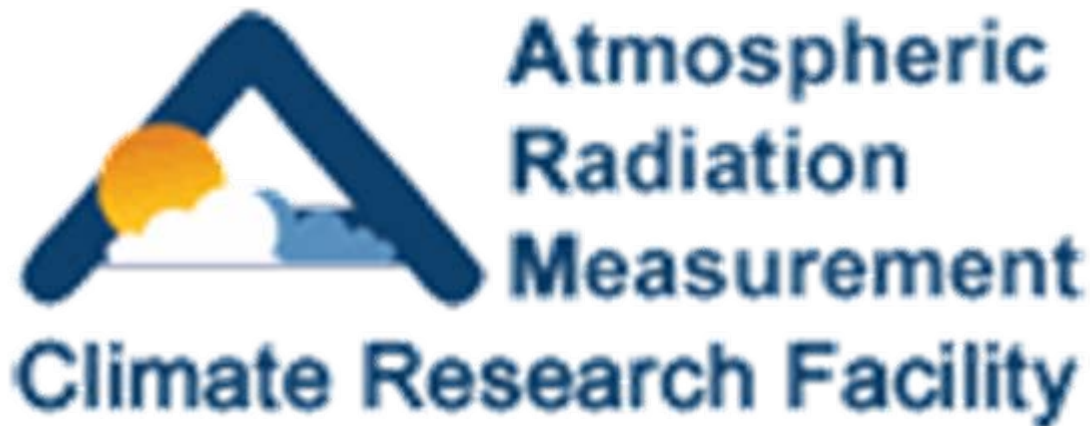




# **Atmospheric Radiation Measurements – ARM**

**Jeff Gaffney**

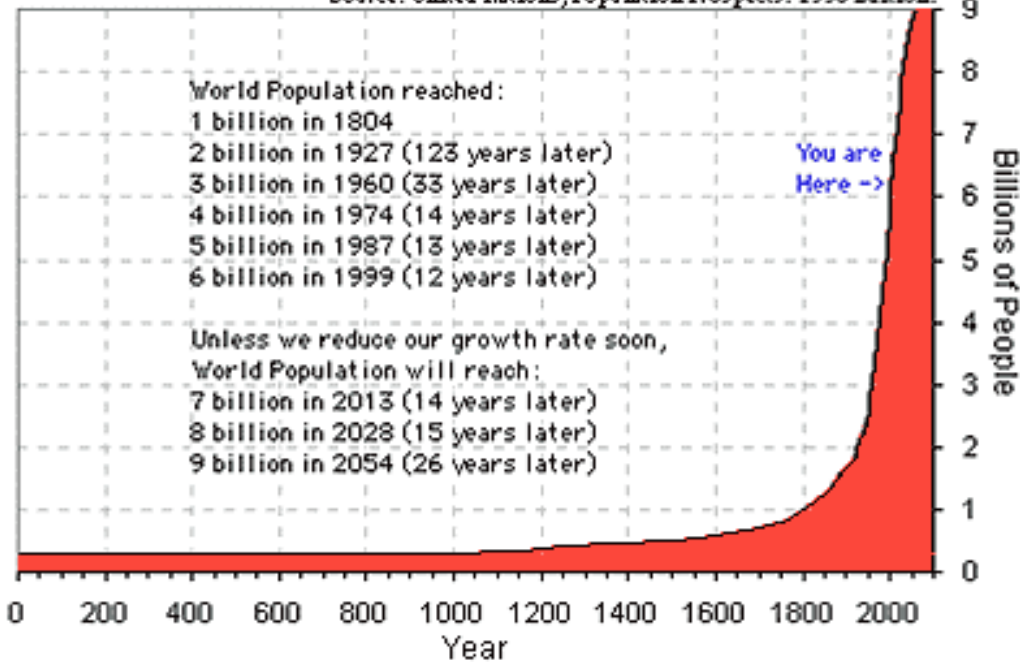


A National User Facility  
for the Scientific Community

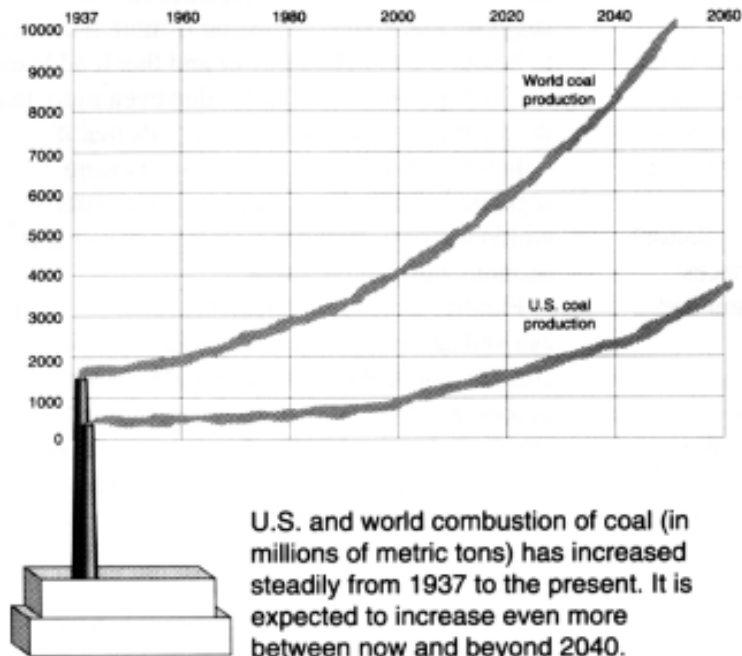
<http://www.arm.gov>

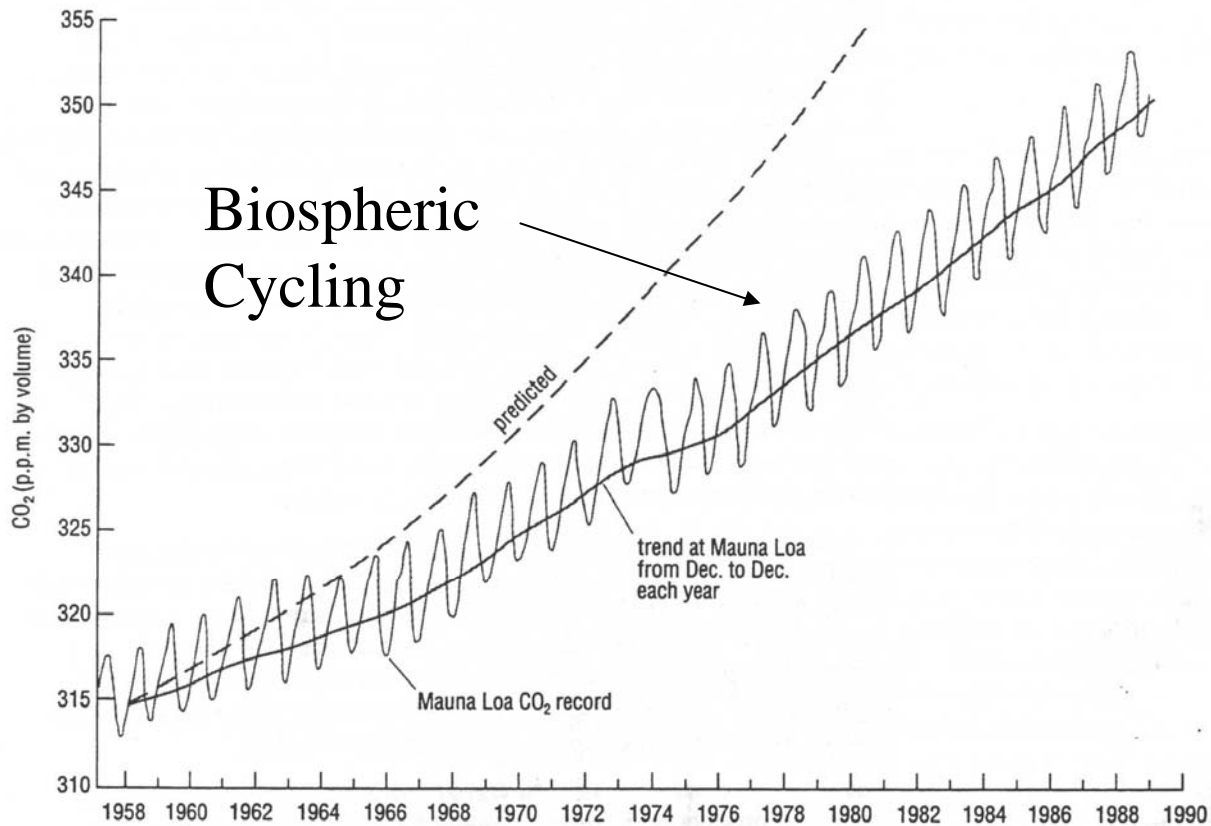
# Population Goes Up – Energy Demand Goes Up!

Source: United Nations, Population Prospects: 1998 Edition.



U.S. AND WORLD COAL COMBUSTION (millions of tons)





