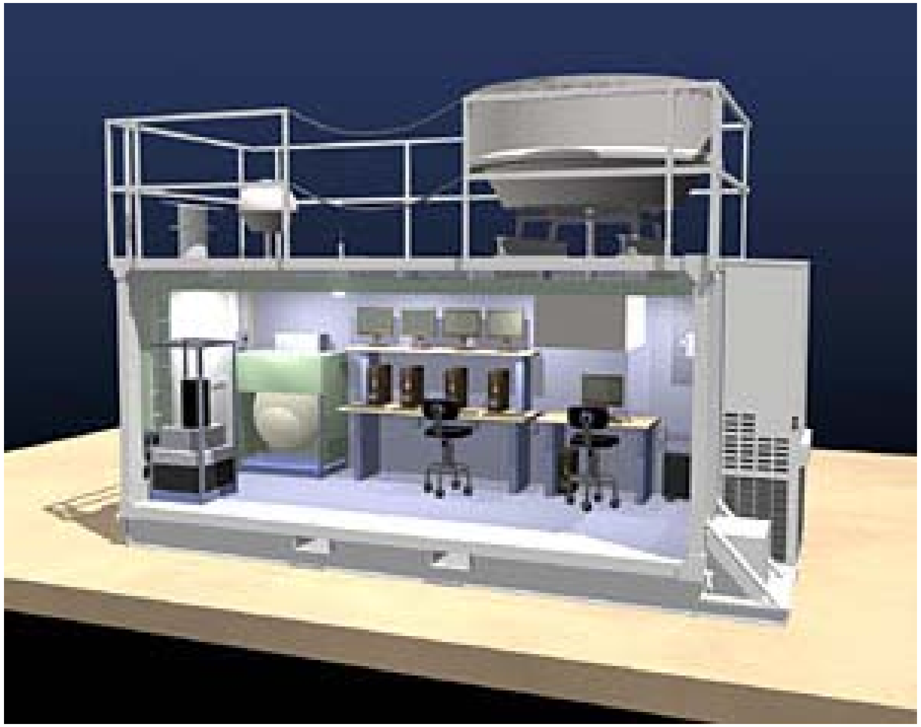
The ARM Mobile Facility (AMF) and UAV Program

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

ARM-UAV

Operational Experience with ARM-UAV Payloads for Climate Research Applications

Will Bolton
Sandia National Laboratories
Livermore, California

Topics for this presentation

- Review of ARM-UAV Program
- Payload and operational experience
  - Moving toward modularity and "commercial off the shelf"
  - Multiple, reasonable-cost communication options
  - Mission monitoring and control displays
  - What worked

ARM-UAV Program objectives

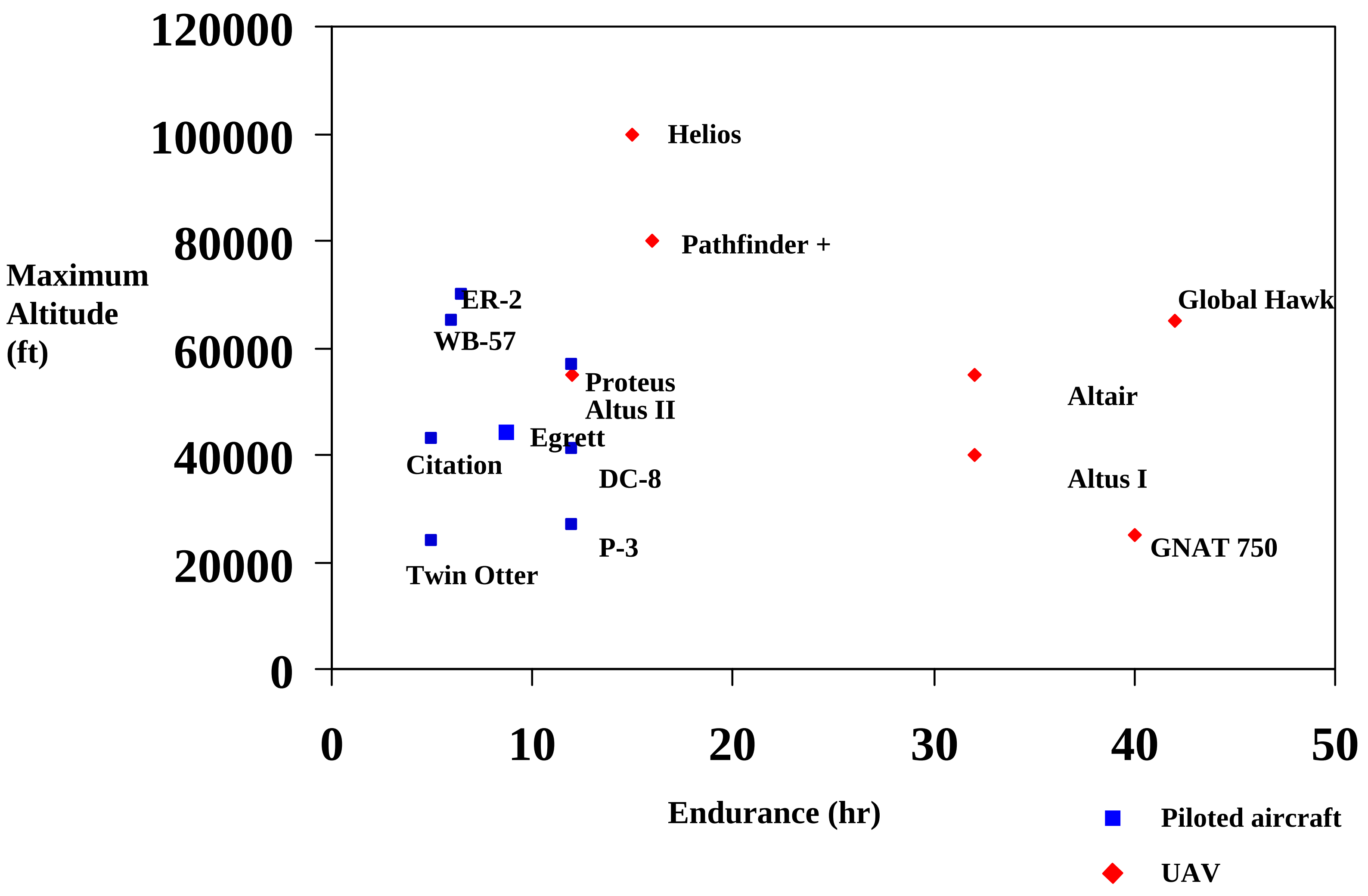
The ARM-UAV Program was established by DOE to…

