PTCE Methodology

An extensive array of aircraft, airborne instruments, surface instruments, and satellite observations was deployed for the TOGA COARE field program. This section describes those facilities used by the NASA component of the program.

AIRCRAFT

Two NASA research aircraft, the DC-8 and ER-2, were deployed in Townsville, Australia in January and February 1993 to support the TOGA COARE experiment. The two aircraft were managed and operated by NASA Ames Research Center's Science and Applications Aircraft Division, Moffett Field, California. The ARC points of contact were: for the DC-8 George Alger of the division's Medium Altitude Branch, and Gary Shelton of the High Altitude Branch.

ER-2 Instruments

The NASA ER-2 aircraft carried a comprehensive set of remote sensing instruments for radiation, convection, and precipitation measurements. An overall list of the PTCE-relevant instruments is given in Table 1. The RAMS instruments are listed in Table 2.

Table 1 - ER-2 Instrumentation

Instrument	PI/Instrument	TOGA COARE Discipline	Data Parameters
Cloud Lidar System	Spinhirne/GSFC	Radiation	Cloud structure, boundaries, and density
MODIS Airborne Simulator (MAS)	King/GSFC	Radiation	Passive multi-channel radiometric data
Advanced Microwave Precipitation Radiometer (AMPR)	Spencer/MSFC Hood/MSFC	Convection, TRMM	High resolution, multifrequency sampling of tropical rain systems
Millimeter Imaging Radiometer (MIR)	Adler/GSFC Racette/GSFC	Convection, TRMM	Cloud structure, rainfall, water vapor profiling, cirrus cloud ice content and particle size distribution
ER-2 Doppler Radar (EDOP)	Heymsfield/GSFC	Convection, TRMM	Vertical air motion, precipitation structure, mass and heat budgets
Radiation Measurement System (RAMS)	Valero/ARC	Radiation	Radiation fields, infrared fluxes, and brightness temperatures
Lightning Instrument Package (LIP)	Blakeslee/MSFC	Convection, TRMM	Components of electrical field and air conductivity

Table 2 - RAMS Measurement Parameters

Radiometer	Spectral Channels	FOV
Broad Bandpass Hemispheric Solar Radiometer	Total Flux	Hemispheric Nadir and Zenith
Broad Bandpass Hemispheric IR Radiometer	IR Flux	Hemispheric Nadir and Zenith Flipping
Total Direct Diffuse Radiometer	Six Narrow Band Visible/Near IR Filters	Hemispheric with Oscillating, Orthogonal Shadow Rings
Narrow Field-of-View Radiometer	6.7 and 10.3 mm Cryogenic BB	Nadir Viewing 15° FOV

DC-8 Instrumentation

The instruments for the DC-8 are listed in Table 3.10. The Microphysical Measurement Package (MMP) and RAMS instruments are listed in Tables 3 and 4, respectively.

Table 3 - DC-8 Instrumentation

Instrument	PI/Instrument	TOGA COARE Discipline	Data Parameters
Visible and Near IR Lidar (VIRL)	Spinhirne/GSFC	Radiation	Cirrus radiation characteristics, structure and boundaries
Airborne Rain Mapping Radar (ARMAR)	Li/JPL	Convection, TRMM	Vertical profile of rainfall in convective systems
Microphysical Measurement Package (MMP)	Pueschel/ARC Heymsfield/NCAR Hallett/DRI	Convection, TRMM	Water budget of clouds; portion of condensate transported to anvil
Advanced Microwave Moisture Sounder (AMMS)	Wang/GSFC	Convection, TRMM	Water vapor, retrieval and microwave precipitation signatures
Electronically Scanned Microwave Radiometer (ESMR)	Wang/GSFC Wilheit/Texas A&M	Convection, TRMM	Two dimensional view of rainfall features-in conjunction with AMMS/AMMR
Airborne Multichannel Microwave Radiometer (AMMR)	Wang/GSFC	TRMM Algorithms	Dual polarized microwave signatures of precipitation
Radiation Measurement System (RAMS)	Valero/ARC	Radiation	Upward & downward radiative flux, ambient temperature
Dropwinsonde	(Facility)	All	Temperature, moisture, wind speed, pressure
Lighting Instrument Package (LIP)	Blakeslee/MSFC	Convection, TRMM	Components of electrical field, lightning characteristics and location

