ARM Climate Research Facility
CLASIC Field Campaign
High Altitude Aircraft Measurements
NASA ER-2

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November 1, 2006

Atmospheric Radiation Measurement
Climate Research Facility
U.S. Department of Energy

Office of Science
U.S. Department of Energy

Overview

- **Desired Measurements and Mission**
- Aircraft Capabilities
- Instrument Systems and PIs
- Instrument System and Measurement Specifications
- Aircraft and Instrument Integration
- Current Status and Next Steps

Desired Measurements and Mission Parameters

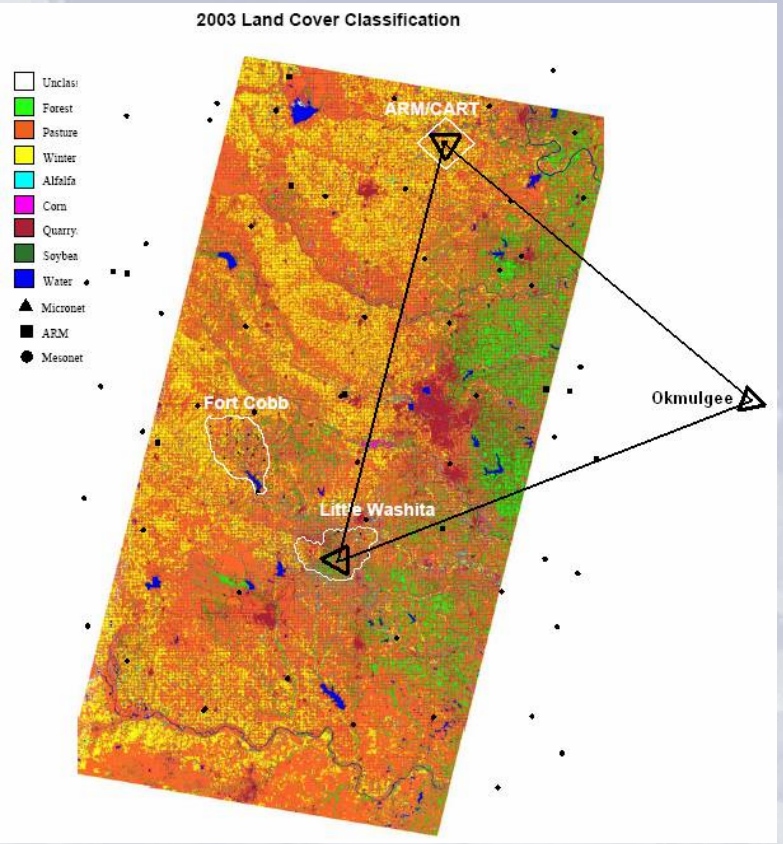
- High resolution measurement of 3-dimensional cloud field boundaries
- Retrieved measures of cloud properties
- Surface properties and soil moisture
- Single Aircraft, Flight Altitude 45,000 to 70,000 Ft.
- Dwell Time – Maximize
- Traverse Velocity – Minimize
- Stable Remote Sensing Platform
- Nadir Pointing Instrumentation

ER-2 and CLASIC

- June 9-30, 2007, at the SGP site
- 6 aircraft (Possibly More!)
  - **ACRF/AVP**; ER-2, Twin Otter, Cessna 206
  - **NASA**; Bell Helicopter
  - **ASP**; G-1, King Air (Hostetler)
- Flight science planning meeting, February (Beat Schmid lead)
- Flight mission coordination meeting, April

CLASIC

- 3 surface super sites: CF, Little Washita, EF-21
- CIRPAS X-band scanning radar (10-s volume scan)
- Enhanced radiosonde network



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Aircraft

Turbo Cessna 206

ARM Turbo Cessna 206 Measurements and Instruments

- In situ aerosol profiling and airborne carbon measurements
- Nephelometers- scattering at four relative humidities
- Aerosol hygroscopic growth
- Particle Scattering for particles >1 micron
- Carbon cycle trace gases

Aircraft

Bell 206-B Helicopter

Helicopter Observation System (HOP) Sensors

- Nose mounted;
  - Sonic anemometer for three-dimensional turbulence (high frequency) at low flying speeds
  - Water and carbon dioxide concentrations
  - Three-dimensional wind, temperature and moisture content measurements at high flying speeds
  - Aerosol count and size distribution

Roni Avissar
&
HOP

- Navigation system that produces computer-generated, three-dimensional images of the aircraft's position in relation to the terrain below

