UNIVERSITY OF WASHINGTON

FLIGHT SCENARIOS FOR THE CONVAIR-580 IN KWAJEX (KWAJALEIN, MARSHALL ISLANDS): 25 JULY-15 SEPTEMBER 1999*

by

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1. GENERAL INFORMATION

(a) The TRMM Satellite

The NASA **T**ropical **R**ainfall **M**easuring **M**ission (TRMM) satellite was launched in November 1997 and has been operating successfully since that time. The prime goal of TRMM is to provide remote sensing measurements that can be used to compare with predictions from climate models of the perturbations caused by tropical precipitating systems. For this purpose, the TRMM satellite carries a microwave imager (TMI) (similar to that which will be carried aboard the Convair-580 in KWAJEX), a precipitation radar (PR), visible and infrared imagers, and a lightning detection system.

For more information on TRMM see http://trmm.gsfc.nasa.gov/.

(b) KWAJEX

The **Kwaj**alein **Ex**periment (KWAJEX) is one of a series of field experiments designed to provide radar measurements and in situ measurements from aircraft in conjunction with TRMM satellite overpasses and TRMM simulators on high flying aircraft. These data will be used to test current TRMM algorithms for deriving cloud properties from the satellite remote sensing measurements, and for improving models for clouds over the tropical oceans. KWAJEX is unique among the TRMM field experiments in that it is the only one to be conducted over the tropical oceans.

In addition to providing validation data for the TRMM algorithms, KWAJEX should also provide a wealth of unique data on the structure of tropical convective clouds and precipitation.

For more information on KWAJEX see http://www.atmos.washington.edu/gcg/MG/KWAJ/kwajex.html.

(c) Location and Period of KWAJEX

The Operations Center for the KWAJEX field study will be based on Kwajalein Island (9.05°N; 167.20°E—see Fig. 1) in the Republic of the Marshall Islands (Figure 2).

The field study will take place from 25 July through 15 September 1999.

(d) Field Facilities Relevant to Aircraft Operations (For complete description see "Kwajex Experimental Plan" (http://www.atmos.washington.edu/gcg/MG/KWAJ/DRAFT1pt2/KwajexPT2.pdf).)

Instruments and facilities for KWAJEX will be based on six islands (see Appendix 1), one ship (the NOAA *Ronald H. Brown*), and three aircraft (the University of Washington Convair-580, the University of North Dakota Citation, and the NASA DC-8).

Rawinsondes will be launched from the NOAA ship *Ronald H. Brown,* Kwajalein, Roi-Namur, Meck, Lae and Woja (Fig. 2) about every 3 hours during aircraft missions.

A tethered balloon (extending up 4900 ft) will operate from Meck Island (Fig. 2). The Convair-580 should not fly over Meck.

Research radars will be located at Kwajalein and on the *Ronald H. Brown*. A nominal position for this ship is 22 nautical miles south of Kwajalein Island from 25 July -20 August and 22 nautical miles to the southwest of Kwajalein Island from 24 August-15 September (Fig. 2).

Two profilers (915 MHz and S-band) will be on Legan Island (Fig. 2). The profilers are used to obtain high resolution vertical profiles of reflectivity and Doppler velocity every few minutes, 24 hours a day. Data from the 915 MHz and S-band profilers can be combined to estimate drop-size distributions. However, to date in situ validation of the profiler-derived drop size distributions has been limited. When precipitating clouds are present over Legan Island and other conditions warrant it, the Convair may fly over the profilers to provide in situ data from its microphysical instruments for use in checking raindrop size distributions derived from the profilers.

