility of the new Gerber g-meter (for measuring optical scattering and extinction, the asymmetry parameter, and the back-to-forward scattering ratio for cloud and precipitation particles in clouds—including mixed phase clouds).

- To obtain measurements of organic and inorganic aerosols in non-cloudy and cloudy conditions, including vertical profiles over the ARM site at Barrow for "closure" studies with a ground-based sunphotometer at that site.

- To exploit the several new scanning modes of the CAR on the Convair-580.

The instrumentation aboard the Convair-580 for these studies is listed in Appendix 1.

## FLIGHT SCENARIOS

### Scenario 1: Coordinated Flights with ER-2

*Objective*

The Modis Airborne Simulator (MAS) aboard the ER-2 will be used to detect and differentiate between clouds, ice and snow, and perform cloud retrievals. Flying over the same scenes almost simultaneously with the ER-2, the Convair-580 will obtain in situ cloud microphysical measurements, surface BRDF measurements, and above-cloud BRDF measurements.

*Appropriate Weather Conditions*

Uniform stratus clouds over various types of ice surfaces.

*Preferred Locations for Measurements*

Barrow ARM site, SHEBA ship, and locations of opportunity.

*Flight Patterns*

(i) **For Cloud Mask Missions** (A "cloud mask" refers to a cloud obstructing a view of the Earth's surface from a satellite.)—see **Figure 1.**

The primary purpose of this mission is to map cloud scenes over green tundra, dark open ocean and bright snow/sea ice, with the ER-2 flying in coordination with Convair-580.

Figure 1 shows a plan view of the ER-2 flight tracks. The ER-2 will fly a racetrack pattern with flight legs eleven nautical miles apart, starting with AB and concluding with CD. The Convair-580 will fly a series of flight tracks in-cloud perpendicular to those of the ER-2 (i.e., U-V, W-X, Y-Z) within a smaller area inside the area covered by the ER-2. In this way, the Convair-580 will criss-cross beneath the ER-2 fly track. The Convair-580 will do vertical profile through cloud layer at designated locations.

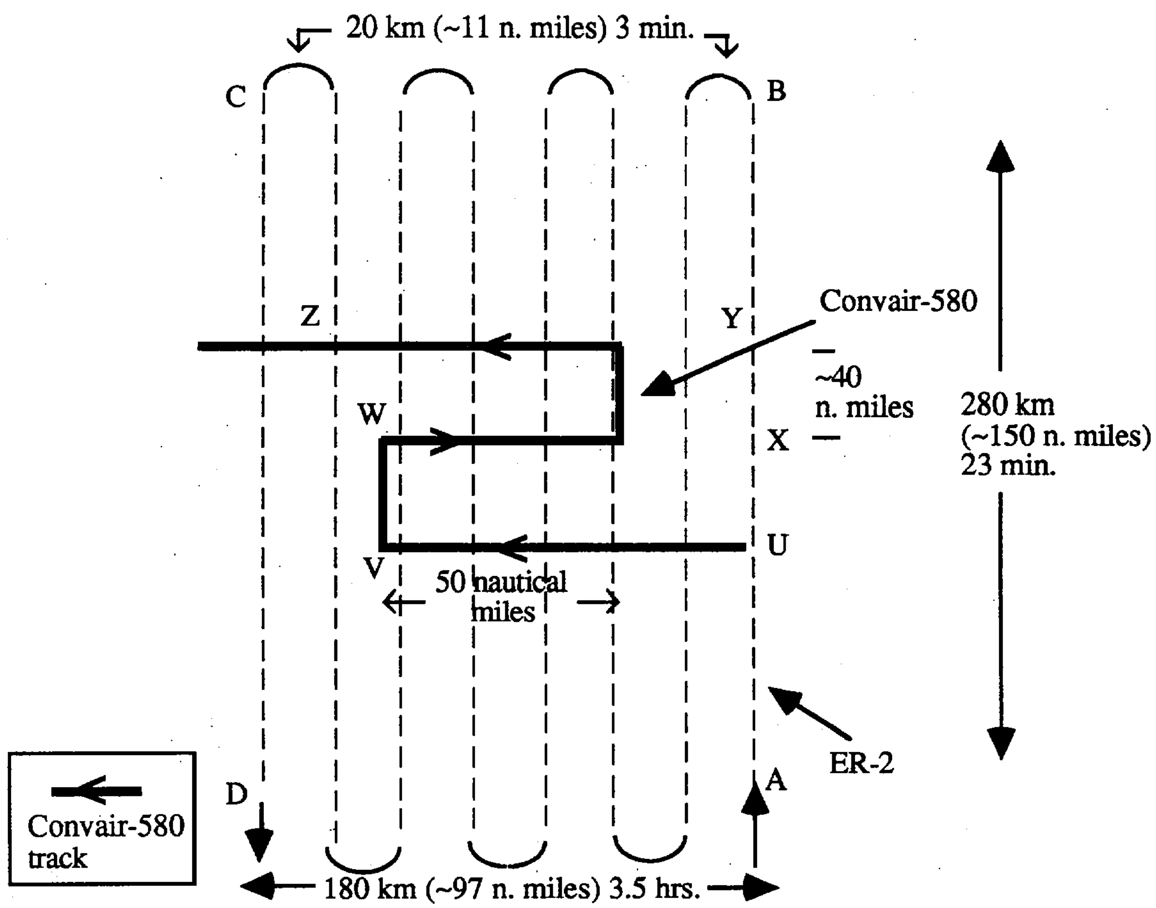


Figure 1. Plan View of ER-2 and Convair-580 Superimposed Flight Tracks for Scenario 1 (i) ("Cloud Mask" Missions).

**(ii) For Cloud Property Measurements (i.e., Cloud Optical Thickness and Cloud Droplet Effective Radius Measurements)—see Figure 2.**

Figure 2 shows the ground tracks of the ER-2 and Convair-580 for these measurements.

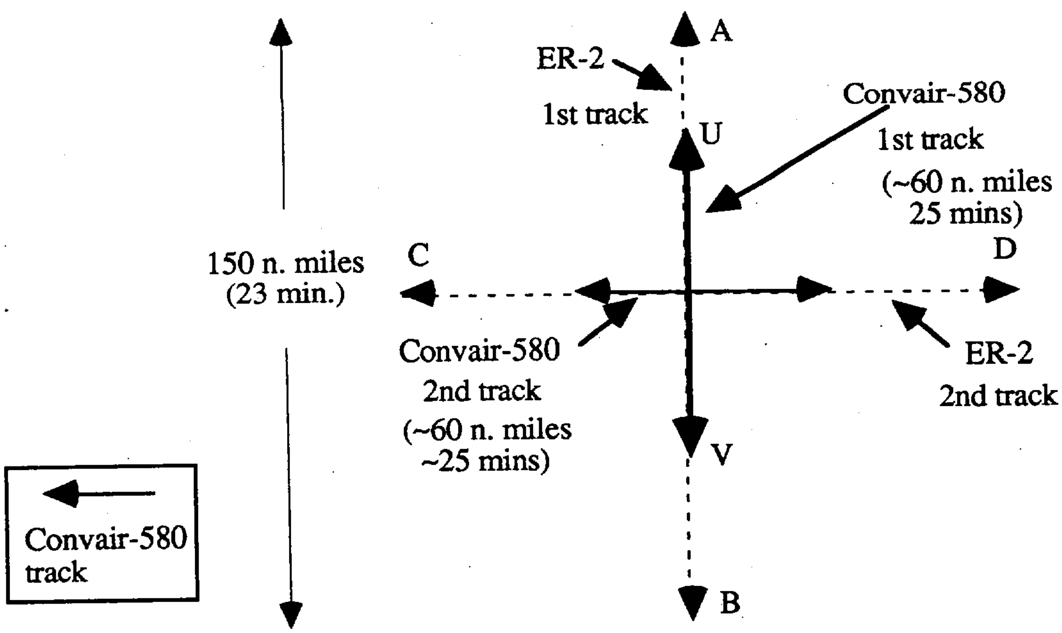


Figure 2. Plan View of ER-2 and Convair-580 Flight Tracks for Scenario 1 (ii) ("Cloud Property" Missions).