NASA ER-2

Contact

- Aircraft; NASA ER-2 High Altitude Aircraft
- NASA Program Contact; Jacques Vachon
- http://www.nasa.gov/centers/dryden/research/AirSci/ER-2/
- Edwards, CA - Based

Specifications

- Payload ; Nose 600 lbs, Q-Bay 750 -1000 lbs, (w/ total forebody weight of 1300 lbs)
- Wing Pod, 1300 lbs (650 lbs each w/ 2 pods total)
- Airspeed; ~740 km/hr, 460 mph at > 65,000 ft
- Altitude; 25,000 to Above 70,000 ft.
- Endurance; Over 10 Hours
- Autonomous Instrument Control Required (through cockpit interface)
- Irdium Satcom avaialble

Availability and Comments

- Aircraft is available in June 2007
- Excellent Remote Sensing Platform
- Compatible with specified instruments

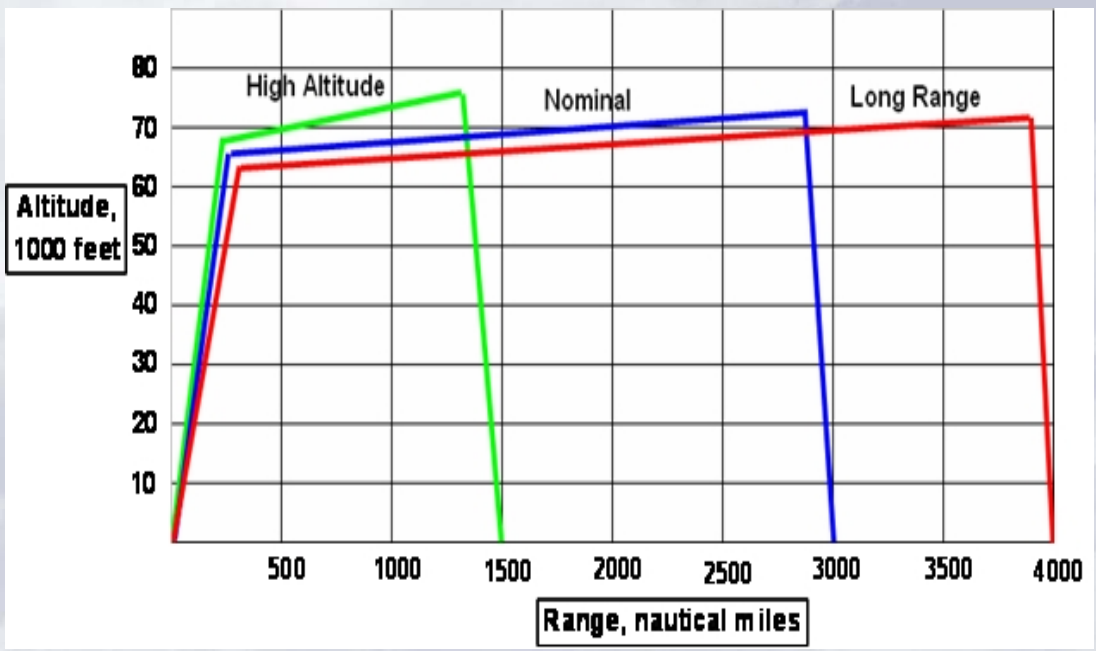
Aircraft Summary

Specifications (per USAF-releasable data)

Crew:	One Pilot
Length:	62 feet, 1 inch
Wingspan:	103 feet, 4 inches
Engine:	One General Electric F-118-101 engine
Altitude:	above 70,000 feet
Range:	over 6000 nautical miles, subject to pilot duty time limitations
Duration:	over 10 hours
Cruise Speed:	~400 knots above 65,000 feet altitude (~210 meters/sec)

Payload

Nose:	600 lbs
Q-bay:	750 lbs
Wing Pods:	1360 lb

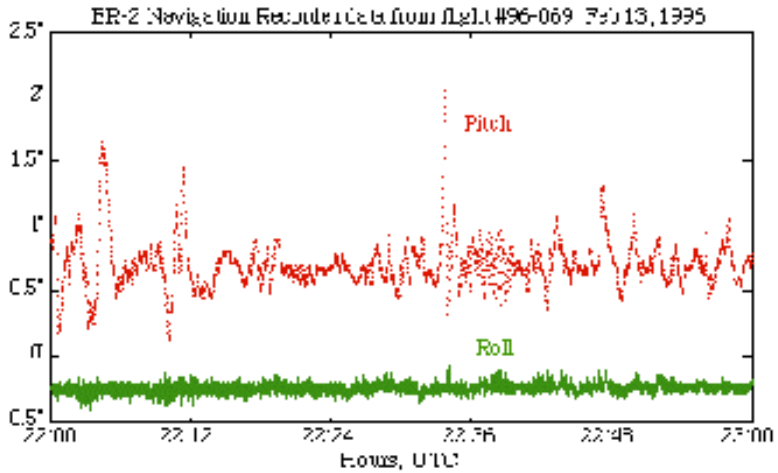


Aircraft Summary

(Continued)