Biospheric  
Cycling

Northern  
Hemisphere

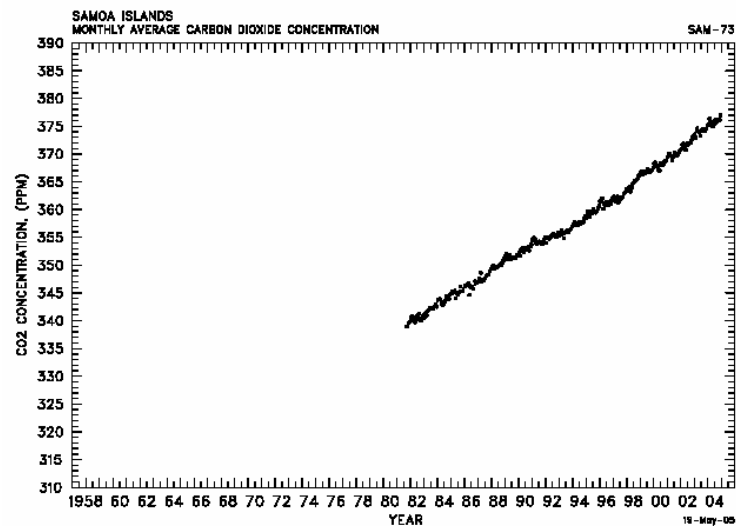
Mauna Loa

Keeling, et. al

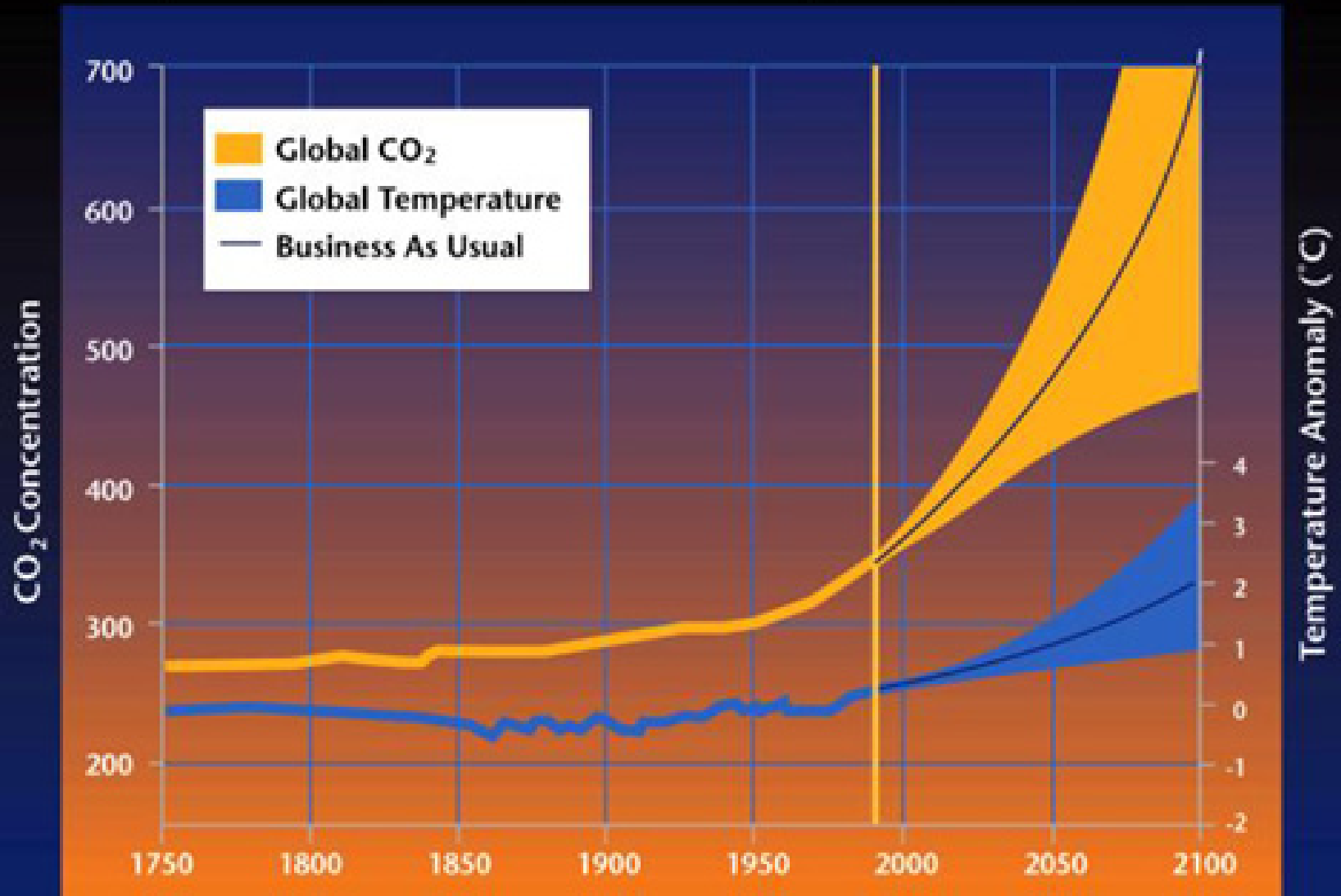
(b)

Southern Hemisphere

Samoa



# Projection of CO<sub>2</sub> and Temperature to 2100



# NOT JUST CARBON DIOXIDE

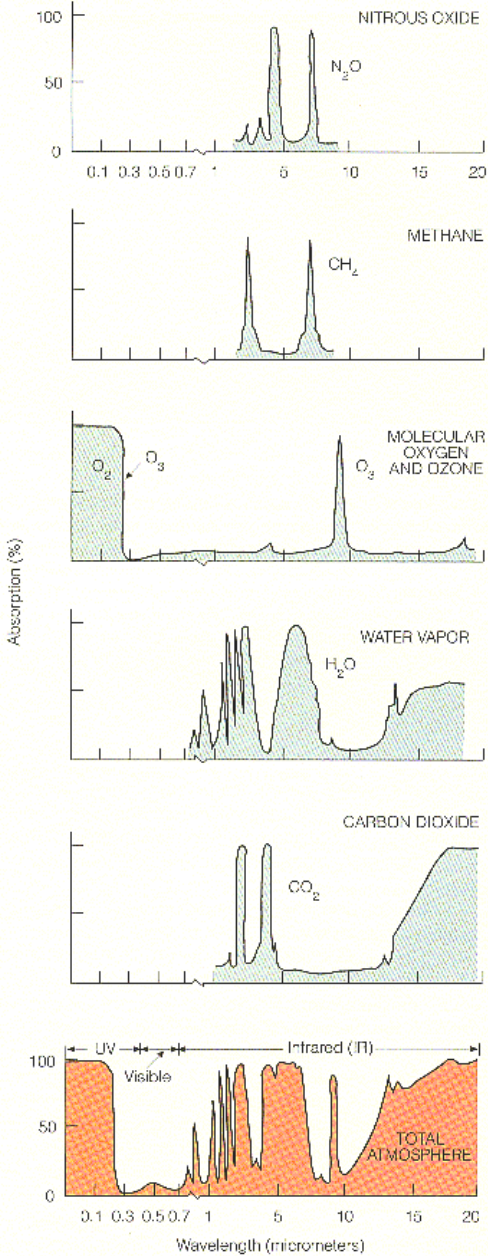
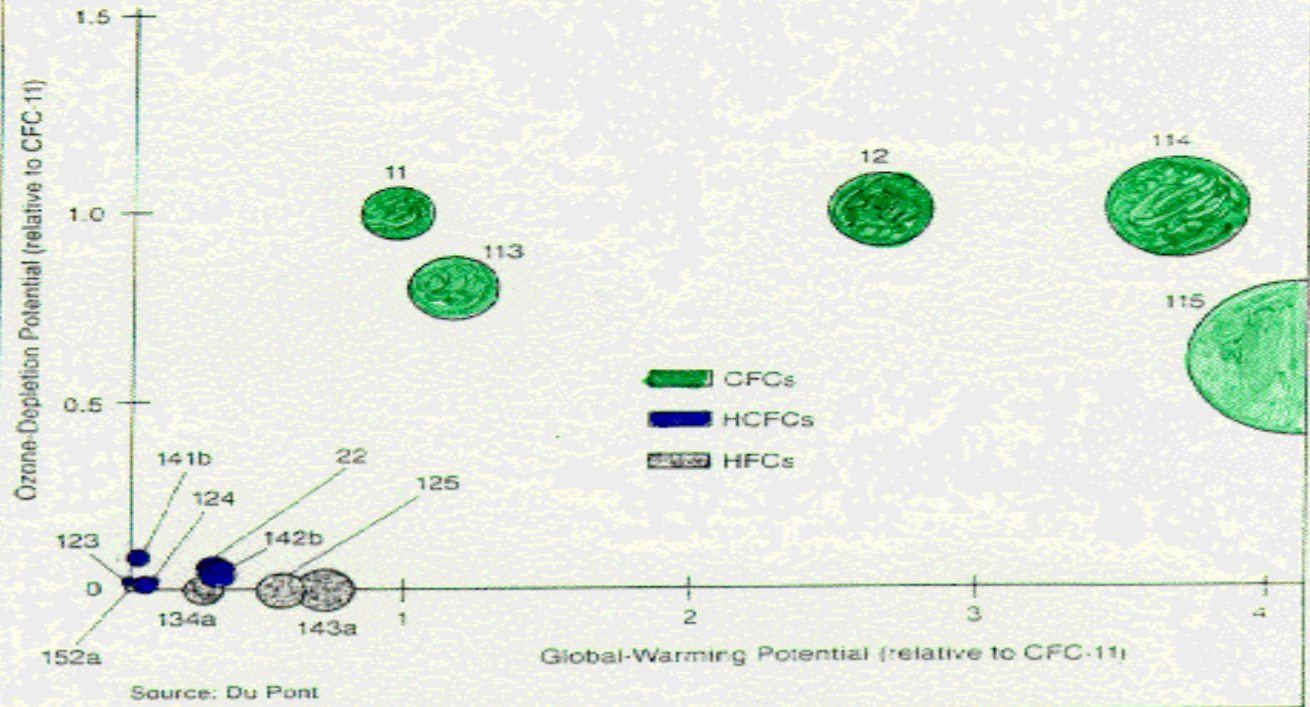


FIGURE 2.10  
Absorption of radiation by gases in the atmosphere.