The ER-2 will fly four horizontal legs (A-B, B-A, A-B, B-A) each 280 km (150 miles) in length (Fig. 2). It will take the ER-2 about 23 mins. to complete one leg (A-B). Note that one of the ER-2 legs is normally along the solar principal plane and the other along the perpendicular direction.

The Convair-580 will fly co-located legs (U-V, V-U, U-V, V-U) beneath the ER-2. These legs will be about 60 nautical miles long (which will take 25 mins) and will be in cloud at about 1/3 of the cloud thickness below cloud top.

If the ER-2 flight tracks are repeated along CD, the Convair-580 tracks will be repeated along a half-length parallel track beneath the ER-2 (see Figure 2—"Convair-580, 2nd track").

In the above flights, the Convair-580 needs to obtain cloud microphysical data in vertical profiles and at selected heights (see **Figure 3**).

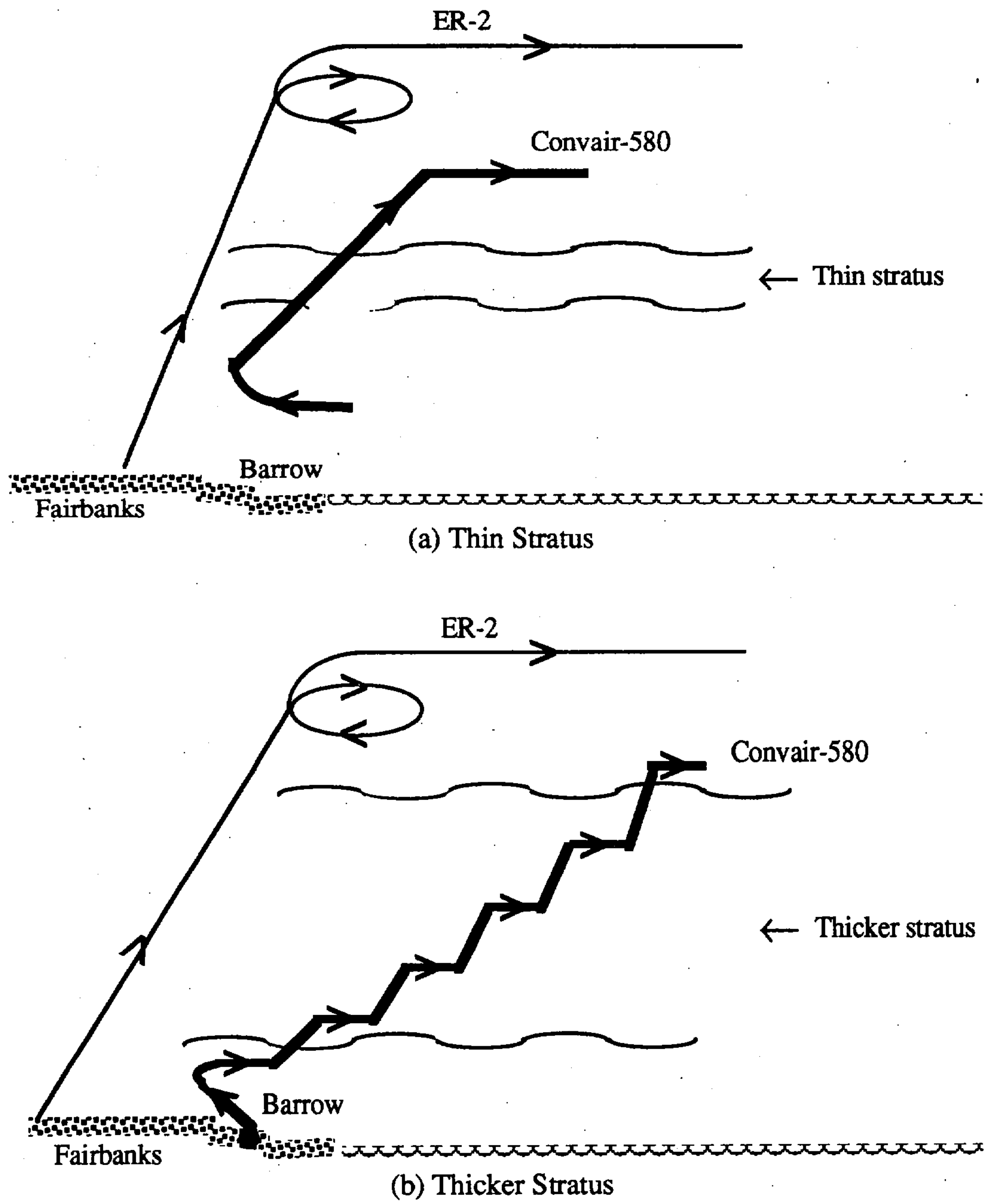


Figure 3. Vertical Profiles for Coordinated Convair-580 and ER-2 Flights for Scenario 1 (ii) ("Cloud Property Measurements").

**(iii) For Cloud Radiative Flux Divergence Measurements with SSFR.** The Convair-580 underflies cloud layer in level legs under ER-2 and closely aligned in space and time with ER-2. The flight legs of the Convair-580 beneath the ER-2 should be at least 10 nautical miles long. Also, can be done as part of (i) or (ii) above.

If time permits, use same flight plan as for Scenario 2 (i) below.

*Primary Instruments*

1. Cloud microphysics (including CPI and g-meter)
2. SSFR radiometers
3. Pressure altitude

## Scenario 2: Absorption of Solar Radiation by Clouds

*Objective*

To measure absorption of solar radiation by layer clouds.

*Appropriate Weather Conditions*

Fairly uniform layer cloud (preferably liquid water, but also mixed-phase clouds) with clear sky above.

*Preferred Locations for Measurements*

ARM site at Barrow, SHEBA ship, regions of opportunity.

*Approach*

**(i) Use of SSFR (See Figure 4)**

1. Fly horizontal leg (AB) (~20 nautical miles long, or ~7 mins.) through center of cloud for cloud microphysical measurements.