Stability

At its cruising altitude, the ER-2 is a very stable aircraft. The automatic flight control system augments stability in the yaw, pitch, and roll axes. Pitch and roll excursions are typically less than one degree over a flight line.



Turn Radius at Altitude

Bank Angle Turn Diameter

degrees	Naut. Mi.	km
5	56.2	104
10	27.9	52
15	18.3	34
20	13.5	25
22 (standard)	12.2	23

At constant Mach number, banking the wings to turn the aircraft inevitably imposes a loss of lift, and thus altitude. This altitude loss can be up to a thousand feet, which is gradually recovered over the next straight-and-level flight leg.

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Instrument Systems and Principal Investigators

- **CPL** (Cloud Physics LIDAR)-
  Matt McGill, Goddard Space Flight Center (GSFC) NASA
- **MAS** (MODIS Airborne Simulator)-
  Jeff Meyers, NASA Ames Research Center (ARC)
  Mike King, Steve Platnick, NASA GSFC
- **CRS** (94 GHz cloud radar system)-
  Gerry Heymsfield, NASA GSFC
- **EDOP** (9.6 GHz doppler, precipitation, radar system)-
  Gerry Heymsfield, NASA GSFC
- **PSR** (Polarimetric Scanning Radiometer C&X-Band) –
  Al Gasiewski, NOAA

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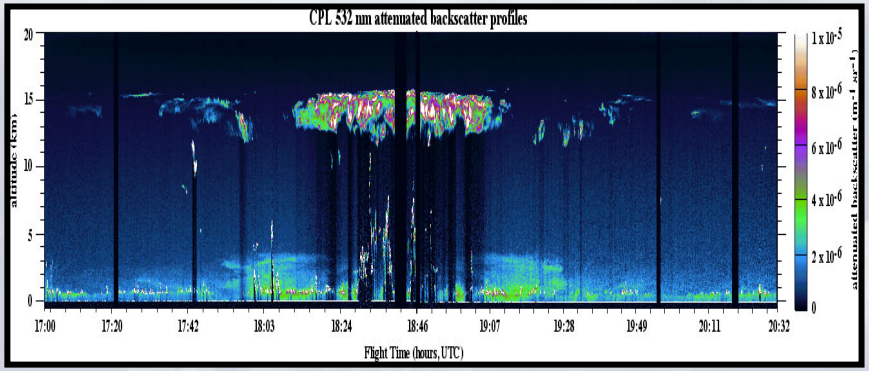
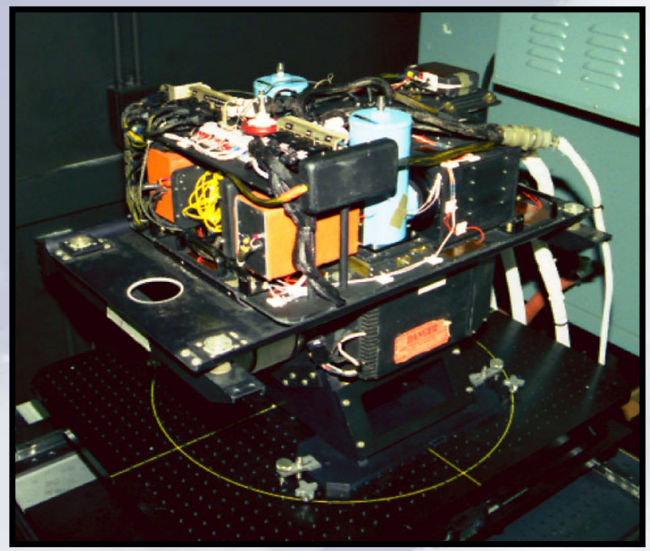
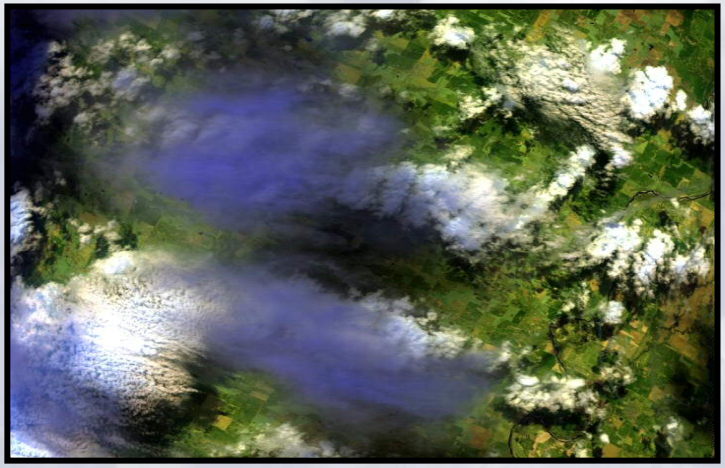
Instrument System and Measurement Specifications - CPL (Cloud Physics LIDAR)