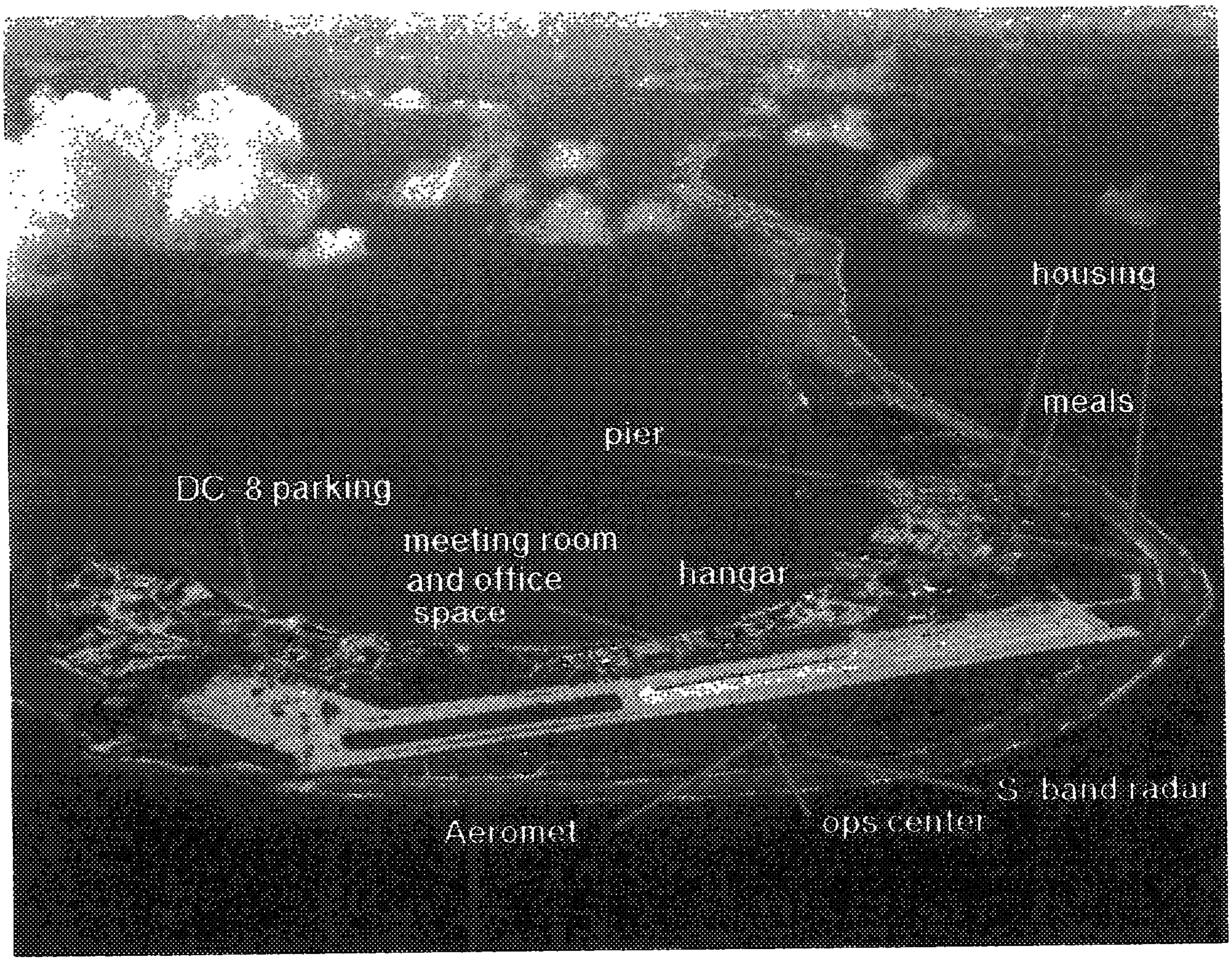


Figure 1. Aerial photo of Kwajalein Island, US Army Kwajalein Atoll/Kwajalein Missile Range. The locations of several primary KWAJEX resources are indicated. The Citation and Convair-580 will be located at the "hangar".

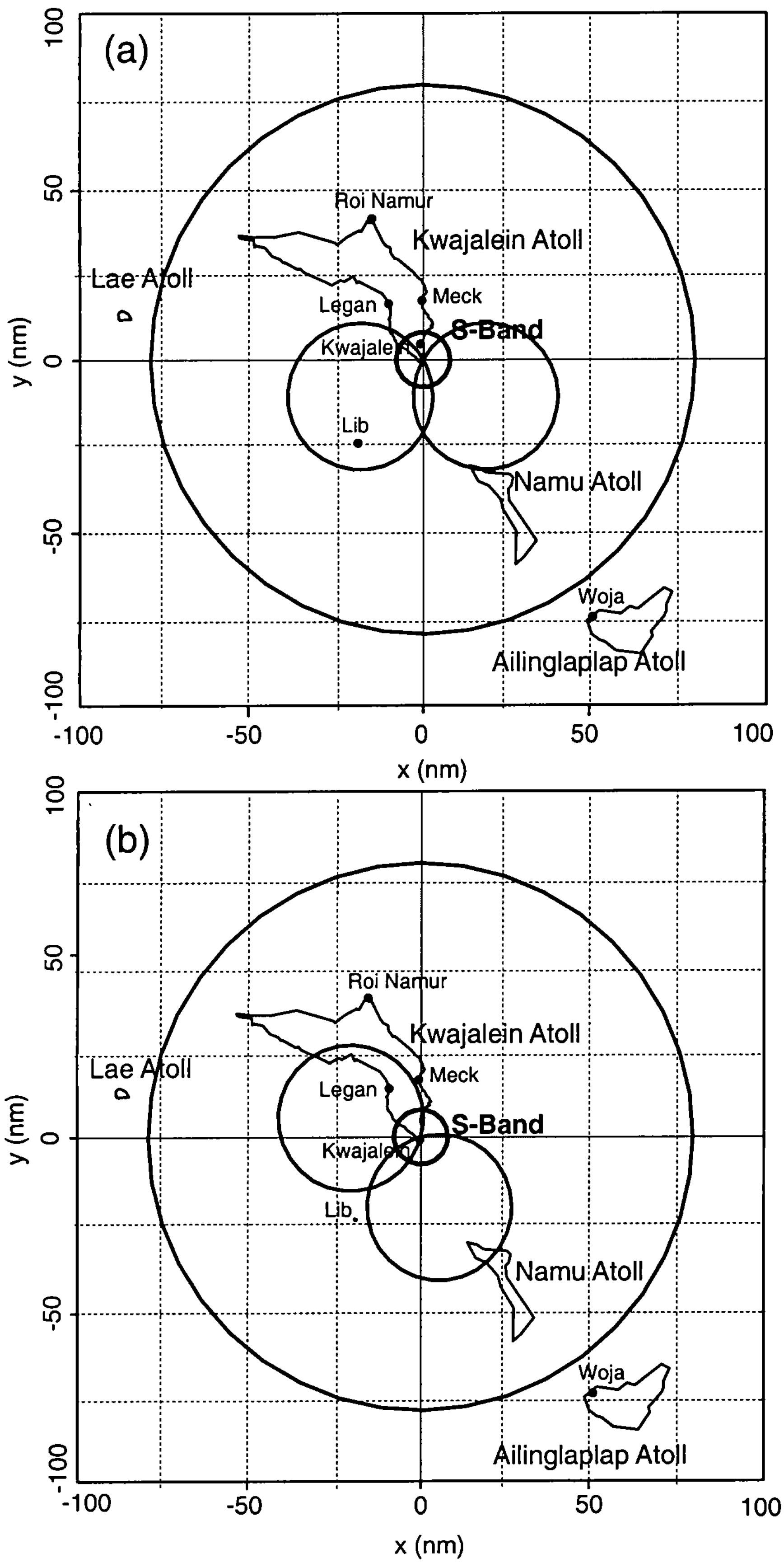


Figure 2. Location of islands with KWAJEX sensors. Also shown are the dual-Doppler lobes when the *R/V Brown* is (a) 40 km south (from 25 July-20 August), and (b) 40 km southwest (24 August-15 September) of the Kwajalein S-band radar. The outer circle is the 80 nm range ring around the Kwajalein radar, within which the aircraft will gather data. Inside the inner 8 nm radius circle data from the Kwajalein S-band radar are not useable for research purposes.