2. Fly horizontal parallel leg (CD) just below cloud base, for SSFR measurements.

3. Climb just above cloud top, and fly third horizontal parallel leg (EF) just above cloud top, for SSFR measurements.

4. Fly final horizontal parallel leg through center of cloud (GH), for cloud microphysical measurements.

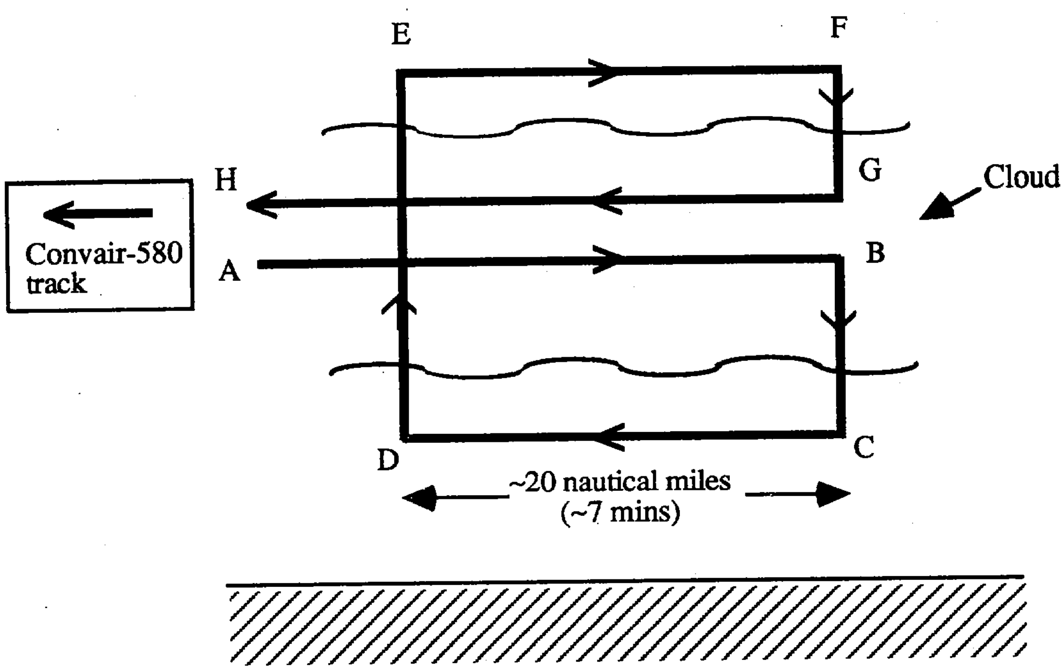


Figure 4. Scenario 2 (i): Measurement of Absorption of Solar Radiation by Clouds Using SSFR. (Aircraft advects with wind so as to sample approximately the same cloud region on each horizontal leg.)

NOTES: 1) Aircraft advects with wind so that approximately the same cloud volume is sampled on each horizontal leg.

2) If cloud conditions are changing rapidly, flight legs can be reduced to 10 nautical miles in length.

3) Ideally done with ER-2 flying above Convair-580.

**(ii) Using CAR (See Figure 5)**

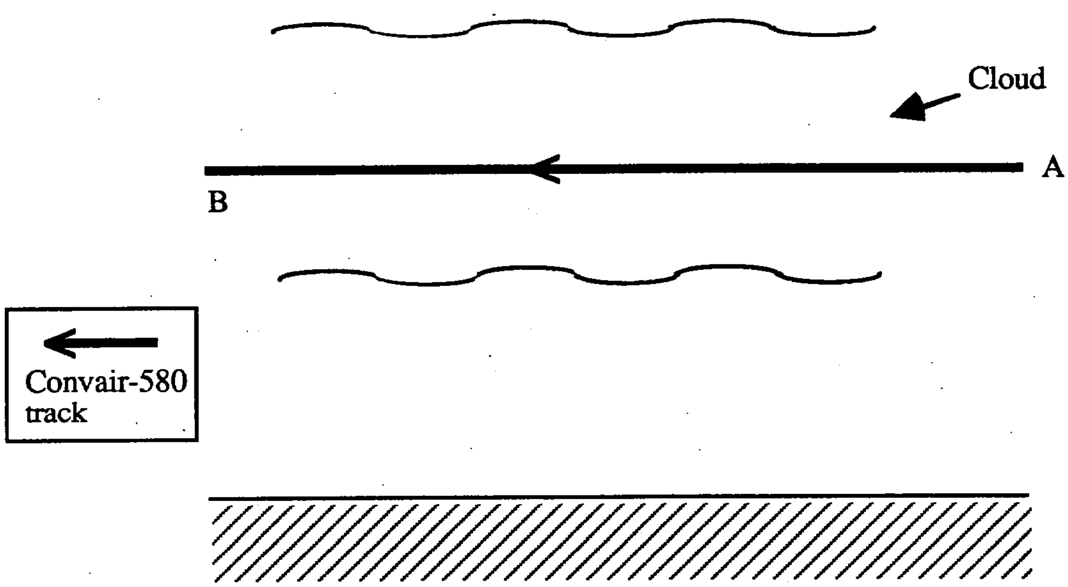


Figure 5. Scenario 2 (ii): Measurements of Absorption of Solar Radiation by Clouds Using the CAR (cloud must be thick enough that AB is in diffusion domain).

For this purpose the cloud layer has to be thick enough to be in the diffusion domain (i.e., when flying horizontally near center of cloud layer, neither the sun's disk nor the ground can be seen).

Fly horizontally through center of cloud in diffusion domain (AB), CAR is operated scanning from zenith to nadir (Position 2 for CAR).

NOTE:
1) This can be done either as a separate task or, preferably, as part of legs AB and GH in Figure 4.
2) The diffusion domain may be difficult to find in arctic stratus. Therefore, do not spend much time looking for it.

*Primary Instruments*

1. SSFR
2. CAR
3. Cloud microphysics
4. UW radiometers
5. Aerosol

## Scenario 3: Measurements of Spectral Albedo and BRDF

*Objective*

To measure the spectral albedo and BRDF of various ice surfaces (tundra, open ocean, sea ice of vary stages, snow, melting ice, refrozen ice) and of cloud decks (stratus up to cirrus).

*Appropriate Weather Conditions*

Either clear sky, with various sun angles, or completely cloudy (diffuse lighting).

*Preferred Location for Measurements*

ARM site at Barrow, SHEBA ship, regions of opportunity.

*Approach*

**(i) Use of SSFR for Spectral Albedo Measurements.**

In clear-sky conditions, and with upward- and downward-pointing SSFR radiometers operating, fly straight and level leg, ~10 nautical miles long, above designated ground scene.

In cloudy conditions, fly a straight and level leg, about 10 nautical miles long, above cloud.