- Multi Wavelength; 1064, 532, and 355 nm
- Laser Repetition rate; 5 kHz
- Processed Data Resolution; 30 m vertical by 200 m horizontal
- Cloud Microphysics
- Aerosol backscatter coefficients
- Depolarization ratio for ice-water phase
- Cloud Particle Size
- Optical Depth (cloud and aerosol)
- Extinction to backscatter ratio
- Eye Safe
- Contact; Matt McGill (mcgill@virl.gsfc.nasa.gov)
- Reference; *Cloud Physics Lidar: Instrument description and initial measurement results, McGill ET AL., Applied Optics Vol. 41, No. 18*

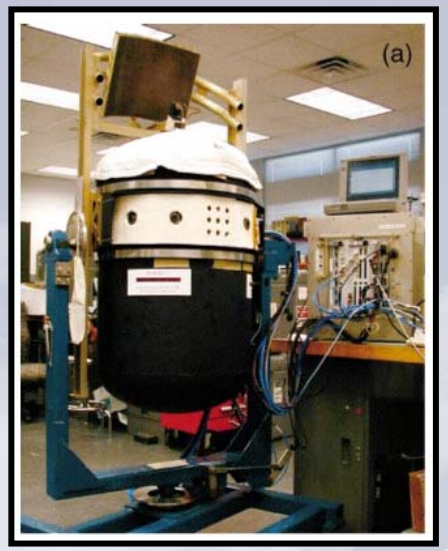
Instrument System and Measurement Specifications – MAS (MODIS Airborne Simulator)

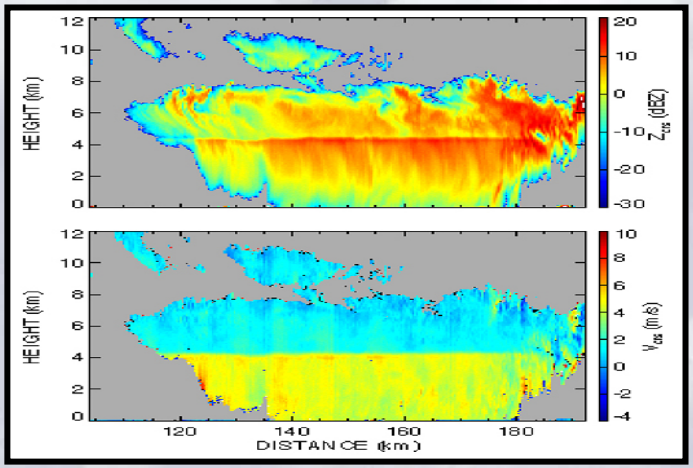




- Multi-Spectral IR Scanner
- 50 Channels
- 0.46 to 14.2 Microns
- IFOV 2.5 mrad (50 m @ 65K Ft.)
- Swath Width at 55K ft ~ 37.5 KM
- Atmospheric Processes (Clouds, Water Vapor and Aerosols)
- Terrestrial Processes (Surface Properties)
- Weight ~300 lb
- Contact; Jeff Myers (jmyers@arc.nasa.gov)
- Reference; *Airborne Scanning Spectrometer for Remote Sensing of Cloud, Aerosol, Water Vapor, and Surface Properties, AMS JAOT, Volume 13, NO. 4*

Instrument System and Measurement Specifications – CRS (94 GHz Cloud Radar System)