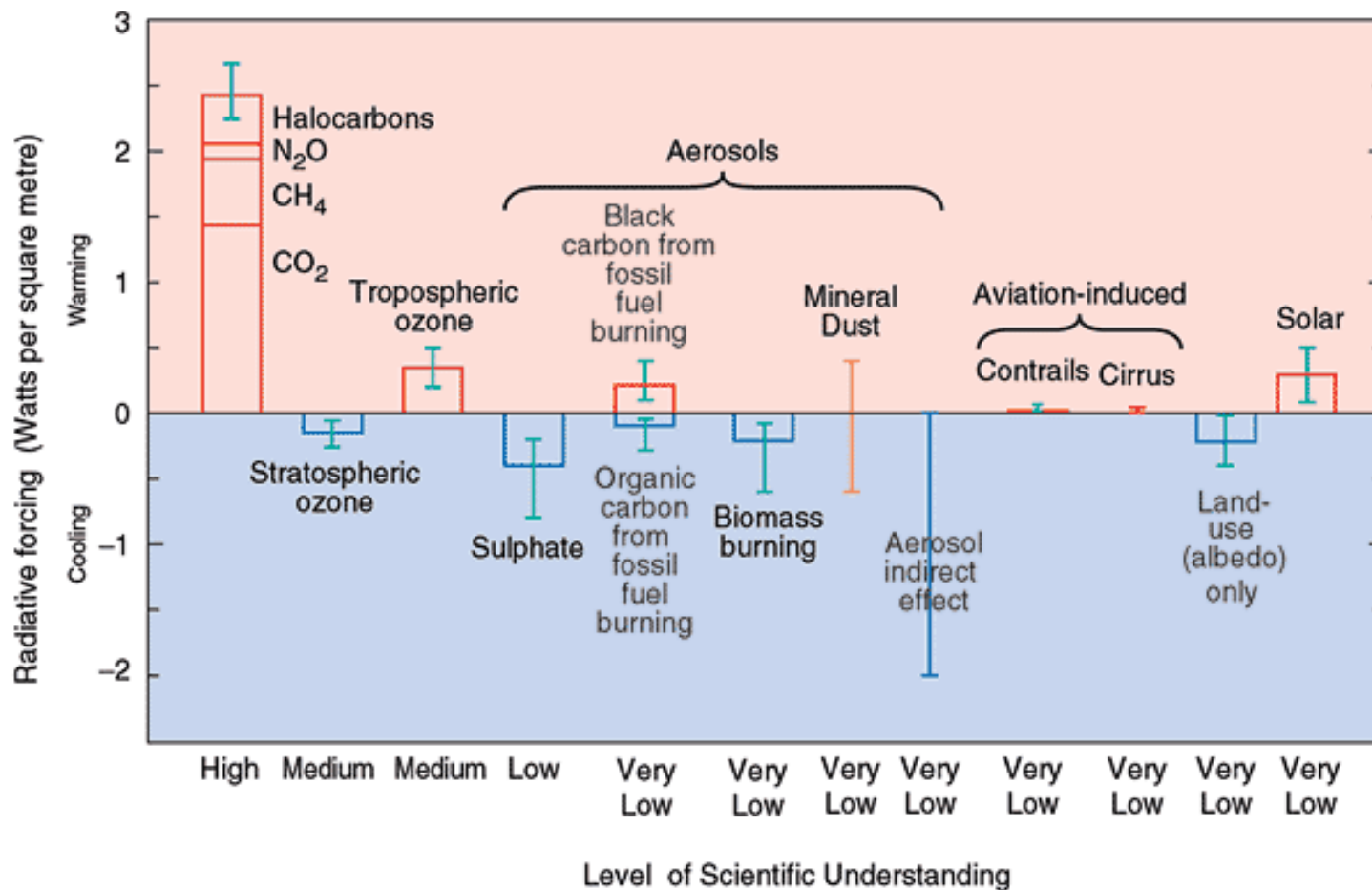
## Double Danger From CFCs

Fully halogenated CFCs and many of the compounds being considered as alternatives have the potential both to deplete stratospheric ozone and to contribute to possible global warming through the absorption of infrared energy. In this graph, the ozone-depletion and global-warming potentials are represented for various compounds relative to CFC-11, which is given a value of 1 on both axes; the circles are proportional in area to the compounds' atmospheric lifetimes. The fully halogenated CFCs have long lifetimes and considerable potential to contribute to both problems. The hydrochlorofluorocarbons (HCFCs) break down much faster in the atmosphere and therefore have only about 2-5% of the ozone-depletion potential of CFCs. The hydrofluorocarbons (HFCs) contain no chlorine to threaten stratospheric ozone, but they do have some potential to act as greenhouse gases.

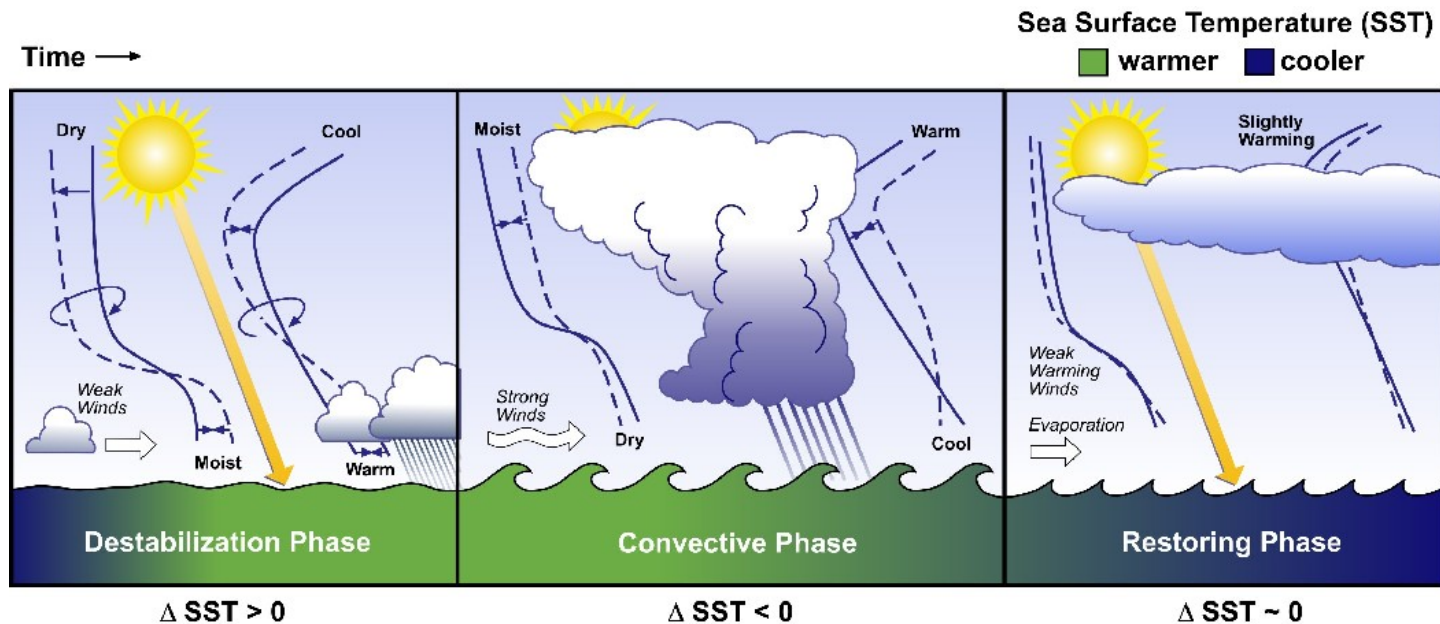



# AEROSOLS-CLOUDS – ARE NOW THE BIG UNCERTAINTY

The global mean radiative forcing of the climate system for the year 2000, relative to 1750



The primary goal of the ARM Program is to improve the treatment of cloud and radiation physics in global climate models in order to improve the climate simulation capabilities of these models.





**Atmospheric  
Radiation  
Measurement  
Climate Research Facility**

---

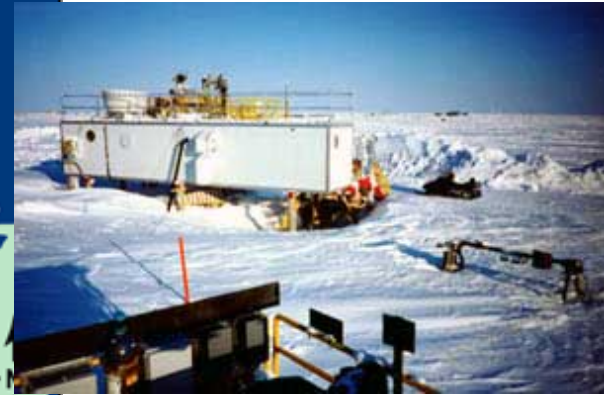
A National User Facility  
for the Scientific Community

## **Mission Statement**

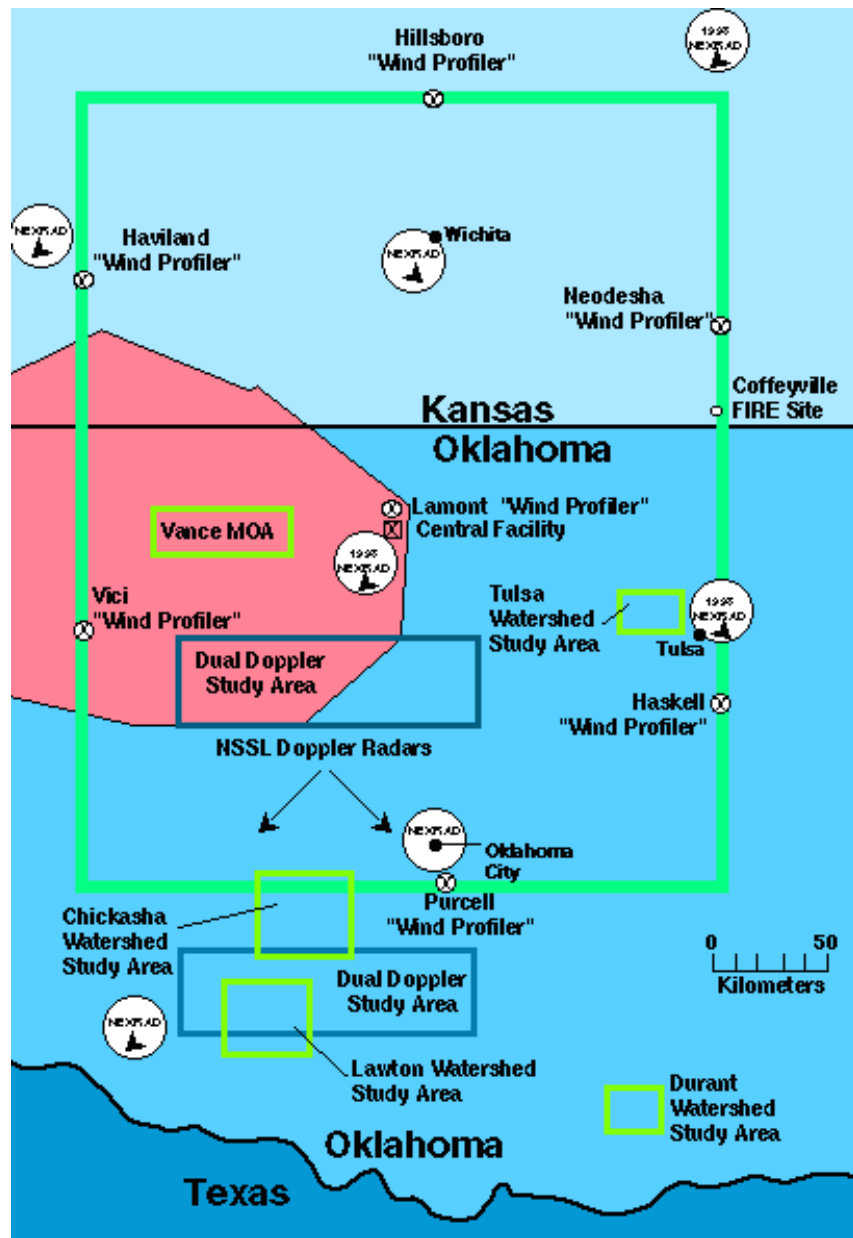
The U.S. Department of Energy's (DOE's) ARM Climate Research Facility (ACRF) has been designated a national user facility for the purpose of providing this unique asset for the study of global change to the broader national and international research community. Research at this facility will include the study of alterations in climate, land productivity, oceans or other water resources, atmospheric chemistry, and ecological systems that may alter the capacity of the Earth to sustain life. Global change research also includes the study, monitoring, assessment, prediction, and information management activities to describe and understand:

- The interactive physical, chemical, and biological processes that regulate the total Earth system
- The unique environment that the Earth provides for life
- The changes that are occurring in the Earth system and the environment and how these changes are influenced by human actions.