**(ii) Use of CAR for BRDF Measurements (see Figure 6).**

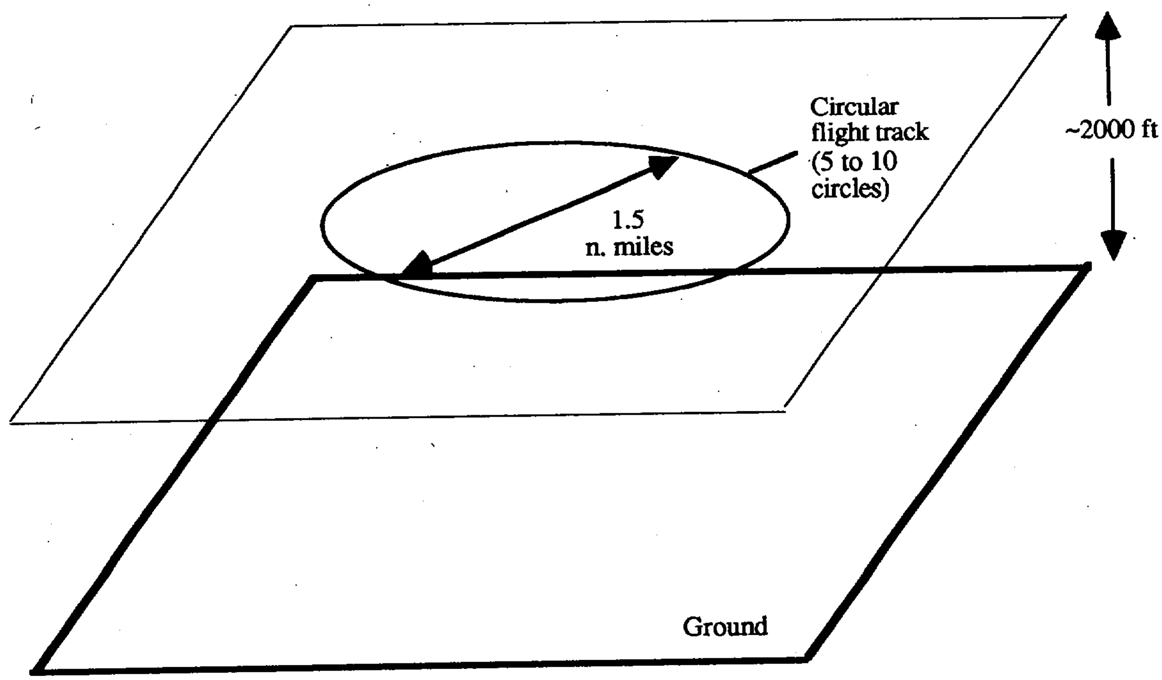


Figure 6. Use of CAR for BRDF Measurements (Scenario 3 (ii)).

The Convair-580 will fly about 2000 ft above the designated ground scene in a circular orbit about 1.5 nautical miles in diameter (each orbit will take about 1 1/2 mins at an aircraft speed of 175 knots). Do 5-10 such circles.

Also, do same flight patterns above cloud layers, to get BRDF of cloud (**cirrus are of particular interest**).

NOTE: This is the same as the "old" BRDF flight pattern with aircraft banked 20° to the right. However, with the new CAR in "Position 3" (20 degree bank angle scanning) it can measure both upward and downward radiation simultaneously. Therefore, there is now no need to circle with aircraft banked 20° to the left, as we did in the past.

*Primary Instruments*

(i) SSFR

(ii) CAR

## Scenario 4: Radiation Interactions Between Layer Clouds (or Highly Reflecting Surfaces) and Overlying Absorbing Aerosol Layers ("Aerosol-Cloud Shading" Effect)

*Objective*

To see if absorbing aerosol layers lying above highly reflecting clouds (or reflecting surfaces) significantly lower effective cloud (or surface) albedo.

*Appropriate Weather Conditions*

Extensive low or middle level cloud deck with an overlying aerosol layer.

NOTE: "Aerosol-Cloud Shading" effect is greatest with *low sun angles*.

*Preferred Locations for Measurements*

Anywhere

*Flight Pattern* (see **Figure 7**)

Measure cloud structure and define properties of aerosol layer (leg AB). Obtain upward and downward measurements of solar radiances with SSFR flying above the aerosol layer (BC) and then between aerosol layer and cloud layer (leg DE).

If there is a hole in cloud, continue measurements in this region (legs FG and HI).

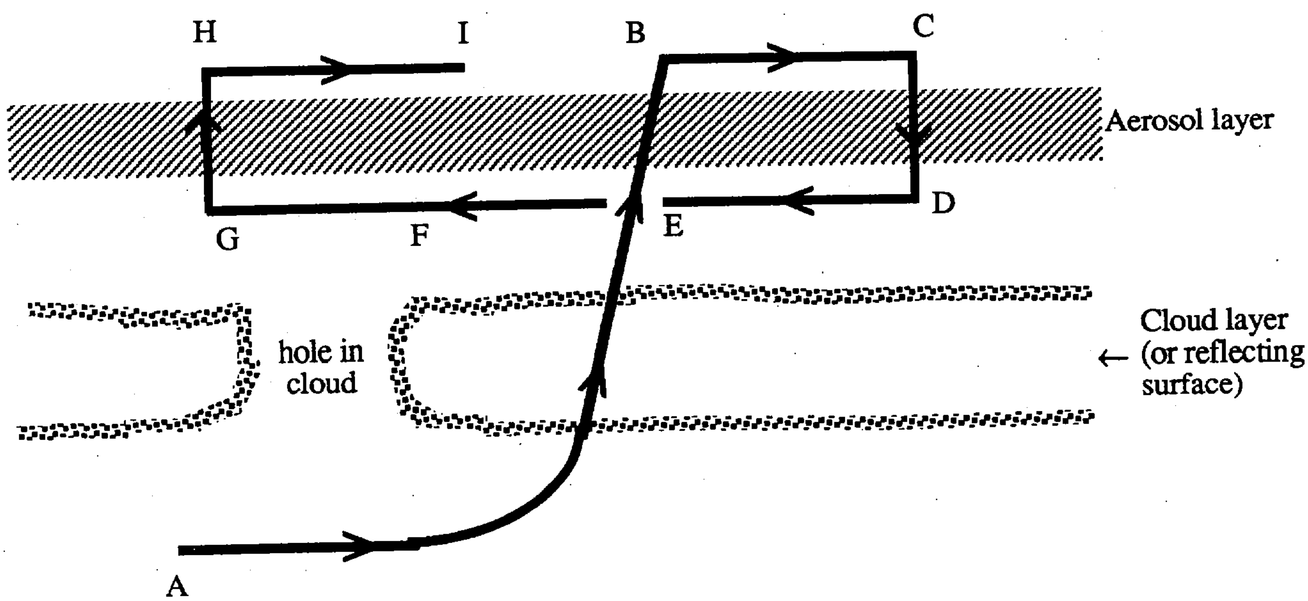


Figure 7. Flight Pattern for Scenario 4 ("Aerosol-Cloud Shading" Effect)

*Primary Instruments*

1. SSFR
2. Aerosol
3. Cloud microphysics

### Scenario 5: Statistical Measurements of Cloud Microstructures

*Objective*

To collect enough data to investigate in a statistical manner the spatial and temporal variabilities in cloud liquid water content, drop size distributions, ice content, asymmetry parameter, effective radius, etc.

*Appropriate Weather Conditions*

Layered clouds (all water, all ice, or mixed phase).

*Preferred Locations for the Measurements*

No restrictions.

*Approach* (See **Figure 8.**)

1. Vertical profile through depth of cloud layer (AB).

2. Drop down *below* cloud top to about *1/3* of cloud depth. Fly a horizontal path *in cloud* at this level (CD) for ~27 mins. (or ~80 nautical miles at 175 knots).

3. Drop down to middle of cloud layer. Fly another horizontal path in cloud at this level (EF) for ~27 mins. (80 nautical miles).

4. Drop down to a height of about 1/3 above cloud base. Fly third horizontal leg in cloud at this level (GH) for about 27 mins. (~80 nautical miles).