- W-Band, coherent, polarimetric, Doppler radar
- Frequency; 94.155 GHz
- Peak Power; 1.7 kW
- PRF; 0.5-20 kHz
- Pulse Width; 0.25-2.0 microsec
- Beam Width / Gain; 0.6 by 0.8 / 46.4 Airborne
- Sensitivity; -29 dBZ
- Stratosphere to Surface detection
- Cloud properties
- Precipitation
- Contact; Gerry Heymsfield heymsfield@agnes.gsfc.nasa.gov
- Reference; *A 94-Ghz Cloud Radar System on a NASA High-Altitude ER-2 Aircraft, AMS JAOT, Volume 21, LI ET AL.*

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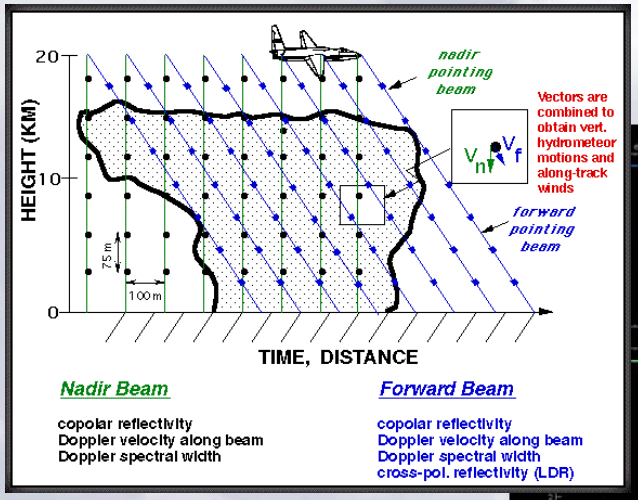
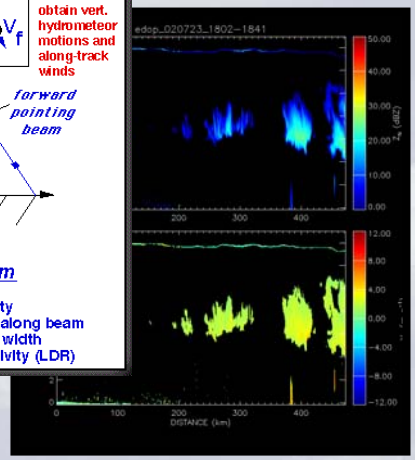
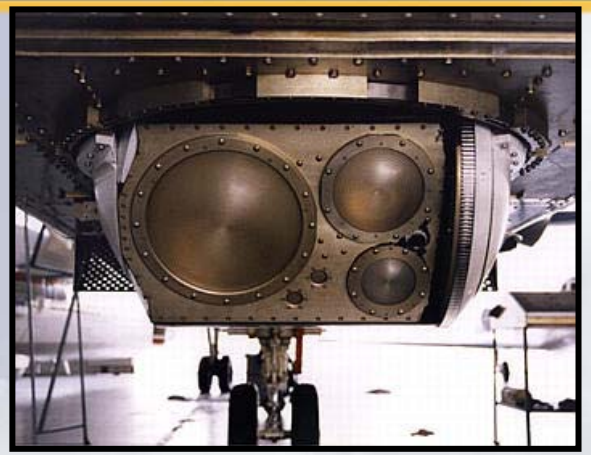
Instrument System and Measurement Specifications – EDOP (9.6 GHz ER-2 Doppler Radar)

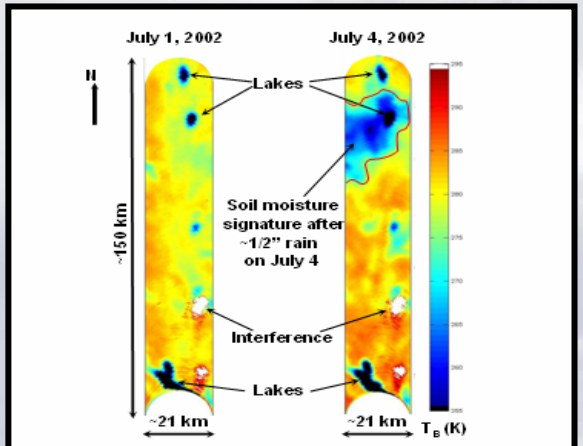




- X-Band, Coherent, Doppler radar
- Fixed Nadir and Forward (33 deg) pointing beams
- Frequency; 9.6 GHz
- Peak Power; 15 kW
- PRF; 4400 Hz
- Pulse Width; 0.5 microsec
- Beam Width / Gain; 2.9 deg / 36 dB
- Dynamic Range; 80 dB
- Minimum Detectable Signal; -5 dBZ
- Precipitation (and microphysical characteristics thereof)
- Contact; Gerry Heymsfield heymsfield@agnes.gsfc.nasa.gov
- Reference; *Heymsfield, G. M., S. Bidwell, I. J. Caylor, S. Ameen, S. Nicholson, W. Boncyk, L. Miller, D. Vandemark, P. E. Racette, and L. R. Dod, 1996: The EDOP radar system on the high-altitude NASA ER-2 aircraft. J. Atmos. Oceanic Tech., 13, 795-809.*