Table 4 - Microphysical Measurement Package for the DC-8

Type of Measurement	Variable	Manufacturer/ Instrument	Loaner/PI	Weight	Power
State Parameters	Temperature/ Direct Flow	Rosemount	NASA/OMM		
	Relative Humidity/ Cryogenic Mirror	NCAR	NCAR/ Heymsfield	75 lbs	150 W
	Relative Humidity/ Chilled Mirror	General Eastern; E.G.& G	NASA/OMM		
	Water Vapor	Lyman-Alpha	NCAR/ Heymsfield	10 lbs	50 W
	Liquid Water	Rosemount Icing Probe	NCAR/ Heymsfield		
	Winds	Delco INS	NASA/OMM		
	Aircraft Position	Collins GPS	NASA/OMM		
Cloud Micro-structure	Cloud drops (.3-20 mm)	PMS/ FSSP300	NCAR/ Pueschel	40 lbs	115 VAC 50-400 Hz; 28VDC 320W
	Cloud Particles (Size: 50-1200 mm Shape: 100-1200 mm)	PMS/OAP-2D-GA2 Grey Scale	NASA/ Pueschel	45 lbs	115 VAC 50-400 Hz; 28 VDC 320 W
	Ice Particles Size: 200-6400 mm; Shape: 600-6400 mm)	PMS/OAP-2D-P Grey Scale	NCAR/ Heymsfield	45 lbs	115 VAC, 50-400 Hz; 28 VDC, 140 W
	Ice Particles/ Size & Shape (2-500 mm)	NCAR/Snow-stick Occasional Sampler	NCAR/ Heymsfield	2 lbs	25 W
	Ice Particles/ Size, Shape, Composition (>0.5 mm)	DRI/Contin-uous Replicator	DRI/Hallett	25 lbs	28 VDC 280 W

	CN Counter (Total nuclei)	TSI	DRI/Hallett	15 lbs	115v 3a

Table 5 - Radiation RAMS for the DC-8

Type of Measurement	Variable	Manufacturer/ Instrument	Loaner/PI	Weight	Power
Cloud Radiative Properties	Up/Down Reversing Hemispheric Broad-band (IR)	NASA/ Ames	NASA/ Valero		
	Hemispheric Multichannel TDD Radiometer (.38-1.6 mm)	NASA/ Ames	NASA/ Valero		
	Up/Down Hemispheric Broadband (.3-2.8 mm)	NASA/ Ames	NASA/ Valero		
	Side-looking 2-channel (15 mm CO2 band Q branch)	NASA/ Ames	NASA/ Valero		

SATELLITES

Observational data from orbiting platforms were acquired from six satellites during TOGA COARE. The satellites and their instruments are given below:

GMS

NOAA-12 and -13: AVHRR, TOVS

Landsat

DMSP: OLS, SSM/I, SSM/T

ERS-1: ATSR/M, AMI, Radar Altimeter

TOPEX/POSEIDON

SURFACE

In addition to the airborne and satellite instruments required for observing and measuring various meteorological, cloud, and radiation parameters, the NASA component of TOGA COARE included the Pilot Radiation Observation Experiment (PROBE) surface station, located on an island in the tropical western Pacific. Described below is a summary of the PROBE facilities.

PROBE

PROBE was designed to serve as an Atmospheric Radiation Measurement (ARM) pilot study to provide a better understanding of the cloud-induced radiative feedbacks to the Earth's energy budget system, and to develop information on the radiative component of the coupling between ocean and atmosphere. The experimental design included a surface radiative measurement and cloud imaging station installed by ARM in collaboration with other organizations, including the National Oceanic and Atmospheric Administration (NOAA), the National Center for Atmospheric Research (NCAR), and the Pennsylvania State University (PSU). Data were collected to examine the role that clouds play in influencing sea surface temperatures and, as a result, the formation of deep convection and the consequential redistribution of water vapor through the troposphere and lower atmosphere.