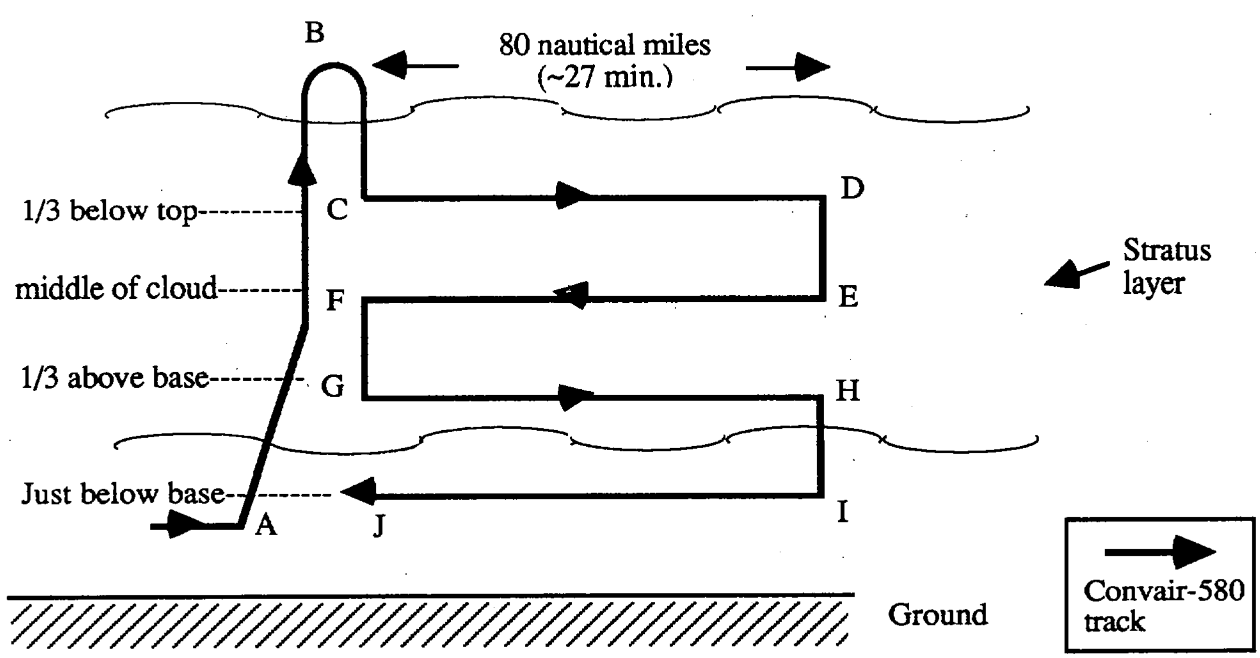


Figure 8. Vertical Cross-Section of Convair-580 tracks for Scenario 5.

5. Drop down just below cloud base. Fly fourth horizontal leg in clear air for about 27 mins. (~80 nautical miles) (and obtain aerosol measurements).

*Primary Instruments*

1. All cloud microphysical measurements (at maximum data collection frequency)
2. Radiometers.
3. Aerosol instruments.

## Scenario 6: Effects of Pollutants from Barrow on Cloud Properties

*Objective*

To document effects of pollutants from Barrow on cloud microstructures and radiative properties.

*Appropriate Weather Conditions*

Uniform stratus clouds over Barrow and surrounding area.

*Preferred Locations for Measurements*

Barrow and vicinity.

*Flight Patterns (***see Figure 9***)*

1. Leg AB: Flight beneath cloud base to see if plume from Barrow can be identified (e.g., in CN count or nephelometer, or radiometer measurements). Also get SSFR measurements.
2. If so, fly in cloud to measure microstructure (leg CD).
3. Fly just above cloud top (EF) to get SSFR measurements.

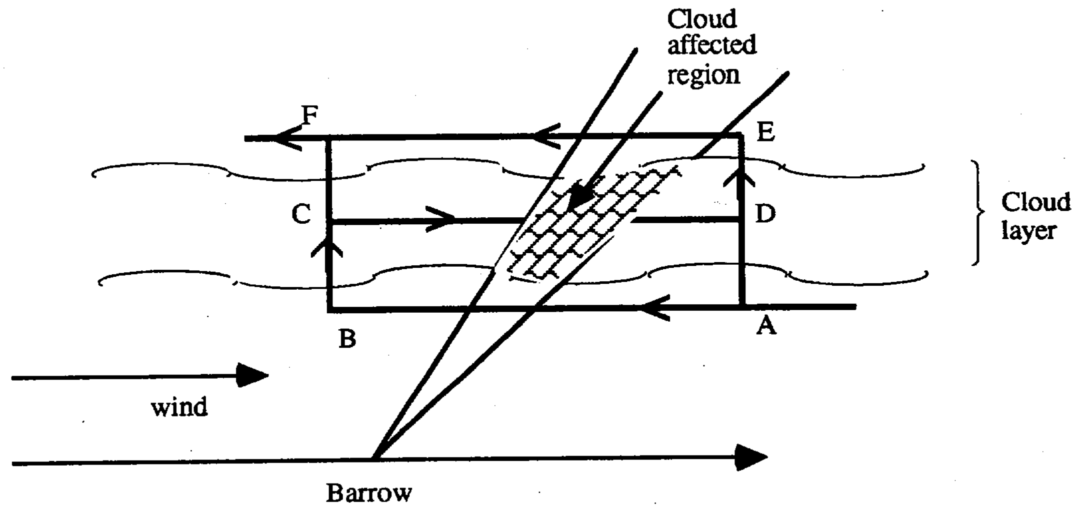


Figure 9. To Investigate Whether Emissions from Barrow Affect Cloud Properties—Scenario 6. (Note: Flight paths are fixed relative to Barrow.)

*Primary Instruments*

1. Aerosol and trace gases
2. Cloud microphysics
3. SSFR, CAR, and broadband radiometers

### Scenario 7: Flights to SHEBA Ship in Beaufort Sea

*Objective*

To obtain in situ column measurements of clouds, aerosols, radiation, etc. for comparison with in situ and remote sensing measurements from SHEBA ship and with ER-2 remote sensing measurements from above. Also, to obtain spectral albedo and BRDF measurements over various surfaces around ship location.

*Appropriate Weather Conditions*

1. Cloud layer over SHEBA ship.
2. Clear sky (or completely cloudy) for albedo and BRDF measurements.

*Preferred Location for Measurements*

Over SHEBA ship.

*Flight Pattern* (**See Figure 10**)

1. Transit to SHEBA ship at about 23,000 ft (sample cloud on route whenever possible.
2. If cloud layers exist, obtain microstructural measurements in vertical profiles over ship (for comparisons with 35 GHz radar measurements from ship).