Instrument System and Measurement Specifications- PSR (C- and X-Band Polarimetric Scanning Radiometer)





Soil moisture signature observed ~150 km NNW of Des Moines, Iowa on July 4, 2001 using the NOAA PSR/CX imaging radiometer. The arrows show the location of rainfall (outlined in red), lakes, and some sources of radio frequency interference.

- C-Band Radiometer; 6.9 Ghz
- X-Band Radiometer; 10.7 Ghz
- Soil Moisture
- Accuracy 3-5% in the upper 5cm of soil
- Spatial Resolution 4 and 2.7 Km respectively at 55,000 Ft (~17 Km)
- Swath Width at 55K ft ~ 21 KM
- Contact; Al Gasiewski
- al.gasiewski@noaa.gov
- Reference; *Polarimetric Scanning Radiometer C- and X-Band Microwave Observations During SMEX03, IEEE Transactions on Geosience and Remote Sensing, Volume 43, No. 11, Jackson ET AL.*

Measurement Details

ER2 Desired Measurements for CLASIC (Cloud Land Surface Interaction Campaign)

June-2007 SGP

	MEASUREMENT SOURCE	POSSIBLE MEASUREMENTS AND PRODUCTS	DESIRED MEASUREMENTS AND PRODUCTS
INSTRUMENT SYSTEMS	**Cloud Radar System (CRS)**, W-Band (95 GHz)	**Reflectivity, Doppler, and linear-depolarization ratio measurements** Z_{hh}, V_{hh}, σ_v, LDR Switching of the transmit polarization by the radar controller provides measurement of the linear depolarization ratio, LDR, differential reflectivity, ZDR, and differential phase measurements.	**1) Vertical profiles of calibrated radar reflectivity** **2) Vertical profiles of Doppler velocity** **3) Vertical profiles of estimated IWC** **4) Vertical profiles of linear depolarization ratio** *(provided, however, may be of limited use)* **5) (ASCII files and quick look plots for all of the above quantities)** **(Resolution: 5 sec resolution?)**
	ER-2 Doppler Radar (EDOP), X-Band (9.6 GHz)	**Two Antennas - Nadir and Forward, each Antenna measures the Doppler velocity, Doppler spectral width, and reflectivity factor.** **Nadir; copolarized reflectivity, Doppler velocity, Doppler spectral width (** Z_{nvv}, V_n, σ_n **)** **Forward; Doppler velocity, Doppler spectral width, the cross polarized return (** Z_{fvv}, V_f, σ_f, Z_{fhv} **) and LDR.** Subscripts *v, h, n, and f* denote vertical polarization, nadir beam and forward beam respectively. (*vv* indicates vertical transmit and vertical receive and *hv* indicates vertical transmit and horizontally polarized receive) The Linear Depolarization Ratio (LDR) is defined as $10\log(Z_{fhv}/Z_{fvv})$ **Doppler velocities provide a measure of the**	**From nadir beam:** **1) Vertical profiles of calibrated radar reflectivity** **2) Vertical profiles of Doppler velocity** **3) Vertical profiles of Doppler spectral width** **From forward beam:** **1) Vertical profiles of calibrated radar reflectivity** **2) Vertical profiles of Doppler velocity** **3) Vertical profiles of Doppler spectral width** **4) Vertical profiles of linear depolarization ratio** *(provided, however, may be of limited use)* **Resolution: 5 sec resolution**

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Wednesday, August 30, 2006

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Measurement Details *(continued)*