A three-dimensional wind field can be computed within the region of the dual-Doppler lobes formed by the research radars on Kwajalein Island and the NOAA ship *Ronald H. Brown* (Fig. 2). To address several KWAJEX objectives, microphysical data from the Convair need to be obtained within the dual-Doppler lobes. When precipitation echoes are widespread, the scientific preference will be to set up flight track patterns such that they intersect the region of the dual-Doppler lobes.

2. FLIGHT SCENARIOS

(a) Location of Flights

The aircraft flights will generally be within 80 nautical miles of the Kwajalein radar (Fig. 2).

(b) Main Research Mission for CV-580

The main research mission for the CV-580 in KWAJEX is to obtain cloud and precipitation microphysical measurements from near cloud base up to 18,000-25,000 ft.

The instrumentation expected to be on the CV-580 is listed in Appendix 3.

(c) Vertical Stacking of Aircraft

Measurements from the Convair-580 and the Citation need to be closely coordinated with the downward-looking radars and radiometers on the DC-8. Therefore, when practical, all three aircraft will fly in closely coordinated tracks both with respect to location (same cloud) and timing. Because of the importance of nadir-pointing instruments on the DC-8, the horizontal locations of the flight tracks need to be within about 2.7 nm of each other, and coordination in time is ideally within 5 min (i.e., different aircraft should pass over the same location no more than 5 mins apart). Since for quality data collection slow speeds are preferable, the Citation should match the research speed of the Convair (~160 knots indicated) when these two aircraft are in a vertical stack. The DC-8 will fly at its minimum speed (~410 knots), and therefore execute longer legs than the other two aircraft. Ideally, the DC-8 legs will be timed to coincide with the Citation/Convair position at the center of the Citation/Convair leg. Depending on aircraft altitudes and wind conditions, the pilots may have to adjust the nominal speeds noted above to keep the aircraft stacked above each other.

Figure 3(a)-(d) shows typical altitude blocks in which the aircraft will fly when more than one aircraft is in the air. However, the exact altitude blocks that will be assigned to each of the aircraft will depend on the heights of cloud base and cloud top. The aircraft will always be separated from each other by "no-fly" zones of 2000 ft. Specific aircraft altitude blocks will be assigned for each mission.

(d) Flight Patterns

Typical flight patterns for the aircraft when flying in coordination in clouds are depicted in Figure 4.

Following a horizontal track just below cloud base, the Convair will fly in a series of horizontal legs between lat/long locations given to the pilot by the UW Flight Scientist. These lat/long locations will probably change quite frequently. The vertical separation between the horizontal legs will depend on the altitude of the freezing level and radar echo top height. (For sampling reasons, it is preferable that the aircraft step up, rather than down, when executing a series of horizontal legs.) Similarly, the length of the horizontal legs will depend on the width of the cloud or cloud system sampled. Figure 4 depicts what might be a fairly typical situation for a large mesoscale cloud system, in which each horizontal leg of the Convair might be 30 nautical miles long.

As noted in (c) above, in each horizontal track the Convair will fly at a speed of ~160 knots (indicated) and the Citation will attempt to keep directly above the Convair. This will require close coordination between the pilots.