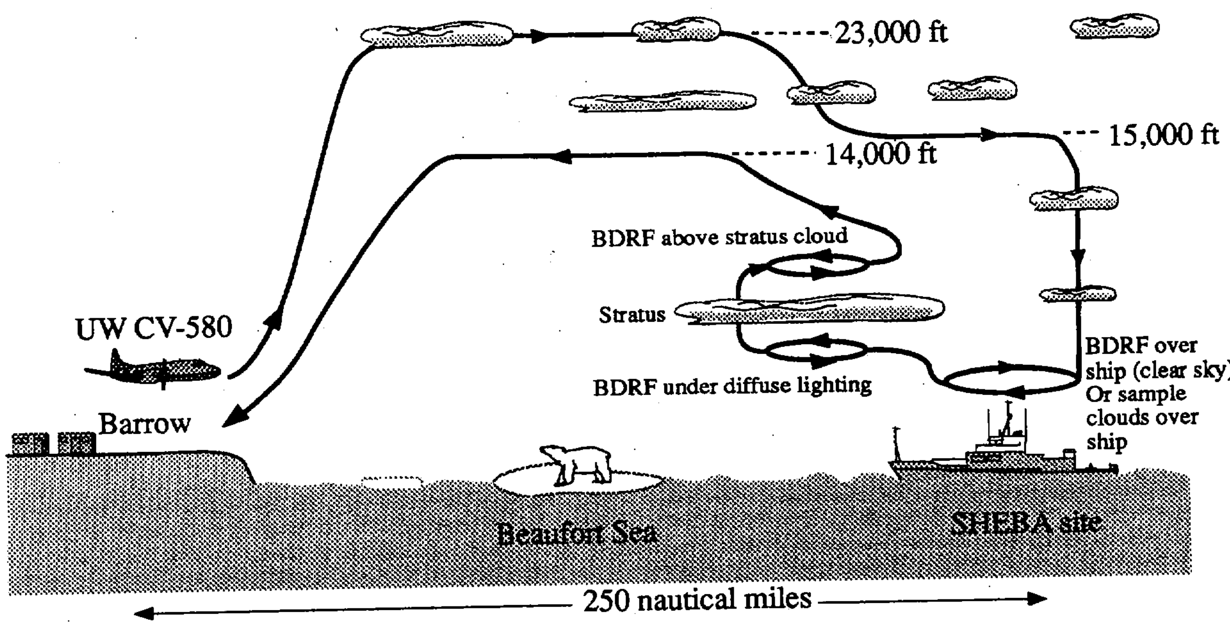


Figure 10. Proposed UW CV-580 Flight Pattern.

<u>Assumptions:</u> (a) SHEBA site is ~250 nautical miles from Barrow or less

(b) Fuel reserve available for Prudoe Bay

(c) Time from T/O to 15000 ft over Ship = 68 minutes

(d) Time from leaving 8000 ft over Ship to landing = 66 minutes

(e) Total research time over Ship = 3.8 hours

3. Descend (through cloud if possible) to ~2000 ft above designated ice surfaces around SHEBA ship. If clear sky (or completely cloudy—with diffuse illumination) obtain albedo and BRDF measurements of surfaces using SSFR and CAR (see Scenario 3). **Take good photographs of surfaces studied (and document on voice recording).**
4. Climb to 23,000 ft over ship (through cloud if possible).
5. Return to Barrow (penetrating clouds whenever possible).

NOTES: 1) Under appropriate conditions, and if time permits, any one of Scenarios 2, 3, and 4 could be carried out over SHEBA ship.

2) During the first four weeks of the project, flights to the SHEBA ship will be at discretion of the UW Flight Scientist.

3) **During the last thirteen days of the project (June 14-June 16), two flights per week (for at least four flights total) should be made to SHEBA ship. These flights should be spread out as evenly as possible over the thirteen days. Albedo and BRDF measurements are of top priority for these four flights. Therefore, clear sky conditions are preferred. If clouds are present over ship, sample them also (see Figure 10).**

## Scenario 8: Use of Gerber g-Meter

*Objective*

To obtain measurements of optical parameters of clouds (all phases).

*Appropriate Weather Conditions*

Cloudy.

*Preferred Locations for Measurements*

Anywhere.

*Flight Patterns*

Any flights in-cloud (Figs. 4, 5, 7, 8, 9, 10 are possible situations).

*Primary Instruments*

1. Gerber g-meter
2. Full cloud microphysics
3. Radiometers

NOTES: 1) Particularly important to run g-meter in Scenarios 2 and 6.

**Scenario 9: Aerosol Measurements**

*Objective*

(i) Vertical profile of aerosols over ARM site at Barrow in clear air.

(ii) To obtain vertical distribution of organic and inorganic aerosol in cloudy and non-cloudy conditions.

(iii) Data on "arctic haze" events (from long-range transport).

*Appropriate Weather Conditions*

See above.

*Preferred Locations for Measurements*

For objective (i): over sunphotometer at ARM site, Barrow.

For objectives (ii) and (iii): anywhere, but preferably over ARM site at Barrow or SHEBA ship preferred.

*Flight Patterns*

**(i) For Objective (i) (see Figure 11).**

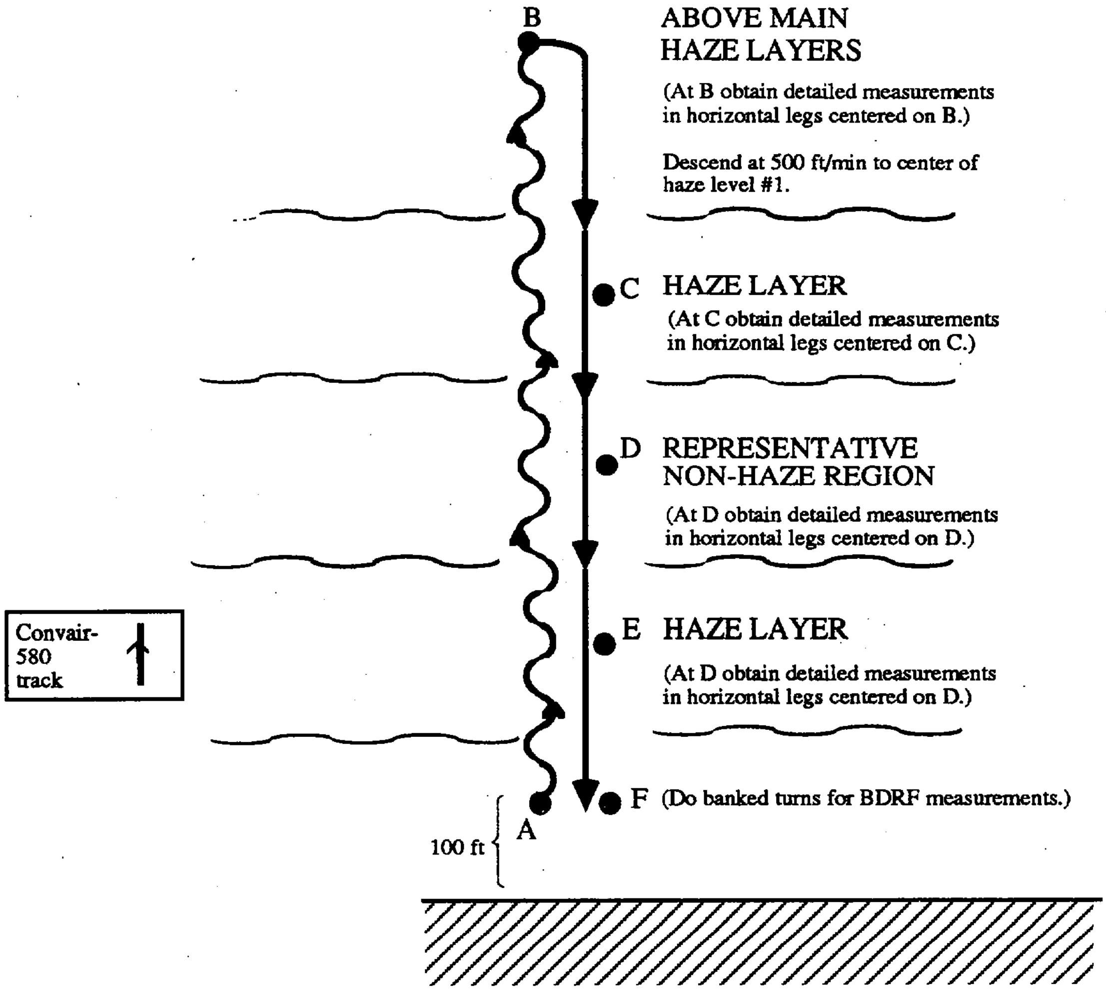


Figure 11. Convair-580 Flight Pattern for Aerosol Vertical Profile Measurements Over Arctic Site at Barrow (Scenario 9 (i)).