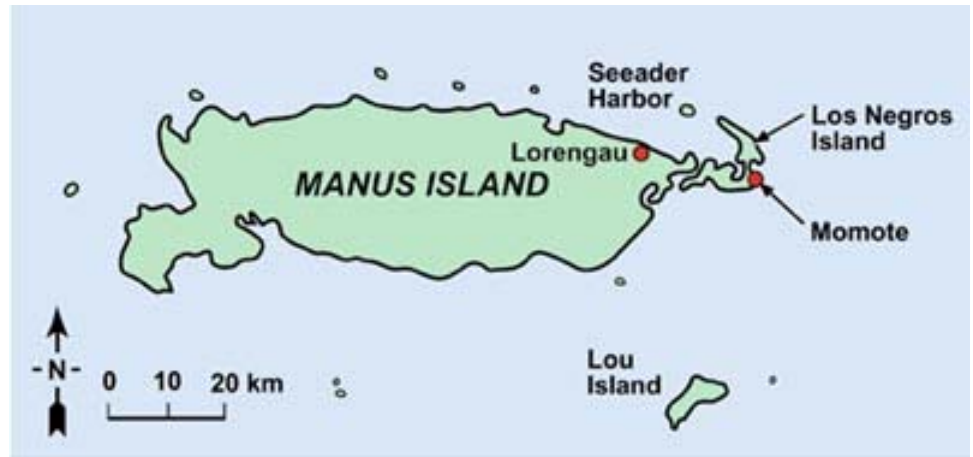




# Southern Great Plains Research Site

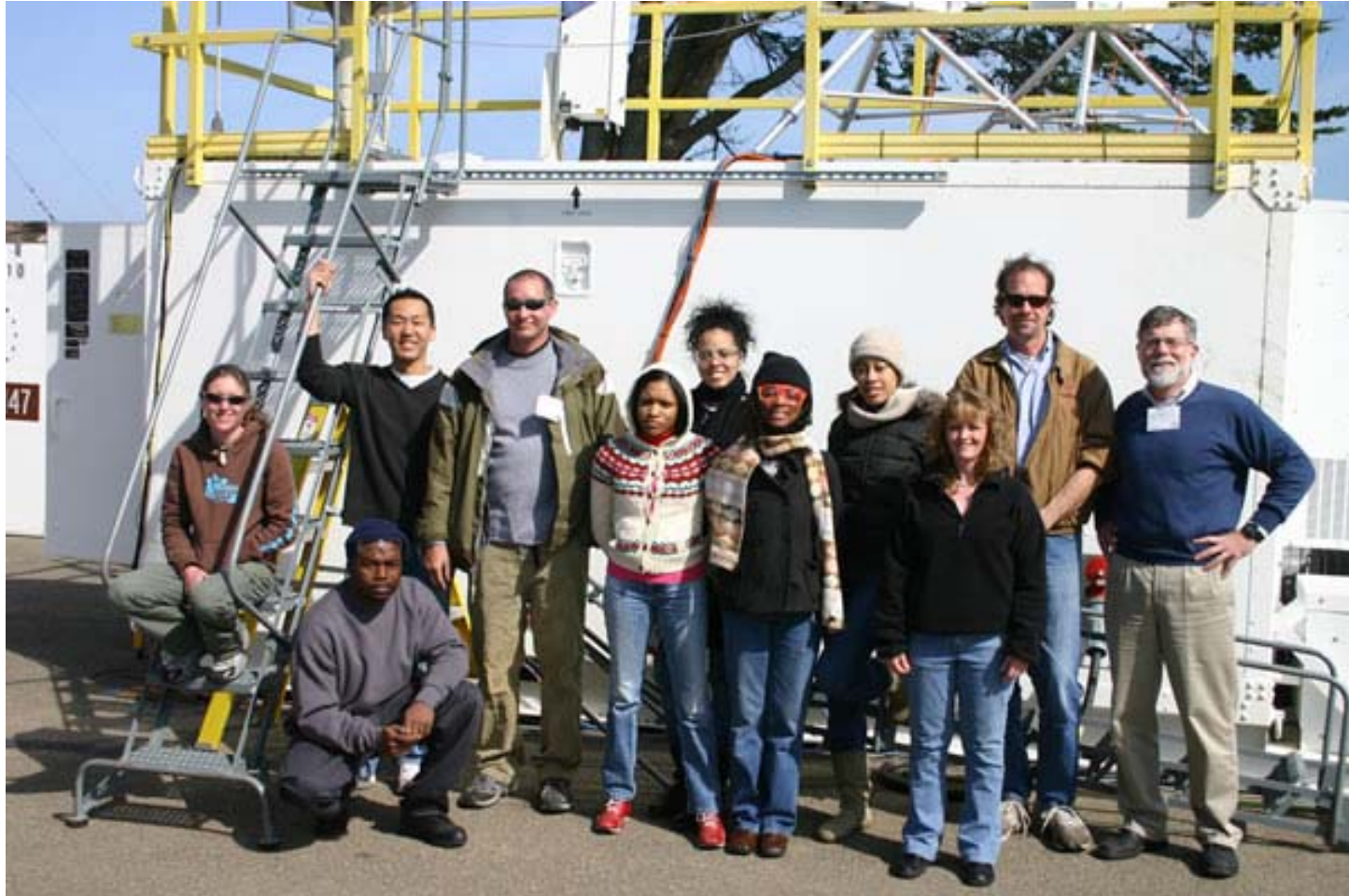


# Tropical Western Pacific



MOBILE FACILITY... more on that later

POINT REYES - California



# ARM INSTRUMENTATION.....

## **Measurement Categories**

- Shortwave Spectral Radiation
- Cloud Properties
- Surface Meteorology
- Atmospheric Profiling
- Surface Energy Flux
- Aerosols
- Atmospheric Carbon
- Airborne Platforms
- Longwave Spectral Radiation
- Longwave Broadband Radiation
- Shortwave Broadband Radiation
- Retired Instruments

## **Shortwave Spectral Radiation**

Radiometric measurements provide data on the propagation of electromagnetic energy through the atmosphere. These types of measurements represent the majority of ARM data, and are obtained using various types of active (such as radar and lidar) and passive (such as broadband radiometers and spectral sensors) sensors.

- Absolute Solar Transmittance Interferometer (ASTI)
- Baseline Solar Radiation Network (BRS)
- Cimel Sunphotometer (CSPHOT)
- Multifilter Radiometer (MFR)
- Multifilter Rotating Shadowband Radiometer (MFRSR)
- Narrow Field of View (NFOV)
- Normal Incidence Multifilter Radiometer (NIMFR)
- Rotating Shadowband Spectrometer (RSS)
- Shortwave Spectrometer (SWS)
- Solar Radiance Transmission Interferometer (SORTI)

## Cloud Properties

Active and passive remote sensing instruments are used to measure the macroscopic properties (horizontal and vertical distributions) of clouds, and the microphysical properties (sizes, shapes, and phases [water or ice]) of the particles that comprise the clouds.

- Belfort Laser Ceilometer (BLC)
- Micropulse Lidar (MPL)
- Microwave Radiometer (MWR)
- Microwave Radiometer Profiler (MWRP)
- Millimeter-Wavelength Cloud Radar (MMCR)
- Narrow Field of View (NFOV)
- Raman Lidar (RL)
- Total Sky Imager (TSI)
- Vaisala Ceilometer (VCEIL)
- Video Time-Lapsed Camera (VTLC)
- Whole Sky Imager (WSI)



**MULTI-FILTER ROTATING SHADOW BAND RADIOMETER**



**METEOROLOGY**

**Measurements**

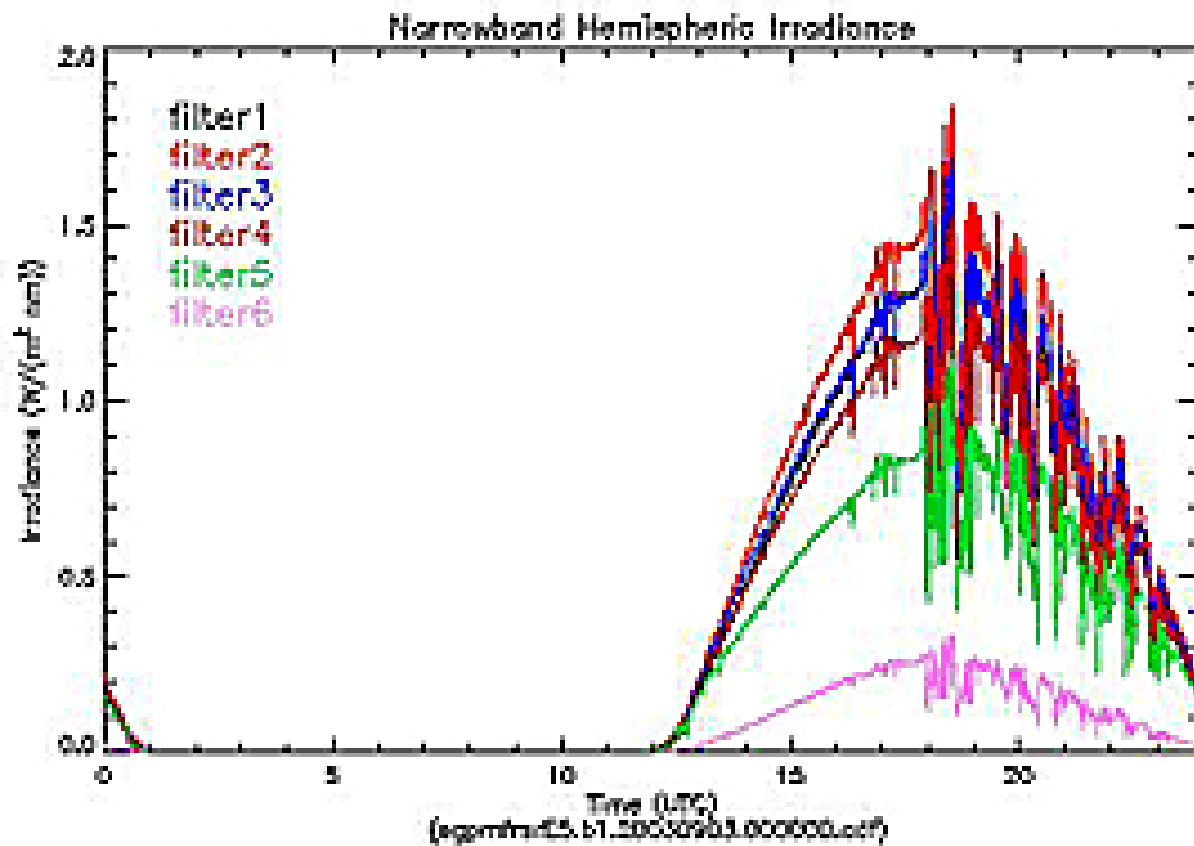
**LOTS OF DATA!**

# Datastreams by Measurement Category

## Shortwave Spectral Radiation

Radiometric measurements provide data on the propagation of electromagnetic energy through the atmosphere. These types of measurements represent the majority of ARM data, and are obtained using various types of active (such as radar and lidar) and passive (such as broadband radiometers and spectral sensors) sensors.

- brs
- brs20s
- mfr10m
- mfr25m
- mfrsr
- nfov
- nfov2ch
- nimfr



RAW DATA – Quality Assured and Archived – Daily

FOR ALL SITES..

HUGE DATA SETS...