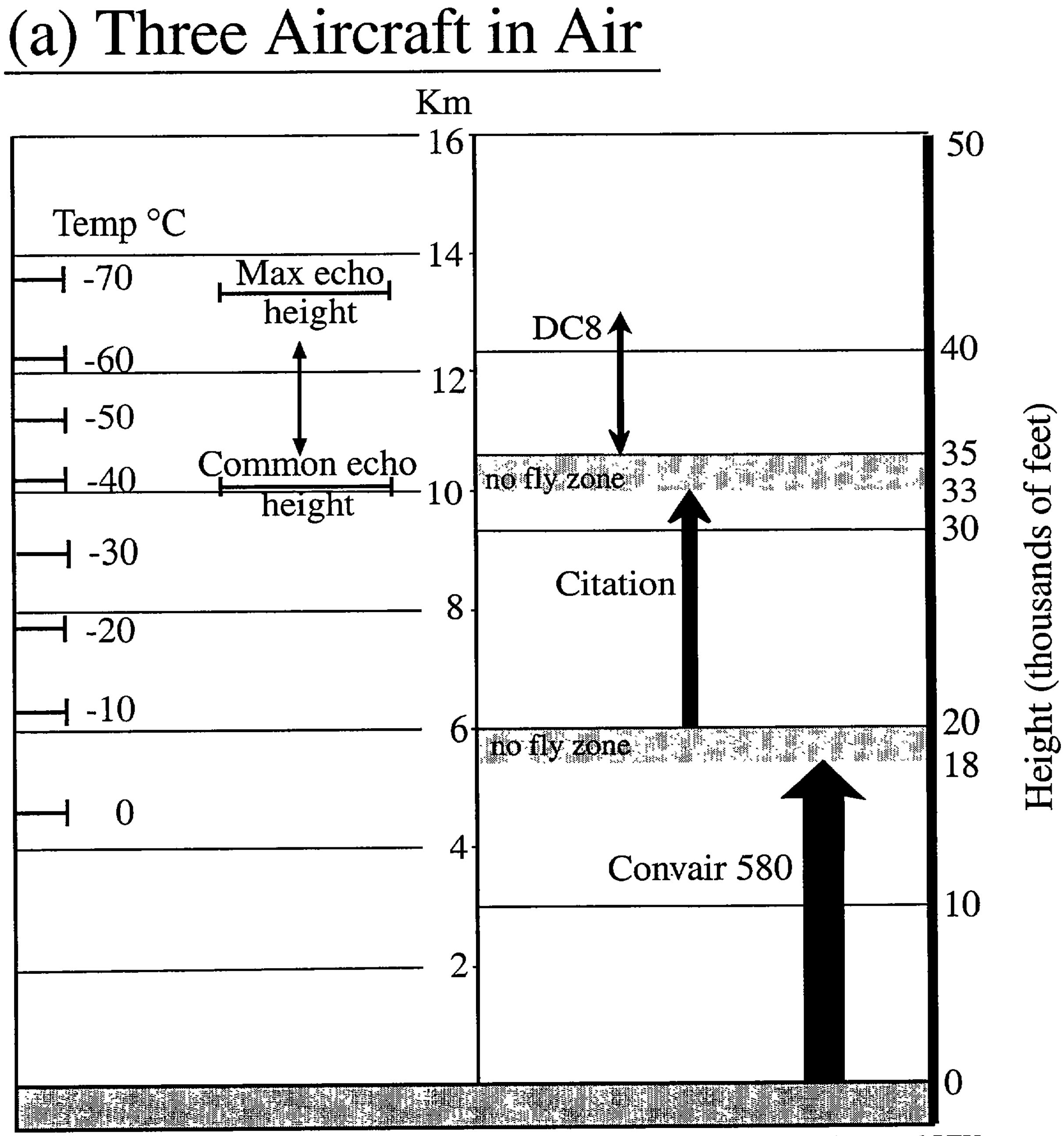


Figure 3. Proposed aircraft altitude blocks for the NASA DC-8, UND Citation, and UW Convair-580. Shaded altitudes indicate "no fly" zones effective during periods when more than one aircraft are in the air. (a) Altitude blocks when all three aircraft are in the air. (b) Altitude blocks when only Citation and Convair are in the air (see page 8). (c) Altitude blocks when only DC-8 and Convair are in the air (see page 