**(ii) For Objective (ii).**

For clear-sky conditions the same flight pattern as that shown in Figure 11 (but over a different location—e.g., Beaufort Sea). Take bag samples and filters (at three of the horizontal legs (C, D, E...) to characterize vertical profile.

For cloudy conditions the flight pattern is shown in Figure 12. Bag samples are taken at the levels between cloud layers.

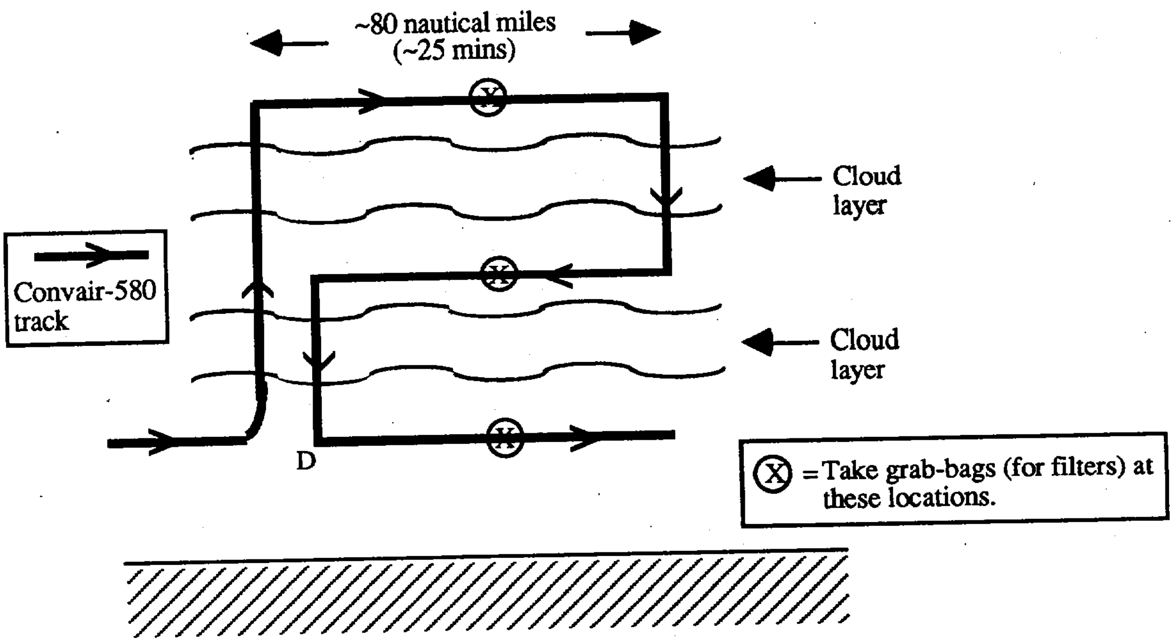


Figure 12. Aerosol Sampling Under Cloudy Conditions (Scenario 9 (ii)).

**(iii) For Objective iii.**

If "arctic haze" layers are encountered, sample their aerosol and chemical structure intensively. Also, (for comparison) characterize aerosols outside of the "arctic haze" layer.

*Primary Instruments*

1. Aerosol
2. Bag house
3. Filters
4. Trace gases

## Scenario 10: New Scanning Modes for the CAR

The CAR now has the following scanning modes:

0 = CAR moving from one position to another

1 = CAR scanning from port to starboard through nadir (i.e., downward)

2 = CAR scanning from zenith to nadir on starboard (i.e., right) side of aircraft (for diffusion domain measurements)

3 = CAR in position for BRDF measurements (aircraft flies in circles banked at 20° to the right)

4 = CAR scanning from port to starboard through zenith (i.e., upward).

### Scanning Mode 1 ("Downwards")

*Objective*

This is for general purpose remote sensing and radiometric intercomparisons between the MAS on the ER-2 and the CAR on the Convair-580.

*Weather Conditions*

Clear-sky or clear above stratus cloud deck.

*Preferred Locations*

Our sea ice with leads or above stratus cloud deck.

*Flight Patterns* (see **Figures 1, 2 and leg EF in Figure 4 and leg EF in Figure 9**)

Convair-580 flies straight and horizontal tracks (beneath ER-2) at a preferred height of about 10,000 ft above surface or above cloud.

*Primary Instruments*

1. CAR
2. Cloud physics (for measurements on clouds that are scanned)

NOTE: When in transit with cloud deck below aircraft, put CAR in this scanning mode 1 ("downward").

### Scanning Mode 2 ("Diffusion Domain")

See **Scenario 2 (ii)** and **Figure 5**. (Low priority.)

### Scanning Mode 3 ("BRDF")

See **Scenario 3 (ii)** and **Figure 6**. (High priority.)

### Scanning Mode 4 ("Upwards")

*Objective*

Image underside of stratus cloud layer.

*Weather Conditions*

Uniform layer cloud.

*Preferred Locations*

Anywhere.

*Flight Pattern*

Straight and horizontal legs just beneath cloud base (e.g., leg CD in Figure 4, leg IJ in Figure 8 and leg AB in Figure 9).

Sample cloud structure.

Repeat straight and horizontal legs beneath cloud base.

NOTE: When in transit with cloud layer above aircraft, put CAR in this scanning mode 4 ("upwards).

## D.3. INSTRUMENTATION ABOARD THE UNIVERSITY OF WASHINGTON'S CONVAIR-580 AIRCRAFT FOR FIRE-III

### (a) Navigational and Flight Characteristics

| Parameter | Instrument Type | Manufacturer | Range (and error) |
|---|---|---|---|
| Latitude and longitude, ground speed and horizontal winds | Global positioning system | Bendix/King KLN900 | Global |
| True airspeed | Variable capacitance | Rosemount Model 831 BA | 0 to 250 m $s^{-1}$ (<0.2%) |
| Heading | Gyrocompass | King KCS-55A | 0 to 360° (± 1°) |
| Pressure | Variable capacitance | Rosemount Model 830 BA | 150 to 1100 mb (<0.2%) |
| Altitude above terrain | Radar altimeter | Bendix Model ALA 51A | |
| Pitch and Roll | Differential GPS | Trimble TANS/Vector GPS Attitude System | 0 to 360° (±0.15°) |

(Cont.)

### (b) General Meteorological

| Parameter | Instrument Type | Manufacturer | Range (and error) |
|---|---|---|---|
| Total air temperature | Platinum wire resistance | Rosemount Model 102CY2CG and 414 L Bridge | –60 to 40°C (< 0.1°C) |
| Static air temperature | Reverse-flow thermometer | In-house | –60 to 40°C (< 0.5°C) |
| Dew point | Cooled-mirror dew point | Cambridge System Model TH73-244 | –40 to 40°C (< 1°C) |
| Absolute humidity | IR optical hygrometer | Ophir Corp. Model IR-2000 | 0 to 10 g $m^{-3}$ (~ 5%) |
| Air turbulence | RMS pressure variation | Meteorology Research, Inc. Model 1120 | 0 to 10 $cm^{2/3}$ $s^{-1}$ (<10%) |
| UV hemispheric radiation, one upward, one downward | Diffuser, filter photo-cell (0.295 to 0.390 μm) | Eppley Lab. Inc. Model 14042 | 0 to 70 W $m^{-2}$ (± 3 W $m^{-2}$) |
| VIS-NIR hemispheric radiation (one downward and one upward viewing) | Eppley thermopile (0.3 to 3 μm) | Eppley Lab. Inc. Model PSP | 0 to 1400 W $m^{-2}$ (± 10 W $m^{-2}$) |
| Surface radiative temperature | IR radiometer 1.5° FOV (8 to 14 μm) | Omega Engineering 053701 | -50° to 1000°C ± 0.8% of reading |
| Video image | Forward-looking camera and time code | Sony Hi8 camera | SVHS tape |

(Cont.)