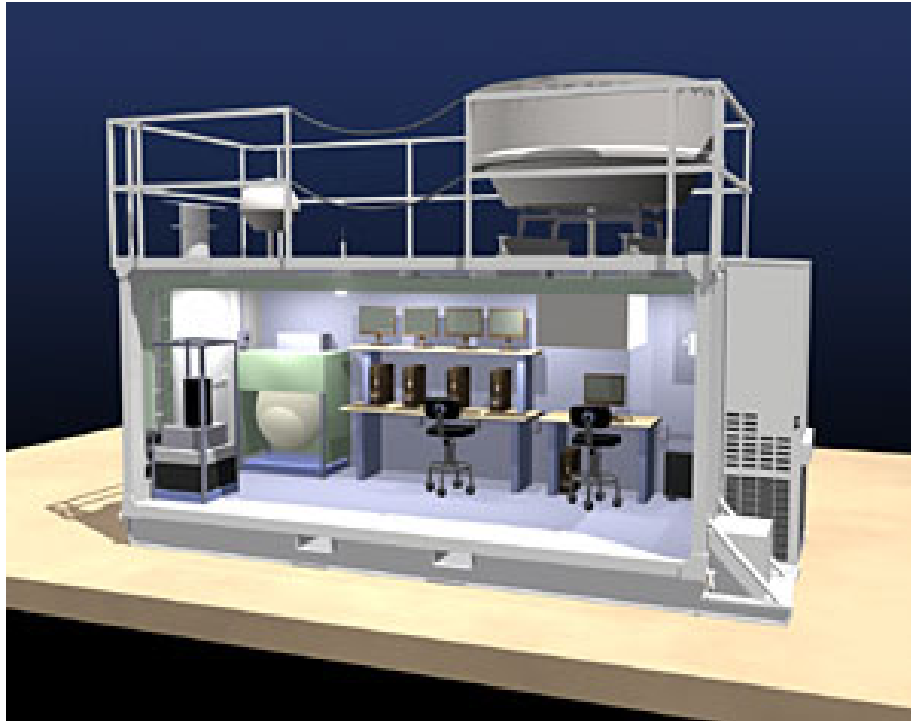
## SOME EXAMPLES OF ARM SCIENCE...

- Dr. Bruce Albrecht, University of Miami, and Dr. Pavlos Kollias, NOAA/CIRES/ETL: "Development and Evaluation of Boundary Layer Cloudiness Parameterization Using ARM Observations"
- NEW*-Drs. Richard Austin and Graeme Stephens, Colorado State University: "Operational Retrieval of Cloud Microphysical Properties Using Combined Measurements by Diverse Instruments"
- NEW*-Dr. Howard Barker, Meteorological Service of Canada: "Advancing the Representation of Radiative Transfer for Cloudy Atmospheres in Global Climate Models"
- NEW*-Dr. Larry Berg, Pacific Northwest National Laboratory: "Development, Evaluation, and Application of New Parameterization Framework for Boundary-Layer Cumuli"
- NEW*- Dr. Christopher Bretherton, University of Washington: "ARM-based Development of a New Combined Parameterization for Shallow and Deep Cumulus Convection in Large-Scale Climate Models"
- NEW*-Dr. Jennifer Comstock, Pacific Northwest National Laboratory, and Dr. Ruei-Fong Lin, NASA/Goddard Space Flight Center: "Investigation of High Ice Supersaturation in Cirrus Clouds Using ARM Measurements and an Explicit Cloud Model"

<http://www.arm.gov>

# *The ARM Mobile Facility ( AMF) and UAV Program*

Jeff Gaffney- Rick Petty (DOE, OBER)



Spring 1999 - Kauai, Hawaii  
Science flights over 55,000 feet

<http://www.arm.gov/sites/amf.stm>

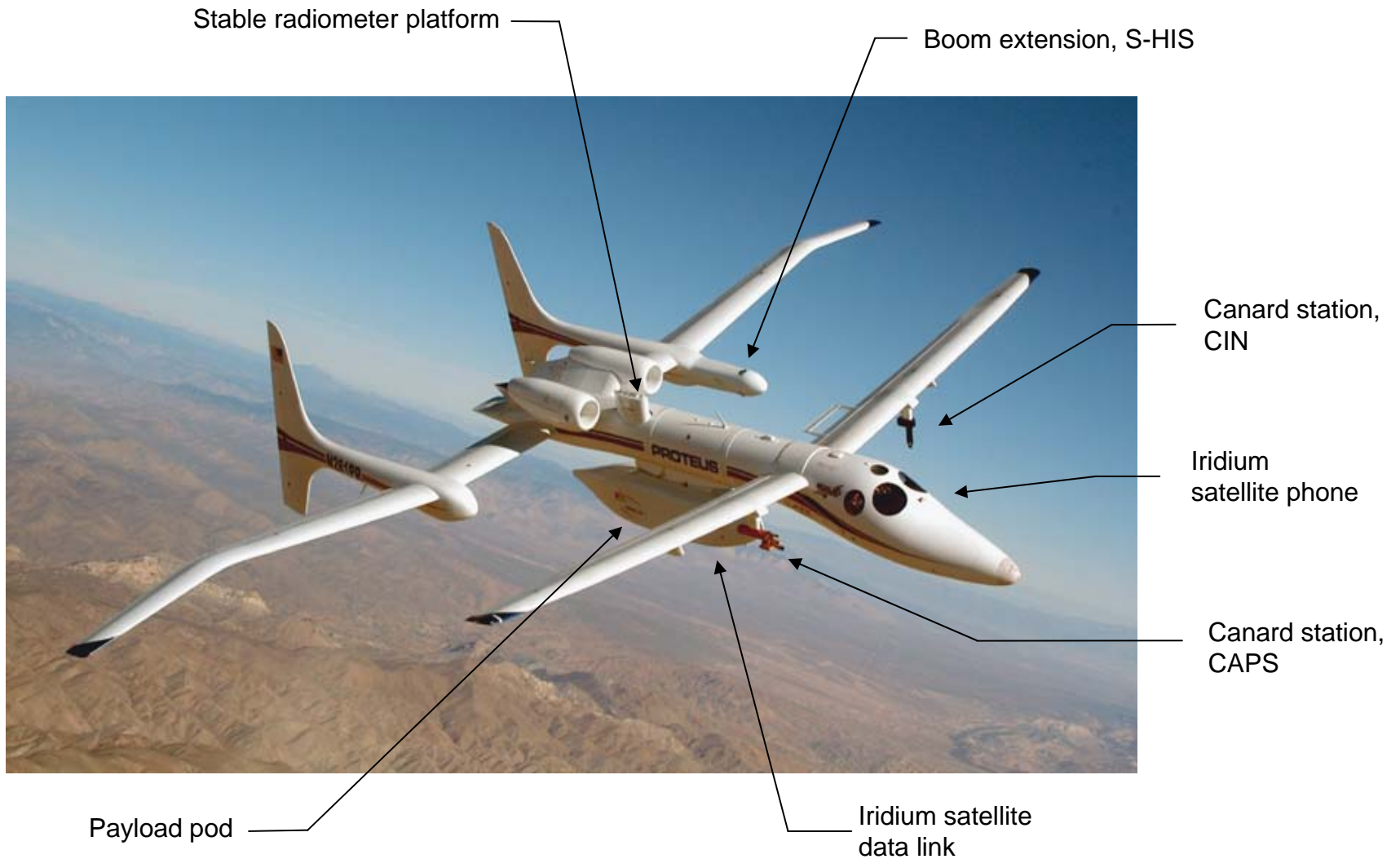
<http://armuav.ca.sandia.gov/armuav.html>

# Proteus performance characteristics



<b>Altitude record (10/25/00):</b>	<b>62,786 feet (peak)</b> <b>61,919 feet (sustained)</b> <b>55,786 feet (w/1000 kg payload)</b>
<b>Ceiling w/ARM-UAV payload:</b>	<b>Approx. 52,000 feet</b>
<b>Stall speed:</b>	<b>65 knots</b>
<b>Top speed:</b>	<b>250 knots/M=0.6</b>
<b>Mission duration:</b>	<b>Approx. 12 hours</b>
<b>Payload electrical power:</b>	<b>30 kW; demonstrated 600 A @ 60 kft</b>

# ARM-UAV/Proteus payload arrangement





# ARM-UAV has conducted ten major field campaigns

## *Field Campaigns to date:*

- Fall 1993, Edwards AFB, CA
- Spring 1994, Northern OK
- Fall 1995, Northern OK
- Spring 1996, Northern OK
- Fall 1996, Northern OK
- Fall 1997, Northern OK
- Spring 1999, PMRF Kauai, HI
- Summer 1999, Monterey, CA
- Winter 2000, Northern OK
- Fall 2002, Northern OK

**Proteus (F02)**

QuickTime™ and a  
Photo - JPEG decompressor  
are needed to see this picture.