9). (d) Altitude blocks when only the DC-8 and Citation are in the air (see page 10).

The situations depicted are generic. Actual assigned altitude blocks for the aircraft depend on cloud depths, etc. and will therefore vary from mission to mission. Altitude blocks will be assigned prior to takeoff, and reconfirmed between the pilots prior to any cloud penetrations.

(b) Citation and Convair-580 in Air

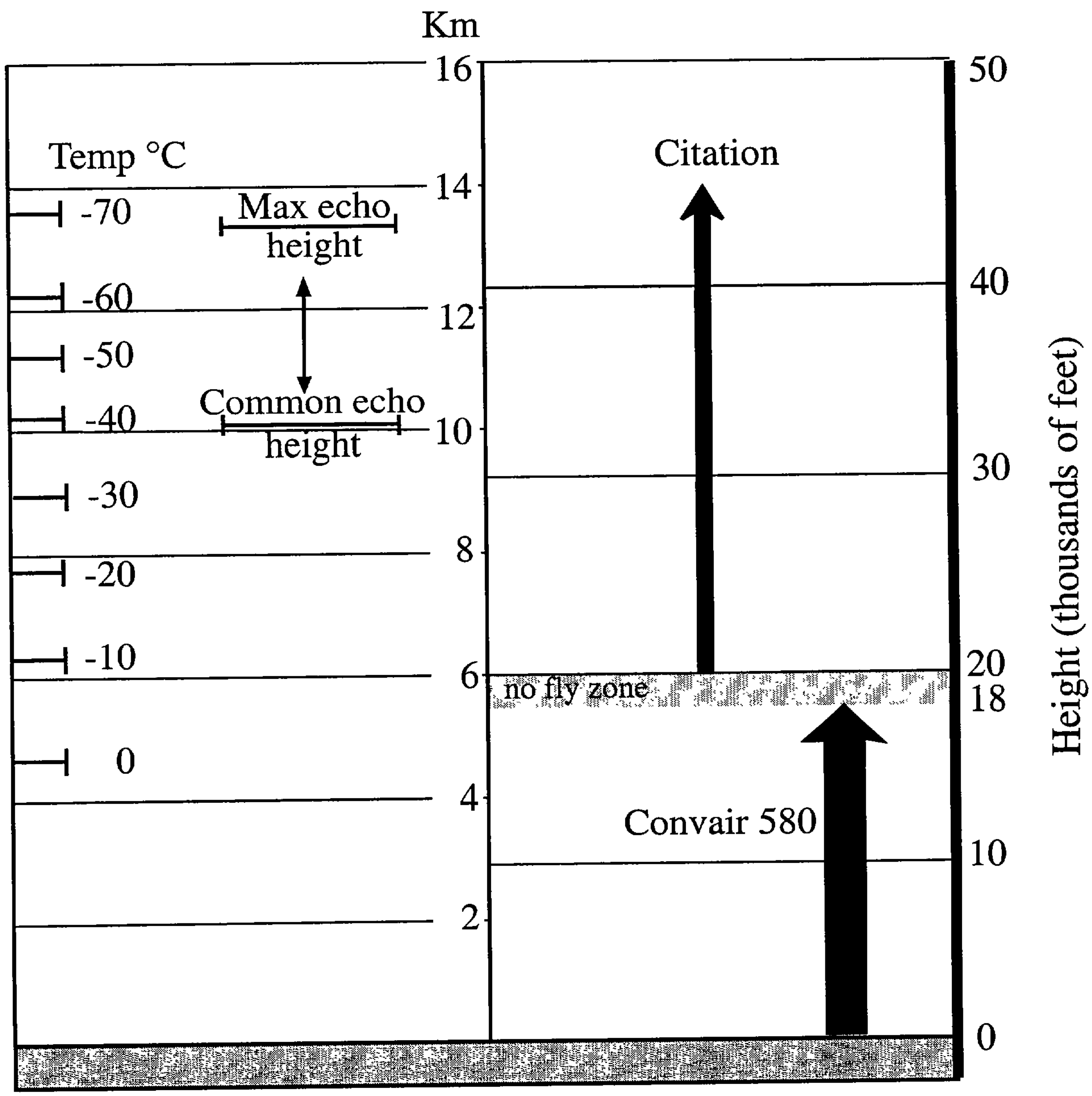


Figure 3 (cont.)