ER2 Desired Measurements for CLASIC (Cloud Land Surface Interaction Campaign)
June-2007 SGP

		pulse volume-weighted hydrometer motion (hydrometer fall speed + air motion). Vertical air motion can calculated from the nadir beam by removing the fall speed contribution with an approximation. Along-track horizontal air motion can be calculated by combining Doppler wind speeds from forward and nadir beams. The linear depolarization ratio (the ration of the cross-polar to the co-polar reflectivity) can be measured along forward beam. Raw data rates in the Doppler mode are approximately 60 megabytes/sec. This information is processed on-board resulting in data storage of about 100 kilobytes/sec.	
	Cloud Physics Lidar (CPL) (1064, 532, and 355 nm)	Cloud profiling with 30 m vertical and 200 m horizontal resolution at 1064 nm, 532 nm, and 355 nm, providing cloud location and internal backscatter structure. Aerosol, boundary layer, and smoke plume profiling at all three wavelengths. Depolarization ratio to determine the phase (e.g., ice or water) of clouds using the 1064 nm output. Cloud particle size determined from a multiple field-of-view measurement using the 532 nm output (off-nadir multiple scattering detection).	1) Vertical profiles of attenuated backscatter coefficient 2) Vertical profile of depolarization ratio 3) Cloud and aerosol layer boundaries at 1 second resolution 4) Vertical profiles of cloud and aerosol extinction 5) Optical depth estimates as a function of time (aerosol optical depth, cloud optical depth, boundary layer optical depth, cirrus optical depth, total optical depth) 6) Extinction to backscatter ratios 7) Vertical profile of cloud particle size for ice clouds *(this property can only be inferred*

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Wednesday, August 30, 2006

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Measurement Details *(continued)*

ER2 Desired Measurements for CLASIC (Cloud Land Surface Interaction Campaign)
June-2007 SGP

		Direct determination of the optical depth of cirrus clouds (up to ~OD 3) using the 355 nm output.	*where coincident CRS data are available not a deliverable)*
	MODIS Airborne Simulator (MAS), Multi-Spectral IR, Near IR, Visible	Level-1B data (calibrated and geolocated radiances). 50 multispectral bands from- 445 nanometers to 14.428 micrometers. There are 5 visible bands, and bands in the near IR, IR and far IR. Calculation of surface albedo is possible using the visible channels. Level-0 quick-look imagry are available in-field and nadir surface temperature plots (1 Km cell along flight track). MAS FOV 2.5 mrad (50 m @ 65K Ft.) Swath Width at 55K ft ~ 37.5 KM Resolution is 30-35 meters at 40-45,000 Ft MSL (desired by CLASIC Ground Science Group) Data are encoded with position, time code, and blackbody calibration information. HDF format files delivered within 60 days of end of mission.	Calibrated and geolocated spectral radiances MAS Channels (50) are listed at this URL; http://mas.arc.nasa.gov/reference/mas_bands_doc.html
	Polarimetric Scanning Radiometer (PSR), C-Band and X-Band (~6.9 Ghz and ~10.7Ghz)	Surface Brightness Temperature—Need MAS data product to derive surface emissivity for retrievals of soil moisture. PSR Spatial Resolution 4 and 2.7 Km respectively (C and X-band) at 55,000 Ft (~17 Km) Swath Width at 55K ft ~ 21 KM	Retrievals of surface emissivity and soil moisture

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Measurement Details *(continued)*

ER2 Desired Measurements for CLASIC (Cloud Land Surface Interaction Campaign)
June-2007 SGP

HIGH LEVEL PRODUCT DEVELOPMENT	**MODIS Airborne Simulator (MAS)**, Multi-Spectral IR Imager	**Geophysical Retrievals- Cloud Location, Shadows, Cloud Optical Properties; Cloud Optical Thickness and Effective Radius. Derived from the level-1B MAS radiances. The Cloud Physics Lidar is desired to verify cloud occurrence and cloud top. There currently no retrieval algorithms for aerosol optical properties, cloud top altitude or water vapor products (even though the information is contained in the MAS radiances).** *Per Mike King: Unable to provide;* "**aerosol & cloud optical depth separately**"	*1) cloud optical thickness* *2) cloud effective radius* *3) cloud top height (temperature)* *4) cloud fraction* *5) cloud phase*
AIRCRAFT STATE PARAMETERS	**ER2 Navigation Recorder**	**Aircraft, attitude, position, velocity, heading, outside air temperature, pressure**	**1) GPS/INS Altitude; 2) Attitude; 3) Pitch; 4) Roll; 5) Latitude; 6) Longitude; 7) Air Temperature; 8) Pressure; 9) Heading; 10) True Air Speed**