## (c) Aerosol

| Parameter | Instrument Type | Manufacturer | Range (and error) |
|---|---|---|---|
| Number concentration of particles | Condensation particle counter | TSI Model 3760 | $10^{-2}$ to $10^{4}$ $cm^{-3}$ (> 0.02 µm) |
| Size spectrum of particles | Forward light-scattering | Particle Measuring Systems Model FSSP-300 | 0.3 to 20 µm (30 channels) |
| Size spectrum of particles | 35 to 120° light-scattering | Particle Measuring Systems Model PCASP-100X | 0.12 to 3.0 µm (15 channels) |
| Size spectrum of particles | 90° light-scattering | Particle Measuring Systems Model LAS-200 | 0.5 to 11 µm (15 channels) |
| Size spectrum of particles | Forward light-scattering | Particle Measuring Systems Model FSSP-100 | 2 to 47 µm (15 channels) |
| Size spectrum of particles | Differential Mobility Particle Sizing Spectrometer (DMPS) | TSI, modified in-house | 0.01 to 0.6 µm (21 channels) |
| Light-scattering coefficient | Integrating 3-wavelength nephelometer with backscatter shutter | MS Electron | $1.0 \times 10^{-7}$ $m^{-1}$ to $1.0 \times 10^{-3}$ $m^{-1}$ for 550 and 700 nm channels, $2.0 \times 10^{-7}$ $m^{-1}$ to $1.0 \times 10^{-3}$ $m^{-1}$ for 450 nm channel |

(Cont.)

## (c) Aerosol (continued)

| Parameter | Instrument Type | Manufacturer | Range (and error) |
|---|---|---|---|
| Light-scattering coefficient (for bag-house) | Integrating nephelometer | Radiance Research | $1.0 \times 10^{-6}$ m$^{-1}$ to $2.0 \times 10^{-4}$ m$^{-1}$ or $1.0 \times 10^{-6}$ m$^{-1}$ to $1.0 \times 10^{-3}$ m$^{-1}$ |
| Light absorption and graphitic carbon | Particle soot/absorption photometer | Radiance Research | Absorption coefficient: $10^{-7}$ to $10^{-2}$ m$^{-1}$; Carbon: 0.1 μg m$^{-3}$ to 10 mg m$^{-3}$ (± 5%) |
| Graphitic and/or Organic Carbon | Quartz filters Thermal optical technique | Lawrence Berkely Lab. (T. Novakov)* | 4 to 160 μg m$^{-3}$ (± 1.6 μg m$^{-3}$) for 1 m$^{3}$ sample |
| Humidification factor for aerosol light-scattering | Scanning humidigraph | In house (designed and built for UW by Mark Rood) | $b_{sp}$ (RH) for 30% ≤ RH ≤ 85% |

(Cont.)

* Guest instrument (uncertain)

## (d) Cloud Physics

| Parameter | Instrument Type | Manufacturer | Range (and error) |
|---|---|---|---|
| Cloud and precipitation particle images | Digital holographic camera* | SPEC, Inc. Model CPI-230 | 5 μm to 3 mm |
| Size spectrum cloud particles | Forward light-scattering | Particle Measuring Systems FSSP-100 | 2 to 47 μm (15 channels) |
| Size spectrum of cloud and precipitation particles | Diode occultation | Particle Measuring Systems OAP-200X (1D-C) | 20 to 310 μm (15 channels) |
| Images of precipitation particles | Diode imaging | Particle Measuring Systems OAP-2D-C | Resolution 25 μm |
| Liquid water content | Hot wire resistance | Johnson-Williams | 0 to 2 or 0 to 6 g $m^{-3}$ |
| Liquid water content | Hot wire resistance | King/PMS | 0 to 5 g $m^{-3}$ |
| Liquid water content; particle surface area; effective droplet radius | Optical sensor | Gerber Scientific Inc. PVM-100A | 0.001-10 g $m^{-3}$; 5-10,000 $cm^2$ $m^{-3}$; 2-70 μm |
| Optical scattering/extinction coefficients at 630 nm, asymmetry parameter, and back-to-forward scattering ratio for cloud and precipitation drops and ice particles | g-meter | Gerber Scientific, Inc.† | Particles 10-2000 μm. Rate 5-100 Hz. Asymmetry parameter (g) to 1-2% accuracy. Optical extinction coefficient to 5-10%. |

(Cont.)

* Ordered (to be delivered 1 March or, at latest, 1 April)

† Guest instrument

## (e) Chemistry

| Parameter | Instrument Type | Manufacturer | Range (and error) |
|---|---|---|---|
| Particulate species $SO_4^{=}$, $NO_3^{-}$, $Cl^{-}$, $Na^{+}$, $K^{+}$, $NH_4^{+}$, $Ca^{++}$, $Mg^{++}$ | Teflon filters and ion exchange chromatography | Gelman Dionix | 0.1 to 50 $\mu g\ m^{-3}$ (for 500 liter air sample) |
| $SO_2$ | Pulsed fluorescence | Teco 43S (modified in-house) | 0.1 to 200 ppb |
| Ozone | Chemi-luminescence ($C_2H_4$) | Monitor Labs Model 8410 A | 0 to 5 ppmv (< 7 ppb) |
| CO | Infrared correlation spectrometer | Teco Model 141 | 0 to 50 ppmv (~0.1 ppmv) |
| $CO_2$ | Infrared correlation spectrometer | LI-COR Li-6262 | 0 to 300 ppmv (0.2 ppmv at 350 ppmv) |
| $NO/NO_x$ | Chemi-luminescence ($O_3$) | Modified Monitor Labs Model 8840 | 0 to 5 ppmv (~1 ppb) |

(Cont.)

## (f) Remote Sensing

| Parameter | Instrument Type | Manufacturer | Range (and error) |
|---|---|---|---|
| Absorption and scattering of solar radiation by clouds and aerosols; reflectivity of surfaces | Thirteen wavelength scanning radiometer | NASA-Goddard/ University of Washington | 13 discrete wavelengths between 470 and 2300 nm |
| Solar Spectral irradiance or radiance; Spectral transmission and reflectance | Up and down looking hemispherical signal collectors | NASA Ames Solar Spectral Flux Radiometer (SSFR) (P. Pilewskie)* | 300-2500 nm (5-10 nm resolution. FOV 1 mrad. 1 Hz spectral sampling rate. |
| Weather radar | Pilot's radar ($\lambda$=3 cm) | Bendix/King (now Allied Signal) | 160 nm |

(Cont.)

* Guest instrument.

## (g) Data Processing and Display

| Parameter | Instrument Type | Manufacturer | Range (and error) |
|---|---|---|---|
| In-flight data processing and recording | Microcomputer | In-house, based on Motorola MVME-133A technology | |
| Recording (analog voice transcription) | Cassette recorder | --- | |
| In-flight data processing and display | Laptop PC | NEC Versa 5060X | |
| Digital printout | Impact printer | Epson MX-80 | |