(c) DC-8 and Convair-580 in Air

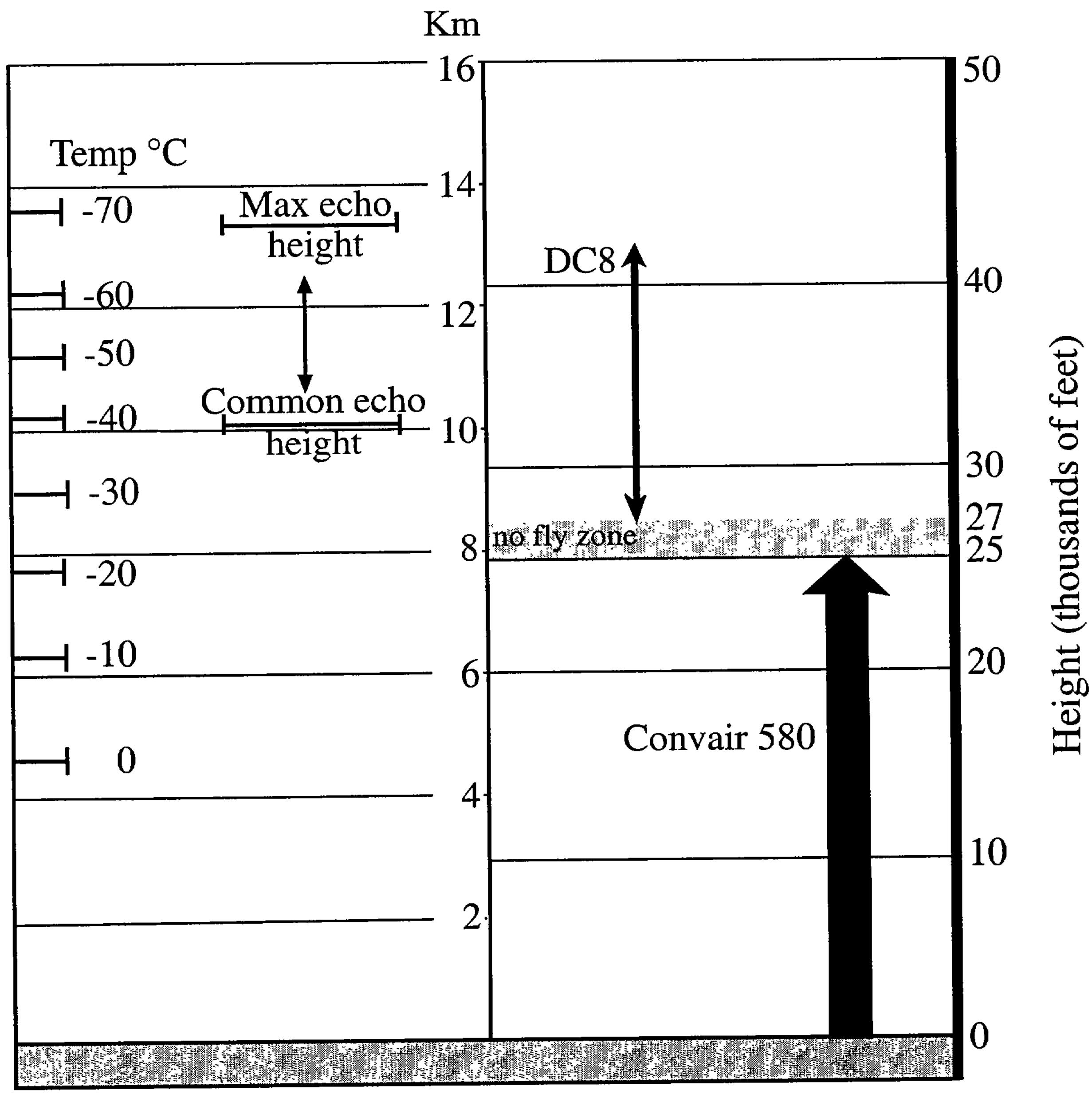
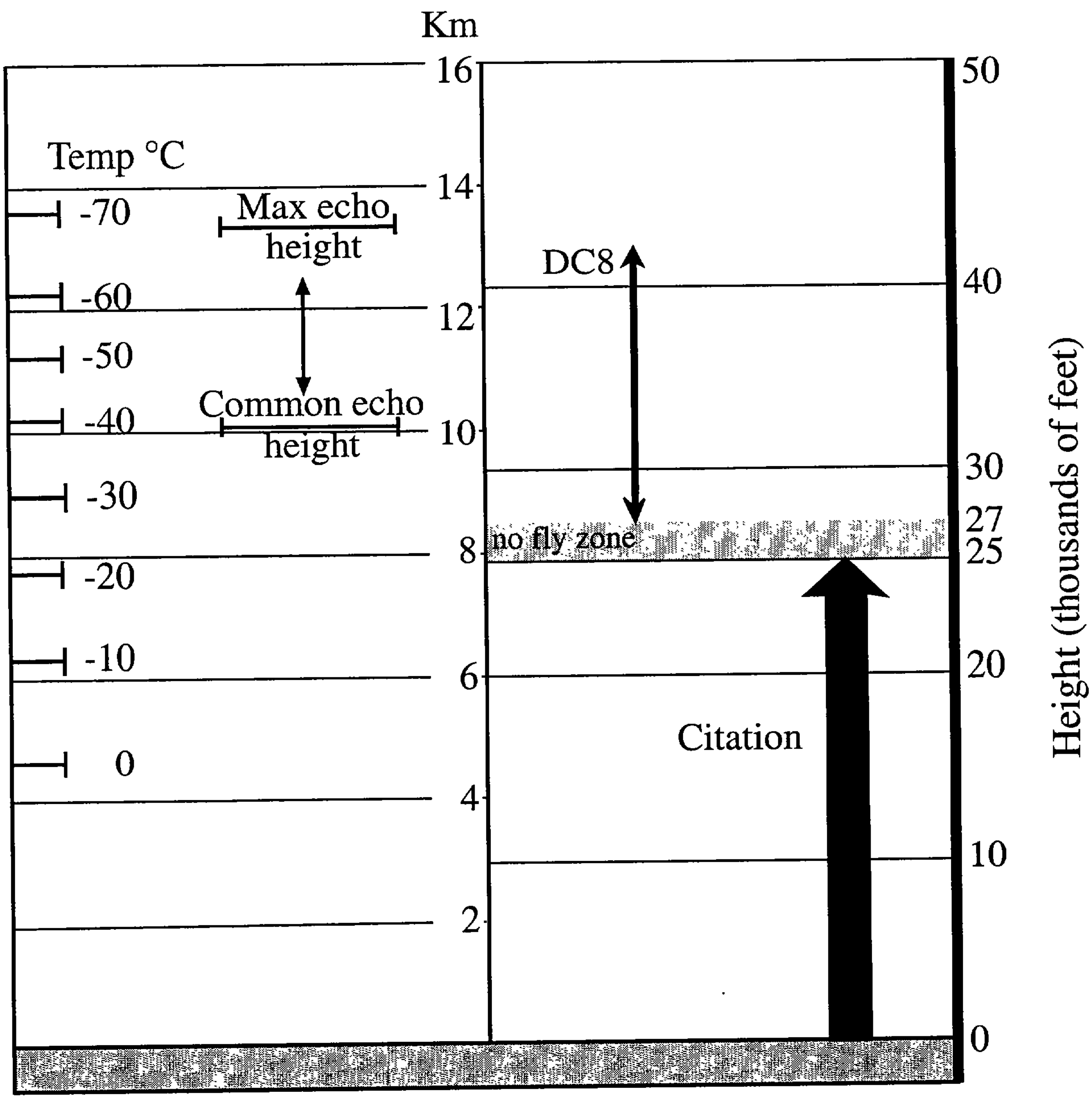