The surface station was located on the island of Kavieng, New Ireland, Papua New Guinea (PNG). While not located directly between Townsville and the TOGA COARE IFA, Kavieng was close enough to take advantage of the aircraft missions, and at the same time was reasonably close to the IFA so that the surface radiative measurements could be related to the less-comprehensive radiative measurements over the IFA.

Table 6 lists the suite of instruments for the surface radiation and atmospheric profiling components of PROBE. Table 7 lists the instruments for the cloud imaging component.

Table 6 - PROBE Instruments for Surface Radiation and Atmospheric Profiling

INSTRUMENT (SOURCE)	MEASURED VARIABLE
1. 915 MHz Wind Profiler/RASS (NOAA/Aeronomy Lab)	Boundary layer winds, depth
2. OmegaSonde Sounding System (NCAR)	Vertical profiles of wind, temperature, RH
3. Surface meteorological station (NCAR)	Temperature, winds, relative humidity, pressure, precipitation, soil moisture/temp.
4. Upward- and downward-looking Eppley pyranometers (NCAR, NOAA)	Broad-band direct plus diffuse solar flux and reflected shortwave radiation (albedo)
5. Eppley shadowband pyranometer (NOAA)	Broad-band diffuse solar irradiance on horizontal surface
6. Normal incidence pyrheliometer (NOAA)	Direct solar radiation
7. Rotating Shadow-band Radiometer (SUNYA)	Total, direct and diffuse solar flux
8. Upward- and downward-looking pyrgeometer (NOAA)	Downwelling and upwelling broad-band long-wave radiative flux
9. Net radiometer (NCAR, NOAA)	Net radiation
10. Interferometer MPAA WPL	Spectral distribution of downwelling longwave radiative flux

Table 7 - PROBE Instruments for Cloud Imaging

INSTRUMENT (SOURCE)	MEASURED VARIABLE
1. Cloud Base Lidar (PSU)	Height of cloud base
2. Multi-wavelength lidar (CSIRO)	Bulk cloud structure, droplet settling
3. 1-3 Video All-Sky cameras (Scripps)	Cloud imaging and motion
4. Narrow-beam infrared window radiometer (PSU/NASA Ames, SIRO, NOAA WPL)	Cloud base emissivity
5. Microwave radiometer NOAA, WPL)	Total water vapor and liquid water in the atmospheric column

MISSION SCENARIOS

For the NASA component of TOGA COARE, mission scenarios were driven by the following Earth science interests: convection, radiation, oceanography, air-sea interaction and the evolution of the TRMM instrument and algorithms. These science interests produced a complex set of mission requirements. The measurement platforms relevant to the science interests are listed in Table 8.

Table 8 - Array of Measurement Platforms

	AIRCRAFT	SATELLITE	SURFACE	AIRCRAFT INSTRUMENTS
Convection	ER-2 DC-8 Turboprop/ Doppler Radar Electra	SSM/I SSM/T2 GMS	Ship Radars Radiosondes Ram Gauges Rain	PMS, ARMAR, ESMR, AMMR, LIP, EDOP, MMS, ELDORA, AMPR, MIR, RAMS
Radiation	ER-2 DC-8 Electra NOAA P-3	GMS SSM/I NOAA Polar (AVHRR, etc) Landsat	ARM Radiation PROBE ISS Sites Research Ships Buoys	MIR, MAS, CLS RAMS, EDOP AMPR, MMS VIRL, PMS, MMP
Air Sea Interaction	ER-2 DC-8 NOAA P-3	ERS-1 GMS SSM/I AVHRR	Radiosondes Rain Gauges Ship Radars	AMPR, AMMR ARMAR, ESMR C Band Scatt
Oceanography	NOAA P-3	TOPEX/ Poseidon SSM/I ERS-1 GOES/AVHRR	Radiosonde Tide Gauges Ships Rain Gauges Doppler Radars	C Band Scatt Surface Contour Radar