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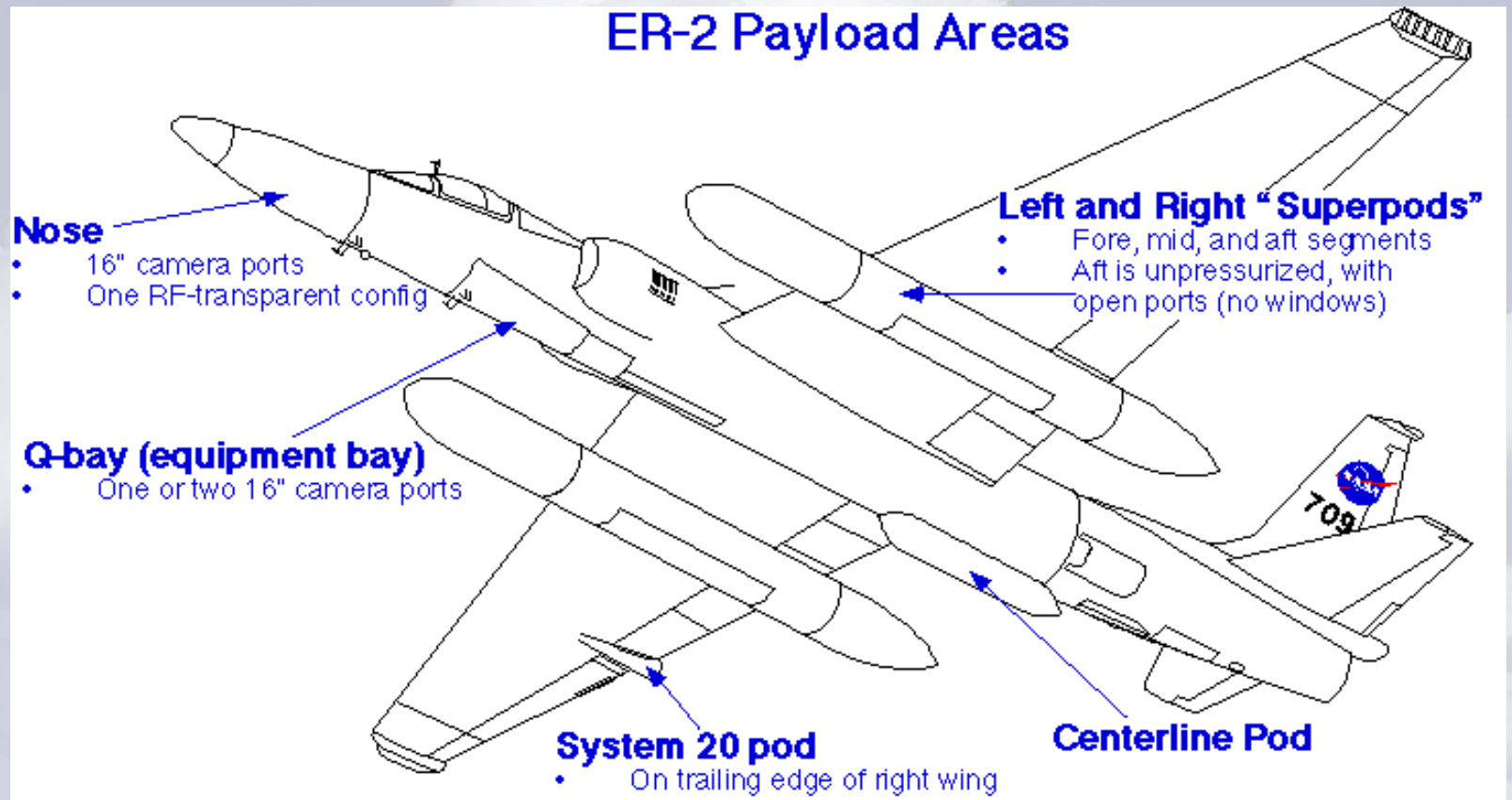
Aircraft and Instrument Integration

- MAS/CPL/CRS/EDOP have been integrated with the ER-2 on past missions
- *Work ongoing to integrate the PSR*
- *Weight and balance adjustments*

Aircraft and Instrument Integration

(Continued)



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Current Status and Next Steps

- Planning target for flight hours is 72 hours (3 weeks, 12 Research flights, 6 hours per flight)
- Flight operations are out of Dryden – flight base from San Antonio, TX
- Specified instrument systems are available for the experiment
- All SOW negotiations for ER2 participation are complete
- DOE Assessment of ER2 flight operations
- Mission planning and coordination

Thank You !