Figure 3 (cont.)

(d) DC-8 and Citation in Air



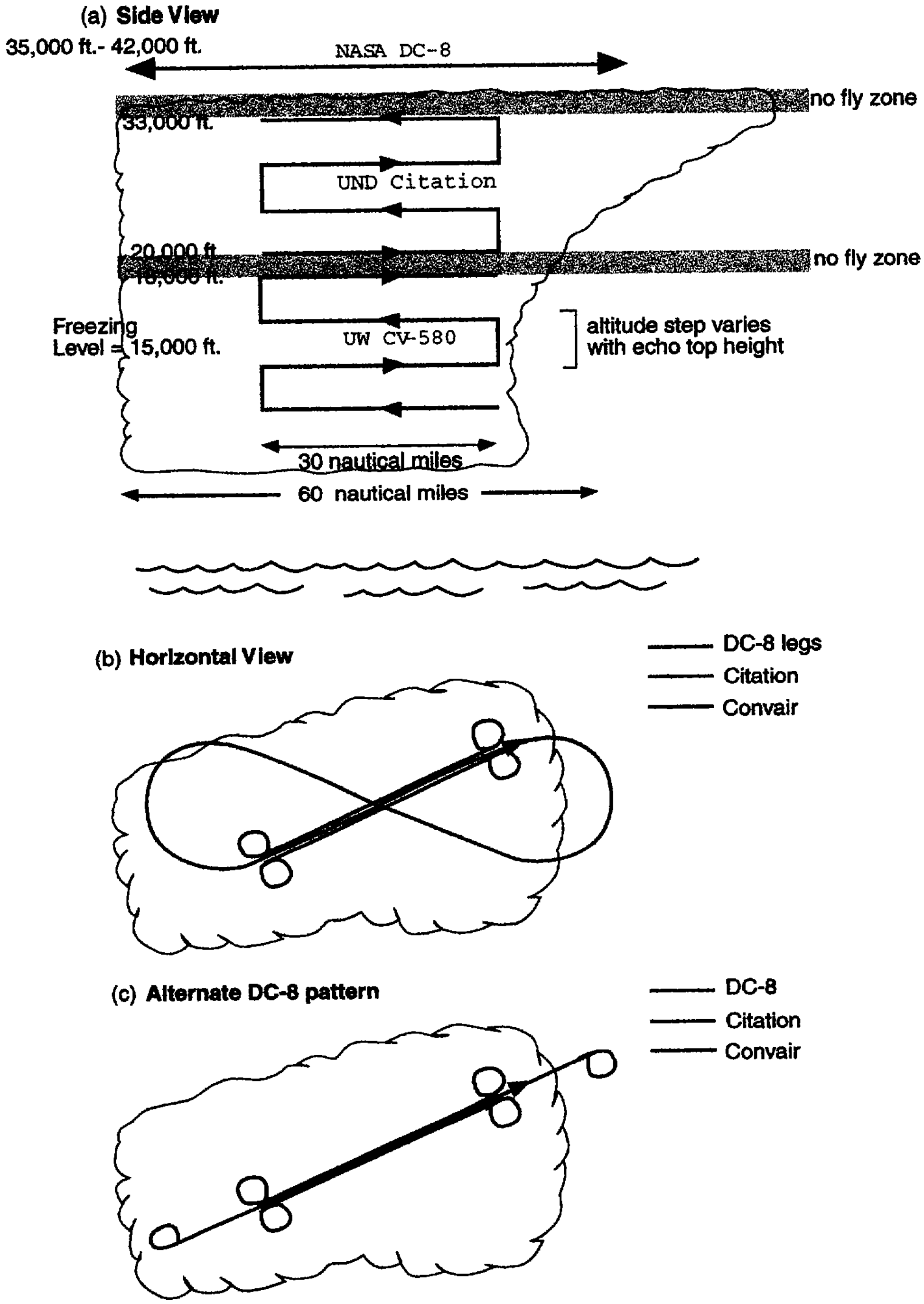


Figure 4. Schematic of proposed multiple aircraft mission flight tracks. a) Vertical view of flight track pattern showing DC-8 (orange), Citation (pink) and Convair-580 (blue) flight track legs. The altitude steps shown are for illustration. In practice, the altitude steps would depend on the depth of the cloud with shorter steps for shallower clouds. Similarly, the flight track leg length would vary depending on the horizontal dimension of the precipitating region. Gray shaded regions indicate "no fly" zones (see Figure 3). b) Horizontal view of flight track pattern with DC-8 flying a "bow-tie" pattern and Citation and Convair flying straight line tracks. Citation and Convair would employ 90-270 turns at the end of each leg. c) Horizontal view of flight track pattern with DC-8 flying straight line tracks with 90-270 turns. Citation and Convair flight tracks are the same as shown in b).

The Convair will climb at 300 ft/min. Therefore, the time to climb from 2,000 to 18,000 ft will be about 1 hour. The time required to do one 30 nautical mile horizontal leg (as shown in Figure 4) at 160 knots will be about 11 mins. Therefore, to do five horizontal legs (at various heights in the cloud), each 30 nautical miles long, will take about 1 hour. Hence, each large mesoscale cloud system (such as that shown in Figure 4) will take about 2 hours to sample.

Cautionary Note on Aircraft Icing. On occasions, we expect to encounter supercooled rain, particularly in the younger portions of clouds at temperatures of -5°C and lower. Such supercooled rain regions may last up to a minute or so before the aircraft encounters the graupel/ice particle regions of older portions of the cloud. The supercooled rain is likely to be preceded by a region of high supercooled cloud liquid water. Heavy ice may buildup in less than a minute, throwing ice off the props onto the fuselage and *cabin windows* (keep your head in!).

Night flights pose a potential problem since we will not be able to identify visually young building towers where icing is expected to be most severe. Therefore, in such cases we will proceed as follows. If we wish to make penetrations at say the -10°C level (where icing could be a problem if it is a young cloud turret), we will first penetrate the turret near -3°C. If icing at that level is not a problem (indicating that the turret is aging), we can then climb to the -10°C level.

In case of rapid buildup of icing, the aircraft can always descend to below the melting level.

3. FLIGHT HOURS

The UW was funded by NASA for a total of 100 research hours for this project, including test and calibration flights. Ten hours for test and calibration of instruments were used in Seattle in preparation for KWAJEX. It is anticipated that three flights, each lasting for about 3 hours, will be needed in Kwajalein for periodic test and calibration of the airborne instruments and for intercomparison flights with the other aircraft. Therefore, is expected that about 80 research hours will be available for KWAJEX cloud studies.

APPENDIX 1: SURFACE FACILITIES

(a) Ground-Based Facilities on the Islands

Kwajalein Island

System	Measurement
S-band Doppler, dual polarization radar	Z, Vr, ZDR, PHIDP
MSS upper-air soundings	profile of wind, temp, and RH from surface to tropopause
Aeromet mesonet	pressure, temp, dewpt, wind speed and direction
Joss Waldvogel disdrometer	drop size distribution
2D video disdrometer	drop size distribution
Tipping bucket rain gauge	rain rate

Meck Island

System	Measurement
MSS upper-air soundings	profile of wind, temp, and RH from surface to tropopause
Tethered sonde	profile of wind, temp, and RH from surface to 1.5 km
10 m tower	boundary layer energy fluxes and microclimate measurements
SODAR	horizontal wind speed and direction, turbulence, mixing depth
Aeromet mesonet	pressure, temp, dewpt, wind speed and direction
Tipping bucket rain gauge	rain rate
LW radiometers	downward LW flux

Legan Island

System	Measurement
915 GHz profiler	vertically pointing Z and Vr, and horizontal winds
S-band profiler	vertically pointing Z and Vr
Joss Waldvogel disdrometer	drop size distribution
Tipping bucket rain gauge	rain rate
2D video disdrometer	drop size distribution

Roi-Namur Island

System	Measurement
MSS upper-air soundings	profile of wind, temp, and RH from surface to tropopause
Aeromet mesonet	pressure, temp, dewpt, wind speed and direction
Tipping bucket rain gauge	rain rate

Lae Island

System	Measurement
VIZ GPS upper-air soundings	profile of wind, temp, and RH from surface to tropopause
Tipping bucket rain gauge	rain rate

Woja Island

System	Measurement
VIZ GPS upper-air soundings	profile of wind, temp, and RH from surface to tropopause
Tipping bucket rain gauge	rain rate