		GMS	Buoy/Wind Stress HRPT Ground Station	
TRMM Algorithms	ER-2 DC-8 NCAR Electra NOAA P-3	GMS SSM/I	Ship Radars Radio Sondes Rain Gauges	EDOP, AMPR, MIR, MAS, MMS, LIP, ARMAR, AMMR, ESMR Dropwinsonde

Adding to the complexity of the diverse observational needs were the operating limitations of the aircraft platforms. Since the two NASA aircraft operated from Townsville, Australia, the one-way distance to the center of the IFA was 1,125 nautical miles. Based on these operating constraints, the DC-8 had three hours flight time available for work in the IFA. The ER-2 had two hours in the test area. These times for observations were extended in cases where the observational regime was outside the IFA and closer to Townsville. Some observations were made on transit flights to and from the prime area of interest.

PTCE MISSION SCENARIOS

A concerted effort was made to measure the radiative budget of cirriform clouds for a wide range of optical and geometric depths. The goal was to measure broadband and spectral fluxes at the top of the atmosphere, above cloud, below cloud, and at the surface. This required specific coordination of aircraft with surface stations and satellite overpasses. The PROBE ground site, specifically dedicated to radiation and ground-based remote sensing measurements, was located at Kavieng, approximately 300 km to the west of the COARE Intensive Flux Array. PROBE was designed to provide specific coordination with the NASA aircraft program, as well as other radiation measurement programs associated with TOGA COARE. This allowed for repeated overpasses by aircraft in transit to the intensive array. For high cirrus, below-cloud measurements were made by the NASA DC-8. Above cloud radiation measurements were the exclusive domain of the NASA ER-2. Since monitoring the spatial and temporal characteristics and variability of cirrus over the tropical ocean could not be accomplished without the use of satellite remote sensing, it was useful to provide as many intercomparison and calibration points as possible for aircraft and satellite. Hence the aircraft radiation flights, particularly those of the ER-2, were coordinated with NOAA Polar and Landsat satellite overpasses.

A second objective was to carry out survey flights designed to sample the radiation budget of tropical cirrus over large spatial areas. The plan was to make microphysical measurements with the DC-8 in the stratiform region of convective systems and radiative and remote sensing measurements with the ER-2 above the same system. This required the coordination of the ER-2 above cloud and the DC-8 below cloud. Since these planes were reasonably well matched in speed, coordinated missions with these two aircraft was possible. At approximately the same time, Doppler radar measurements of the system would be made with the low level aircraft. At the surface site, a complete set of radiative flux measurements, coupled with remote sensing and visual recording of cloud conditions, was obtained by PROBE. This type of mission provided scientists with the needed *in situ* data to help interpret the Doppler radar measurements from below and the remote sensing measurements from above.

Aircraft missions that aided in radiation budget studies of convective systems were also of importance. In this case, the DC-8 was used to make thermodynamic measurements at altitude and dropped radiosondes. Working in concert with the low altitude aircraft, these missions helped fill in missing information from the sounding array and radars.

Four generic flight patterns were used by PTCE:

1. Long-leg radiation flights with the DC-8 and ER-2; the goal was long (500-1000 km) survey legs with the ER-2 above cloud and the DC-8 below cloud. Some of these flights were accomplished in transit from Townsville to Kavieng and/or the IFA.

2. Flights of opportunity over the Kavieng PROBE site, the objective was to get simultaneous aircraft and surface fluxes as frequently as possible.

3. Coordinated ER-2, DC-8, and turboprop Doppler radar flights, the objective was to use the Doppler radar to guide the DC-8 positioning in cloud. The ER-2 was vectored over the top of the convective region for simultaneous coverage.

4. A four-level coordinated aircraft stack (ER-2, DC-8, turboprop with microphysics, turboprop with Doppler radar) flying moderately long legs (250+ km) from the convective into the cirriform region.