**GA-ASI "GNAT 750"  
(F93, S94)**



**Grob "Egrett"  
(F95, S96)**



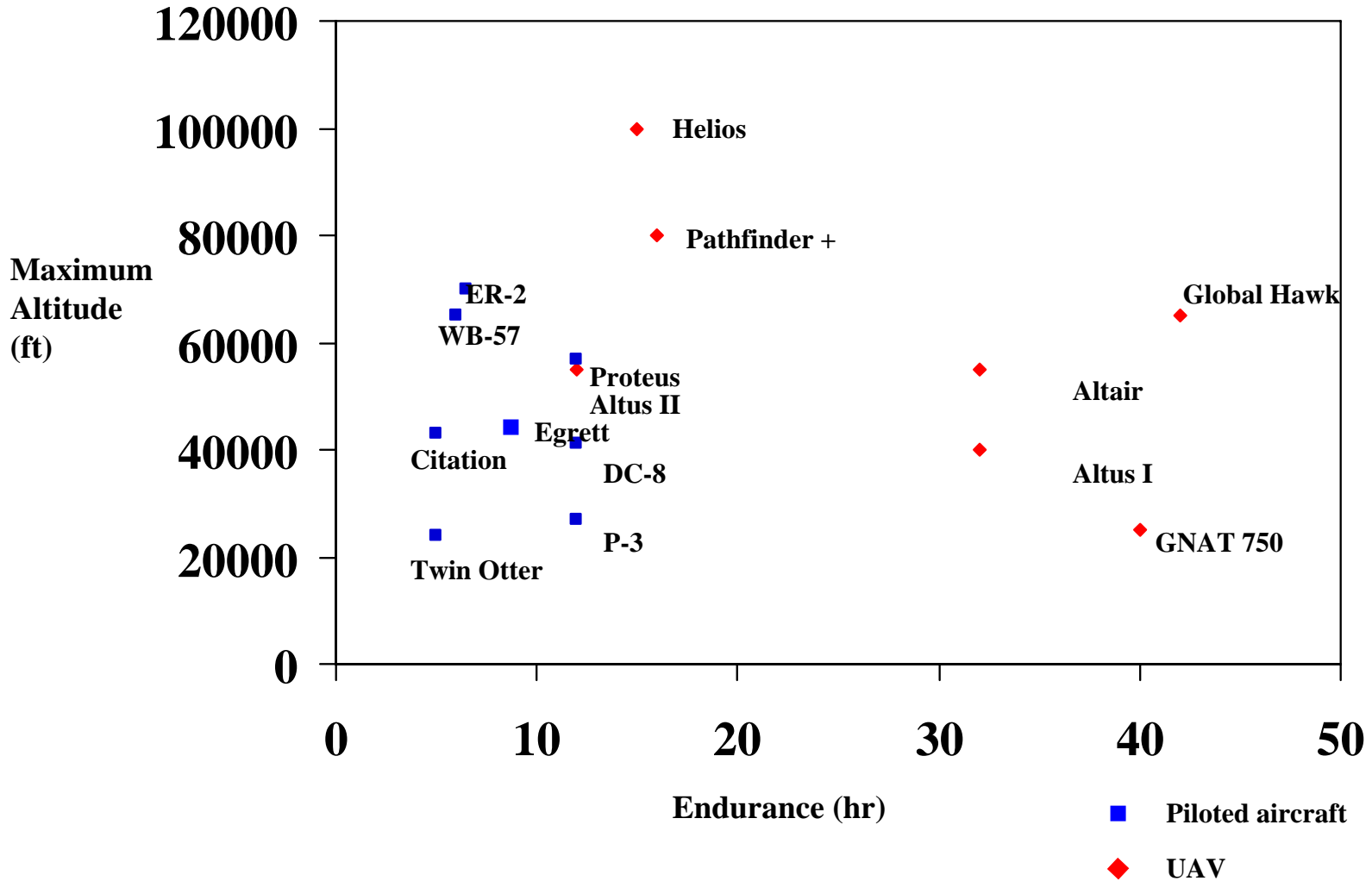
**GA-ASI "Altus I" (F96, F97)**

**GA-ASI "Altus II"  
(Su99)**



**Twin Otter  
(F93, S94, F95, S96, F96,  
F97, Sp99, Su99, W00)**

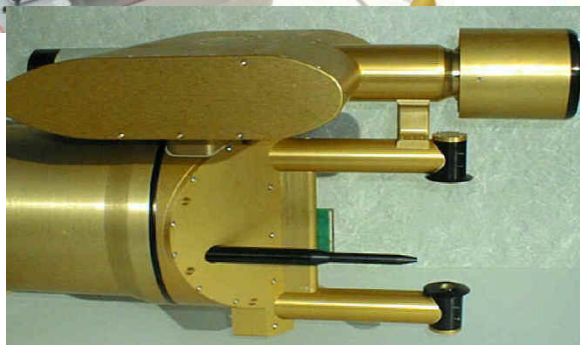
# High altitude, long endurance aircraft options



# Recent additions to ARM-UAV payload instruments

Instrument	Description	Lead organization
Compact millimeter-wave radar (CMR)	95 GHz cloud radar	University of Massachusetts-Amherst
Cloud, Aerosol, and, Precipitation Spectrometer (CAPS)	Cloud particle size measurement, 0.3 $\mu\text{m}$ to over 1.5 mm	Droplet Measurement Technologies
Cloud Integrating Nephelometer (CIN)	Cloud optical extinction characteristics	Geber Scientific, Inc.
Nevzorov Probe	Cloud liquid/total water content	Sky Tech Research, Inc.
Video Ice Particle Sampler (VIPS)	Cloud ice particle morphology, 5 to 150 $\mu\text{m}$	NCAR

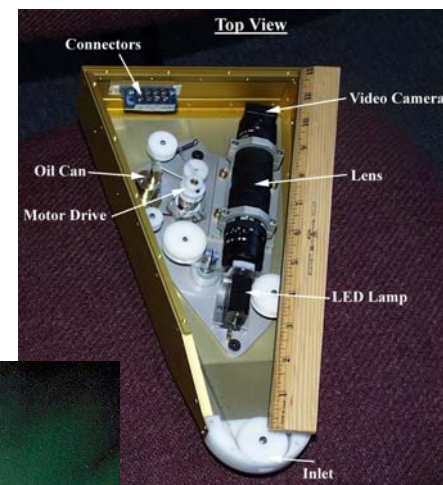
CMR



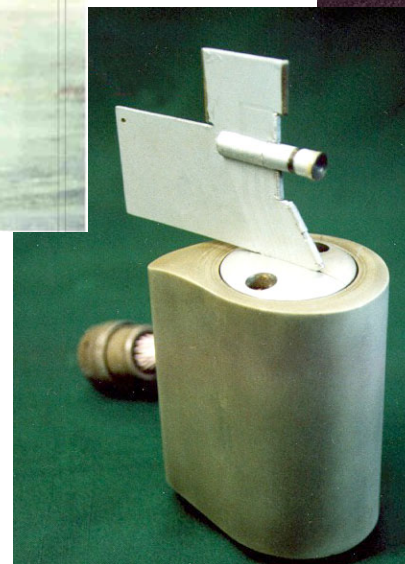
CAPS



CIN



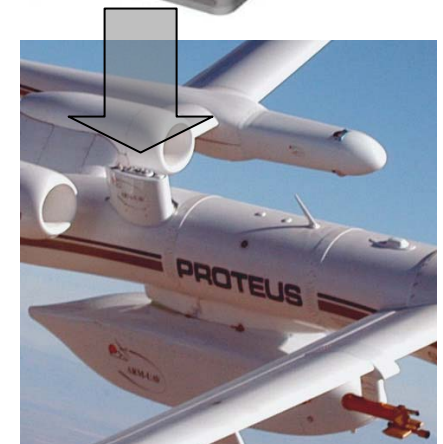
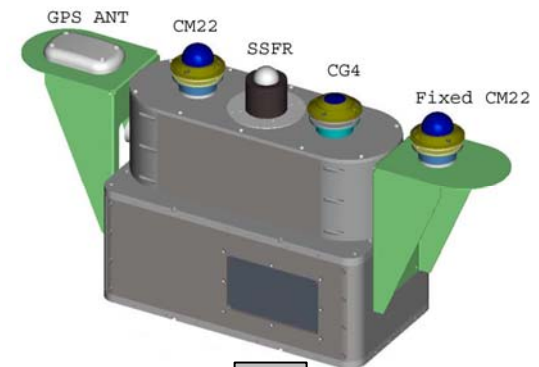
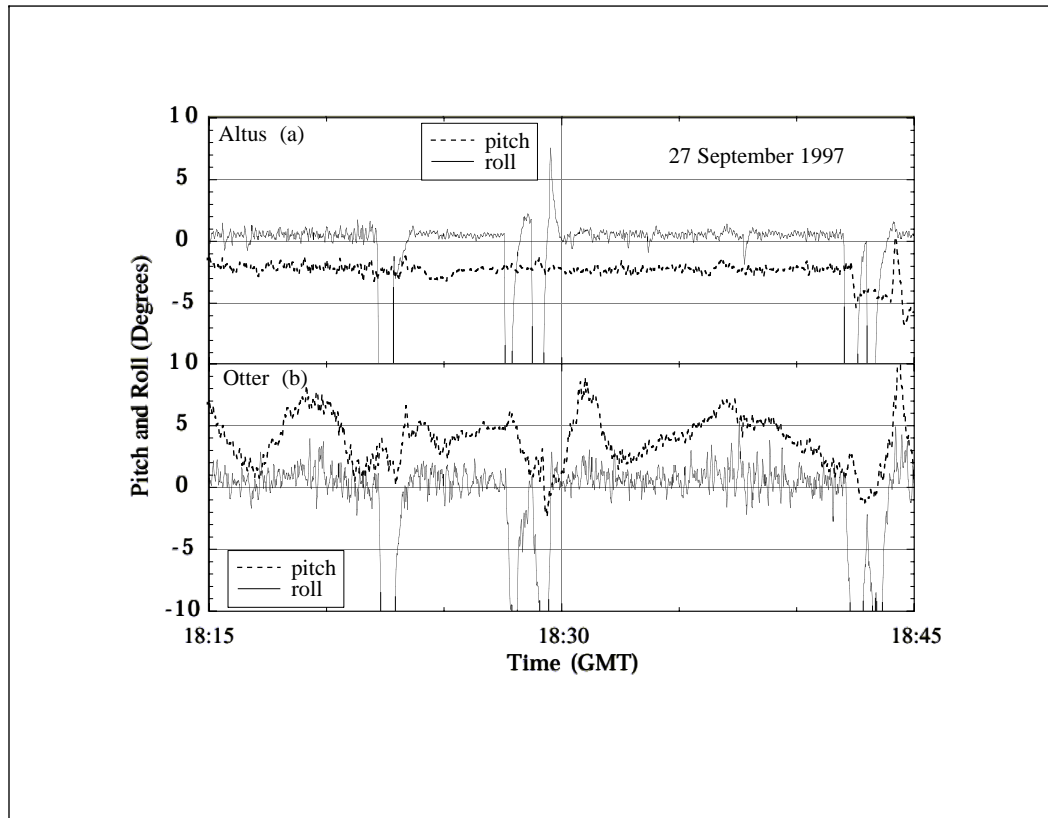
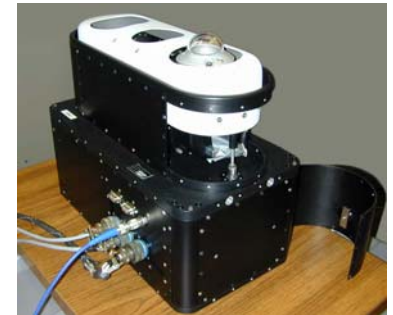
VIPS



Nevzorov

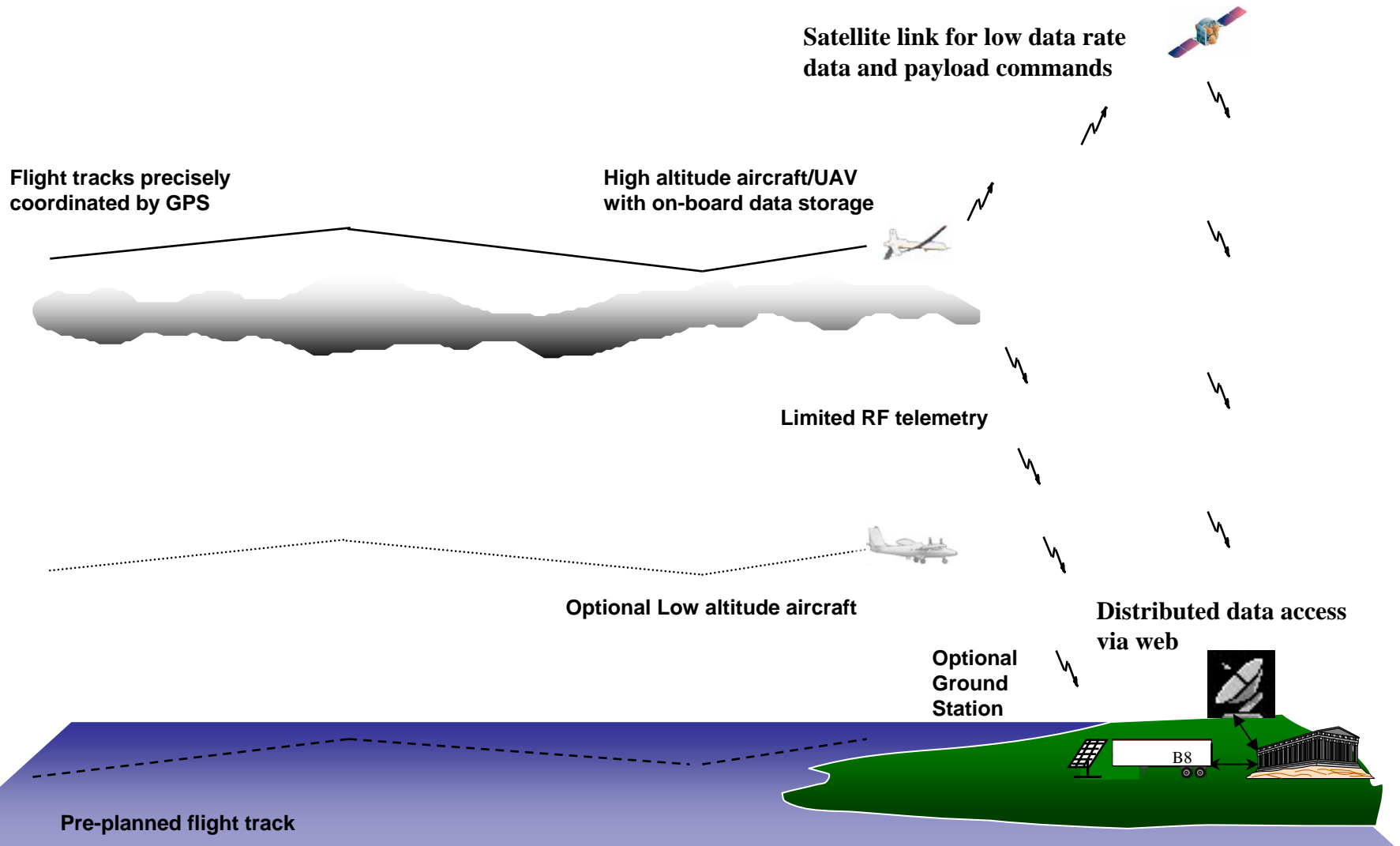
# Stabilized radiometer platform improves measurements