(b) Facilities on the Ship *Ronald H. Brown*

System	Measurement
Viasala GPS upper-air soundings	Tropospheric wind, temperature, and RH
Scanning C-band Doppler radar	3D structure of precipitation and velocity
IMET	Surface Meteorology (wind direction, wind speed, T, RH, pressure, SW flux, rainrate)
SCS	Navigation/siphon and optical rain gauges
Thermosalinograph	Near sea surface temp and salinity
S-band profiler	Precipitation profiles
Ku-band microwave	Scattering off ocean surface at TRMM PR angle and frequency w/ and w/o rainfall
Water vapor H and O isotopes	Distinguish evap from rain versus evap from sea water
Scanning microwave polarimeters (10, 15 and 37 GHz)	Polarized emission from rain and ocean surface
Air-sea flux system	Motion-corrected turbulent fluxes
Ceilometer	Cloud base height
915 MHz wind profiler	Lower tropopheric winds
5 mm scanning radiometer	Sea-air temp difference and SST
Water vapor/liquid radiometers (23.87, 31.65 GHz)	Column water vapor and liquid
Disdrometers	Drop size distribution

APPENDIX 2: LAT/LONGS OF ISLANDS

Island	**Lat/Long (degs)**
Kwajalein (FAA radar)	8.72/167.72
Legan	8.98/167.58
Roi Namur	9.39/167.49
Lae Atoll	8.92/166.27
Namur Atoll (NW tip)	8.19/167.98
Ailinglaplap Atoll (Woja Island)	7.43/168.56
Ship *Ronald H. Brown* from 25 July-20 August	8.36/167.73
Ship *Ronald H. Brown* from 24 August-15 September	8.46/167.47

APPENDIX 3

INSTRUMENTATION ABOARD THE UNIVERSITY OF WASHINGTON'S CONVAIR-580 INSTRUMENTATION FOR KWAJEX*

(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	
Heading	Gyrocompass	King KCS-55A	0 to 360° (± 1°)
Pitch and Roll	Differential GPS	Trimble TANS/Vector GPS Altitude System	0 to 360° (±0.15°)

(b) Communications

Parameter	Instrument Type	Manufacturer	Range (and error)
Weather satellite imagery†	HF and satellite	ICOM-R8500	Worldwide
Air-to-ground telephone	Via Iridium satellite	Motorola	Worldwide
Air-to-ground e-mail	Via satellite	Magellan	Worldwide
Two-way voice communications	Radios	Various	Variable

(c) General Meteorological

Parameter	Instrument Type	Manufacturer	Range (and error)
Radar reflectivity	3 cm wavelength (pilot's radar)	Bendix/King (now Allied Signal)	160 nm
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%)
3-D winds†	Differential GPS	In-house (based on NOAA/BAT)	?

(Cont.)

* Some of the instruments listed are part of the Convair-580 permanent installation, and may not be of particular relevance to KWAJEX.

† May not be installed.

(c) General Meteorological (continued)

Parameter	Instrument Type	Manufacturer	Range (and error)
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% or reading
Video image	Forward-looking camera and time code	Sony Hi8 camera	SVHS tape

(d) 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)
Number concentration of particles	Condensation particle counter	TSI Model 3022A	0-10^{7} cm^{-3} (d>0.003 µm)
Number concentration of particles	Condensation particle counter (continuous flow)	TSI Model 3025A	0-10^{5} cm^{-3} (d>0.003 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	1.0×10^{-7} m^{-1} to 1.0×10^{-3} m^{-1} for 550 and 700 nm channels, 2.0×10^{-7} m^{-1} to 1.0×10^{-3} m^{-1} for 450 nm channel
Light absorption and graphitic carbon	Particle soot/absorption photometer	Radiance Research	Absorption coefficient: 10^{-7} to 10^{-2} m^{-1}; Carbon: 0.1 µm m^{-3} to 10 mg m^{-3} (±5%)
Humidification factor for aerosol light-scattering	Scanning humidigraph	In house	b_{sp} (RH) for 30% ≤ RH ≤ 85%

(Cont.)

(e) Cloud Physics

Parameter	Instrument Type	Manufacturer	Range (and error)
Cloud and precipitation particle imagery	Digital holographic camera	SPEC Inc. Model CPI-230	5 μm to 3 mm
Size spectrum of precipitation particles	256 photodiode CCD array	SPEC (1 channel HVPS)	5 μm-5 cm. 5 cm × 20 cm optical cross section. 200 μm resolution with 1 $m^3 s^{-1}$ sampling rate
Size spectrum cloud particles	Forward light-scattering	Particle Measuring Systems FSSP-100	2 to 47 μm (15 channels)
Images of cloud particles	Diode imaging	Particle Measuring Systems OAP-2D-C	25-800 μm (resolution 25 μm)
Images of precipitation particles	Diode imaging	Particle Measuring Systems OAP-2D-P	200-3200 μm (resolution 200 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	DMT	0 to 5 g m^{-3}
Liquid water content; particle surface area; effective droplet radius	Optical sensor	Gerber Scientific Ins. PVM-100A	0.001-10 g m^{-3}; 5-10,000
Thermal emission (°K) from surface and atmosphere (hydrometeors)*	Airborne multichannel microwave radiometer (AMMR)	NASA Goddard (J. Wang)	?

(f) 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 μg m^{-3} (for 500 liter air sample)
Hydrocarbons CO, CO_2	Collected in stainless steel canisters; analysis by GC/FID	R. Gammon	Variable
SO_2	Pulsed fluorescence	Teco 43S (modified in-house)	0.1 to 200 ppb
O_3	UV absorption	Thermo Environmental Inst. Model 49C	1-1000 ppbv (<1 ppbv)
CO_2	Infrared correlation spectrometer	LI-COR Li-6262	0 to 300 ppmv (0.2 ppmv at 350 ppmv)
NO/NO_y	Chemiluminescence (with heated catalytic converter to NO_y)	Air Quality Design Model HSS-200 (NO_y)	10 pptv-100 ppbv (±5% for NO, ±10% for NO_y)
CO, H_2, alkenes	Oxidation over hot HgO	Trace Analytical RGA3 Reduction Gas Analyzer	Detection limits: sub-ppb

* To be reinstalled in Kwajalein and removed at end of KWAJEX.

(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	

PAGES FOR NOTES