Stabilized radiometer platform prevents small-scale angular motion

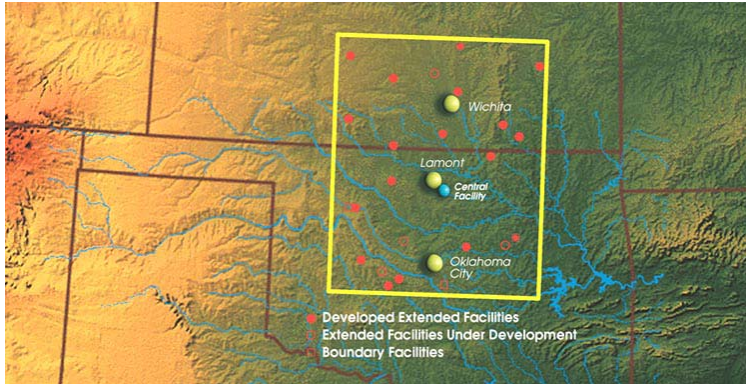


*Angular stability is important for radiometric measurements*

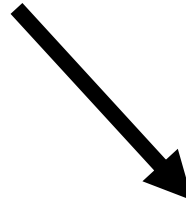
# Arrangements for recent and future ARM-UAV deployments



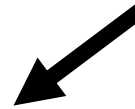
# The ARM-UAUV “Grand Tour”



**Southern Great Plains - Oct/Nov 2002**  
**Cirrus cloud tops**  
**Microphysical properties**



**North Slope of Alaska - October 2004**  
**Arctic cirrus properties**  
**Surface melt radiation budget**



**Darwin, Australia - February 2006**  
**Tropical cirrus clouds**

# ARM-UAV mission control and display capabilities

Mission Controller monitors and controls payload by three means:

- Ethernet direct connection (hangar/ramp only)
- RF modem (line-of-sight,  $\leq$  about 30 miles from base)
- Low data rate/low cost satellite data link (Iridium)

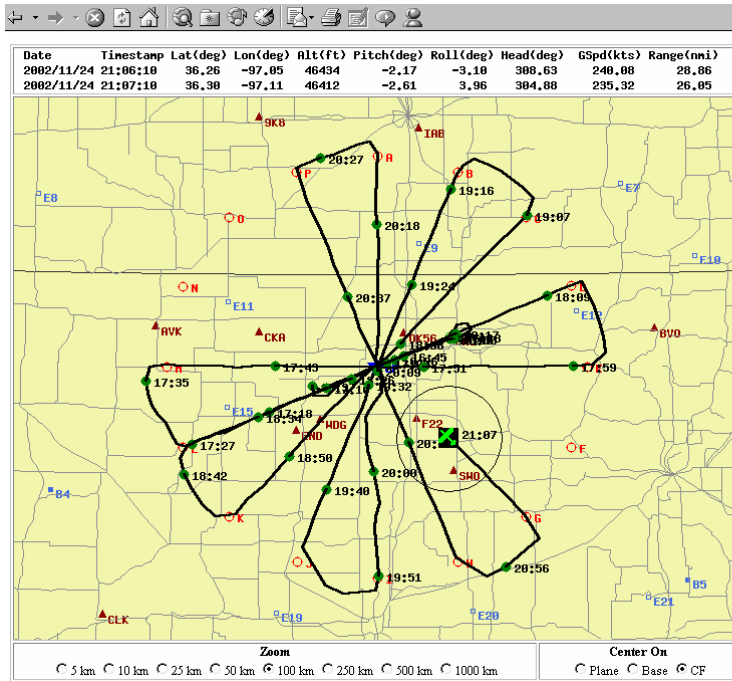
*Payload senses connected links and automatically selects fastest available*

During flight:

- Uplink commands and downlinked data during flight via Iridium satellite data link or line-of-sight RF from Mission Ground Station computer
- “Housekeeping” instrument and aircraft data displays aid mission planning and monitoring
- Scientific “quick look” data accessible to scientists during flight from anywhere with internet access
- Instrument and payload power uplink commands allow the re-configuration of payload during flight
- Voice communication with flight crew via VHS radio (line-of-sight) or Iridium satellite phone (over-the-horizon voice link to pilots via



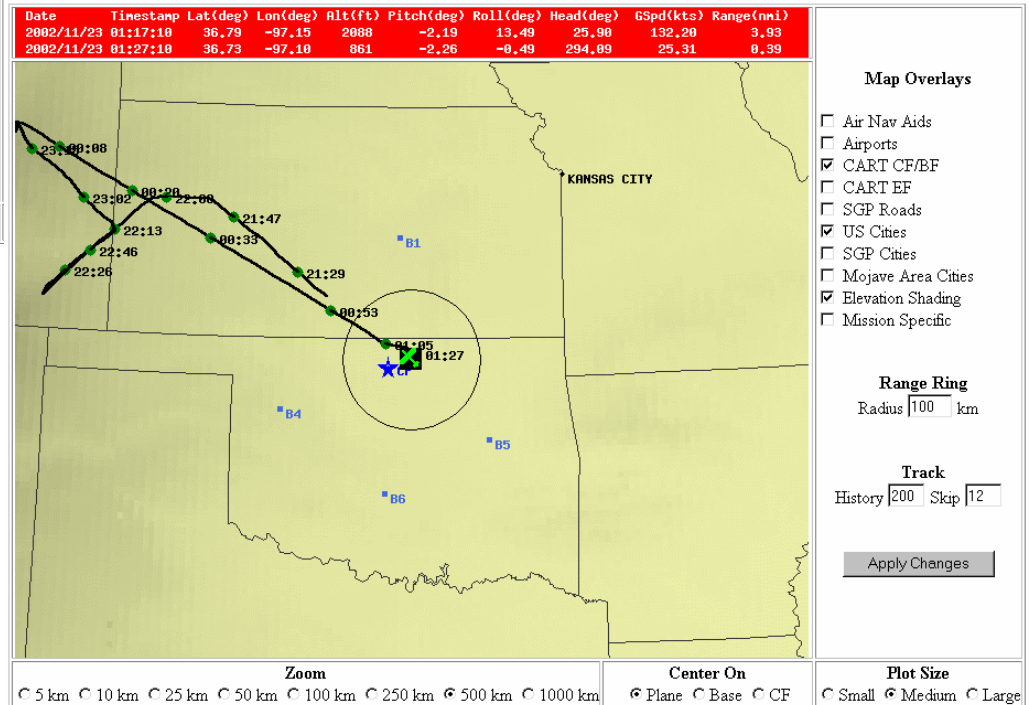
# ARM-UAV mission control and display capabilities



100 km range

Map display allows monitoring flight path in near real time

500 km range



# Mission control and display capabilities

## State of health displays monitor instrument and payload at various levels of detail

### Health and Status for Active Flight, Cube DFC

#### Health and Status Summary for Active

MGS: 2002/11/24 21:28:17 Last SOH: 2002/11/24 21:24:00 (Delta 4 minutes)

Payload Communication Link: [LOW SPEED](#)

Click on a variable name to view plots and time history

Now: 2002/11/24 20:59:34 Last File: 2002/11/24 20:59:00 (Delta 1 min)

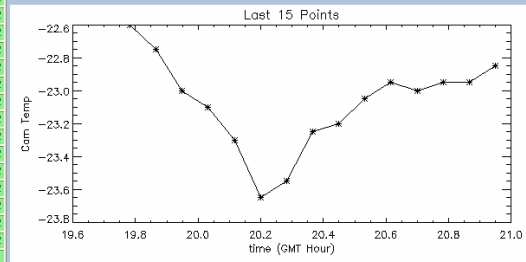
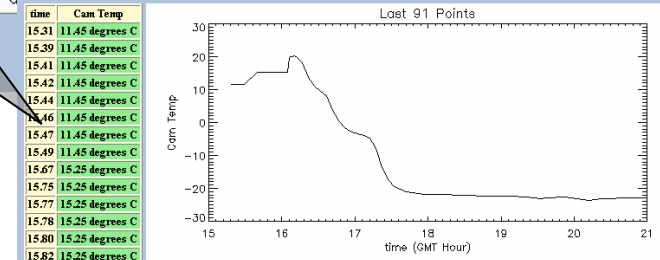
AGS	TotalMsgFiles	TotalCmdFiles	TotalSohFiles	TotalDatFi
BRP CM1	flux_val 430.2	flux_avg 538.1	flux_min -1395.9	flux_ma 4513.3
BRP CM3	flux_val 445.3	flux_avg 502.9	flux_min -1382.3	flux_ma 4657.9
BRP CM5	flux_val 193.9	flux_avg 60.1	flux_min -1648.0	flux_ma 5225.0
BRP CM7	flux_val -36.9	flux_avg -33.5	flux_min -1128.9	flux_ma 2.5
BRP CG2	flux_val 142.8	flux_avg 173.8	temp_val 225.2	temp_av 226.7
BRP CG4	flux_val -0.6	flux_avg 33.7	temp_val 229.3	temp_av 240.9
BRP CG6	flux_val 188.3	flux_avg 263.7	temp_val 224.7	temp_av 236.4
CAPS	Feel Good			
CDL	adc01 24.94	adc02 28.85	adc07 27.38	
CIN	Feel good	cin running	conversions 860740	
CMR	GV_Log YES	TX diode 55.06	GVA_VoltReg 46.39	BatmanCPU 40.46
DFC DFV	DAT File Count 586	Cam Temp -22.85 degrees C	Remaining Disk 0544555008 Bytes	15GHz DRO 42.31
DFC DFI	DAT File Count 586	EPA Temp -6.69312	Remaining Disk 0544555008 Bytes	
MET PTA	static temp -59.5	static pressure mb 134.9	airspeed true m/s 148.4	pressure alt m 14283.3
MET DEW	balance 1317.000000	mirror tm -73.120003		altitude rate m/s -0.1
MET CR2	balance -2584.000000	mirror tm -70.879997		
NAV	latitude degrees 35.750332	longitude degrees -96.808235	altitude meters 14191.859375	pitch degrees -1.736052
NEV	twr sig 2.3	twr ref 2.7	hwr sig 3.7	hwr ref 3.1
PWR	bus pwr volts 26.6	12 SPPTFP -23.2	10 DUDTEC 49.1	02 ALDTMC 9.65
SDG	latitude degrees 35.757403	longitude degrees -96.837643	altitude meters 14190.272461	op mode (ACTIVE)
SHIS	payloadRayTemp no shis file	RSHblockLength no shis file	bus1Current no shis file	bus2Current no shis file
SRP	Feel Good	srpband running	srpviz running	srpnir running
SSFR	zen temp no ssfr file	nad temp no ssfr file	internal temp no ssfr file	
VIPS	SOH File Count 70	DAT File Count 9647	Remaining Disk 0576061440 Bytes	

DFC internal time: 2002/11/24 21:21:57

Cam Exp	Cam Gain	Cam HRes	Cam Info	Cam LL Mean
95	3.12924e-007 dB	1300 pixels	1312AMDVC6.1	0
Cam LL Std Dev	Cam LR Mean	Cam LR Std Dev	Cam Mode	Cam Offs
0	0	0	HNL	2.06169 %
Cam Temp	Cam UL Mean	Cam UL Std Dev	Cam UR Mean	Cam UR Std Dev
-22.95 degrees C	0	0	0	0
Cam VRes	Cap Count	Cap Error	DAT File Count	Instrument
1030 pixels	634	0	636	DFC
Remaining Disk	SOH File Count			
0451821568 Bytes	92			

#### Plots and Time History for Active Flight, Cube DFC, variable: Cam Temp

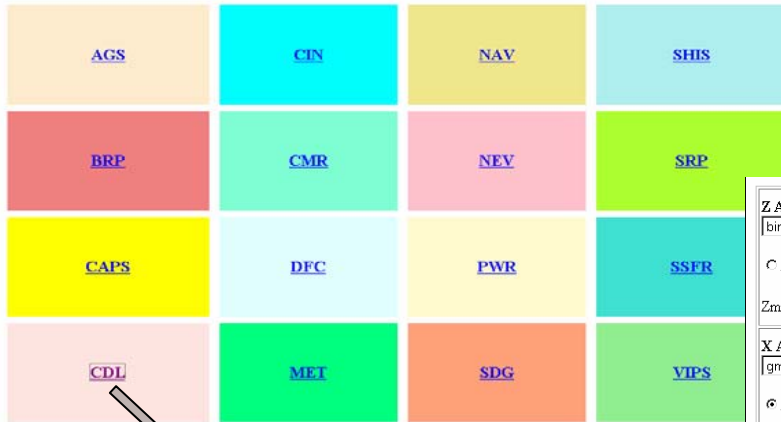
[Summary Page](#) [MGS User Page](#)



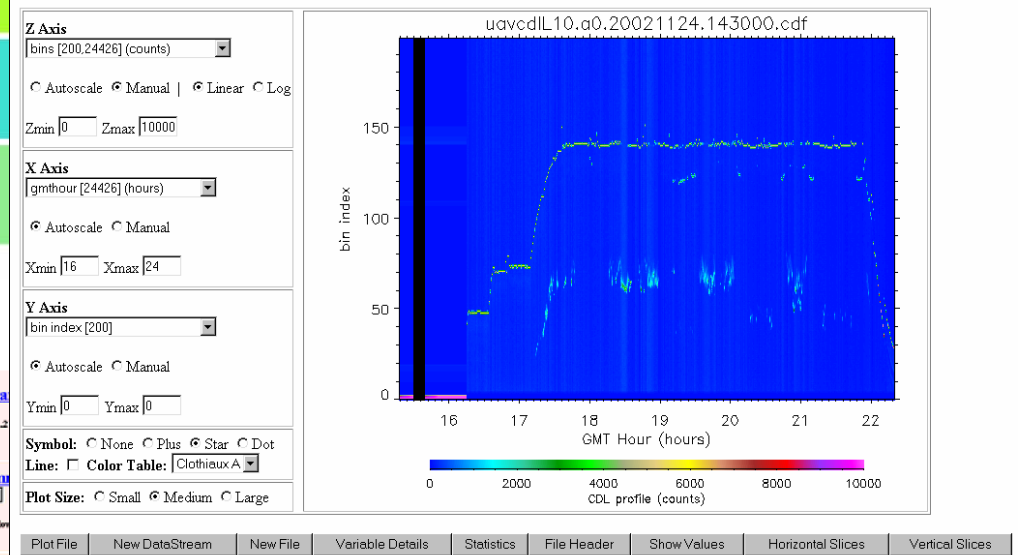
# Mission control and display capabilities

## Uplink controls instruments

Instruments



Interactive plotting allows data access



[MGS User Page](#)

### Uplink Commands for CDL

<a href="#">LIDAR Disable</a> CDL 0	<a href="#">Standby Off</a> STANDBY off	<a href="#">Standby On</a> STANDBY on	<a href="#">Detector Gate Delay</a> [0] GATELAG (0-255)	<a href="#">Debug Command</a> DEBUG (10-255)
<a href="#">LIDAR Enable</a> CDL 1	<a href="#">Mode Standby</a> MODE 0	<a href="#">Set Time</a> TIME	<a href="#">Counter Bin Delay</a> [0] CNTRLAG (0-255)	<a href="#">WFOV Command</a> WFOV (off-on)
<a href="#">Laser Disable</a> LASER off	<a href="#">Background</a> MODE 1	<a href="#">Set Data File Interval (min)</a> [5] DATA_TICS (1-60)	<a href="#">Bin Width</a> [2] BINW (1-1024)	
<a href="#">Laser Enable</a> LASER on	<a href="#">Single Shot</a> MODE 2	<a href="#">Set SOH File Interval (min)</a> [5] SOH_TICS (1-60)	<a href="#">Measurement Duration</a> [1] DURATION (1-1000)	
<a href="#">Heater</a> [off-on] HEATER (off-on)	<a href="#">Free Run</a> MODE 3	<a href="#">Neutral Density Filter</a> [0] NDF (0-7)	<a href="#">Laser Shot Rate</a> [0 5000 Hz] SHOTRATE (0-7)	

[Return to Instrument List](#) [MGS User Page](#)

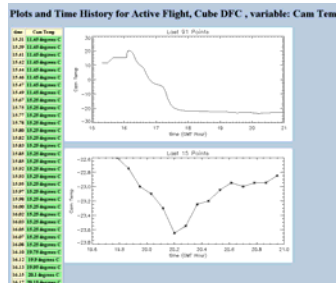
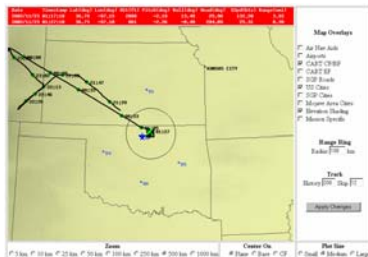
# Many elements of the payload approach were notable

On board storage in dedicated PC-104-based “data cubes”

Modular instrument/data cube

Commercial cables and components

Low-cost, over-the-horizon data communication



# Summary

---

- **ARM-UAV has...**
  - **developed equipment and operational capabilities for scientific use of UAVs**
  - **utilized UAVs in a number of major flight campaigns, acquiring valuable scientific data in over 430 hours of scientific flight**
- **Conclusion:**
  - **UAVs offer unique capabilities for important scientific applications**
  - **UAV cost, reliability/maintenance, availability, and airspace access need to improve**
  - **Payload approaches using commercial elements appear satisfactory (satellite phones/data transmission, COTS cables/connectors/components)**

*For more information about ARM-UAV, please see:*  
<http://armuav.ca.sandia.gov/armuav.html>



*U.S. Department of Energy's  
Office of Science*

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**NOAA/NASA/DOE**

**UAV**

**Interagency Collaboration**

**Rickey Petty**

*March 24, 2004*

# AMF Baseline Instruments



## Atmospheric Profiling

- [Balloon-borne Sounding System \(BBSS\)](#)
- Profiling Microwave Radiometer (P-MWR)

## Clouds

- W-band (95 GHz) Cloud Radar
- [Micropulse Lidar \(MPL\)](#)
- [Vaisala Ceilometer \(VCEIL\)](#)
- Sky Imager

Artist's 3D rendering of the inside of the Mobile Facility.

## Radiometers

- FTIR
- [Infrared Thermometer \(IRT\)](#)
- Profiling Microwave Radiometer (P-MWR)
- [Multifilter Rotating Shadowband Radiometer \(MFRSR\)](#)
- Broad-Band Instruments
  - [Pyranometers](#)
  - [Pyrgeometers](#)
  - [Pyrheliometers](#)
  - [Ultraviolet-B Radiometer \(UV-B\)](#)
- Radiometric Instrument Systems (groupings of individual broadband instruments at sites)
  - [Upwelling Radiation \(GNDRAD\)](#)
  - [Downwelling Radiation \(SKYRAD\)](#)

# ARM MOBILE FACILITY

## Balloon-Borne Sounding System (BBSS)

### Primary Quantities Measured

The following quantities are measured as functions of time during a free-balloon ascent:

- Pressure (hPa)
- Temperature (degC)
- Relative Humidity (%RH)
- Wind speed (m/s)
- Wind direction (deg)



Secondary (derived) quantities included in the data stream, also measured as functions of time, are:

- Altitude (gpm)
- Dew Point (degC)
- Ascent Rate (m/s)
- Latitude of Sonde (degN)
- Longitude of Sonde (degW)
- u-component of wind velocity (m/s)
- v-component of wind velocity (m/s)

## Surface Meteorology

- Surface Meteorological Instruments (SMET)



### Primary Quantities Measured

The SMET stations directly measure:

**Wind speed at 10 m**, Precision: 0.01 m/s; Uncertainty: +/-1% for 2.5 to 30 m/s (see *Assessment of System Uncertainties for Primary Quantities Measured* for wind speeds below 2.5 m/s)

**Wind direction at 10 m**, Precision: 0.1 deg; Uncertainty: +/-5 deg

**Air temperature at 2 m**, Precision: 0.01 C; Uncertainty: +/-0.41 C

**Relative humidity at 2 m**, Precision: 0.1% RH; Uncertainty: +/-2% RH (0% to 90% RH), +/-3% RH (90% to 100% RH)

**Barometric pressure at 1 m**, Precision: 0.01 kPa; Uncertainty: +/-0.035 kPa

**Precipitation**, Precision: 0.1 mm/hr; Uncertainty: +/-0.1 mm/hr

ARM MOBILE VAN Completed Testing at Point Reyes

January 2006 Collecting Data from NIGER... Coast of Africa!

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