- **Address the largest source of uncertainty in global warming: the interaction of clouds and solar/thermal energy**
- **Support the climate change community with valuable data sets**
- **Develop measurement techniques and instruments suitable for use with the new class of high altitude, long endurance UAVs**
- **Demonstrate these instruments and measurement techniques in field measurement campaigns**

Aircraft and payload requirements are based on measurement needs:

Altitude - ~ 60,000+ ft (above tropical cirrus clouds)
Endurance - ± 2-3 hours from solar noon = 8 hours (radiometric measurements)
Payload weight - 175+ kg (adequate for radiometric and in situ instruments)
Electrical power - ~ 50+ amps @ 28 v (highly variable depending on instruments)

High altitude, long endurance aircraft options



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)

Proteus performance characteristics

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

Current ARM-UAV payload instruments

The payload consists of 12 major instruments:

Remote sensing -

- **Cloud Detection Lidar**
- **Compact Millimeter wave Radar**
- **Spectral Radiance Package (SRP)**
- **Scanning-High-resolution Interferometer Sounder (S-HIS)**
- **Solar Spectral Flux Radiometer (SSFR)**
- **Modified CM-22 and CG-4 Kipp & Zonen radiometers**
- **Diffuse Field Camera (DFC)**

In situ -

- **Nevzorov Probe**
- **Cloud, Aerosol, and Precipitation Spectrometer (CAPS)**
- **Video Ice Particle Sampler (VIPS)**
- **Cloud Integrating Nephalometer (CIN)**
- **Dew- and frost-point hygrometers**

These instruments place a variety of constraints on payload design

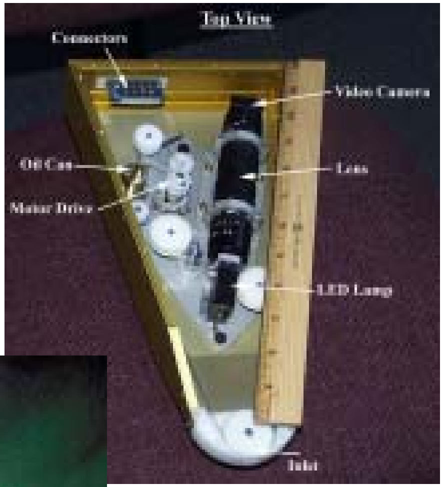
Recent additions to ARM-UAV payload instruments

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 μm to over 1.5 mm	Droplet Measurement Technologies
Cloud Integrating Nephalometer (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 μm	NCAR

CMR

CIN

CAPS

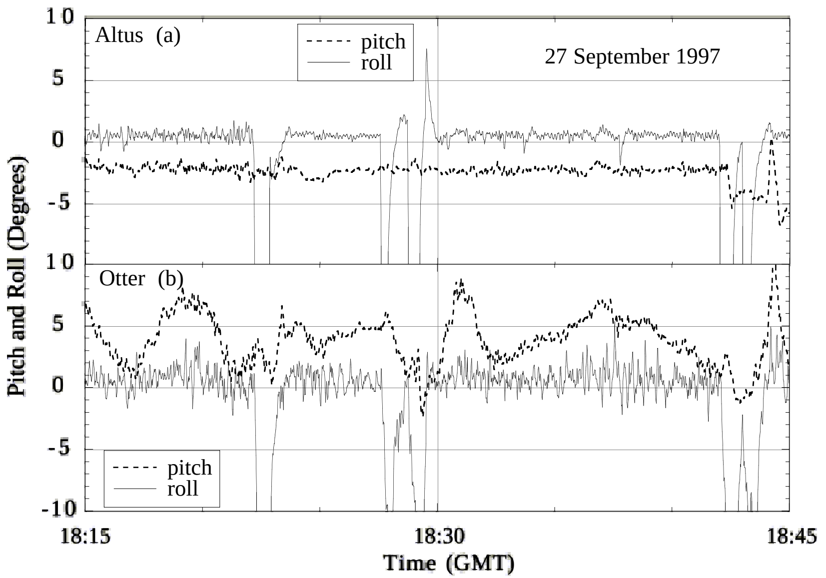


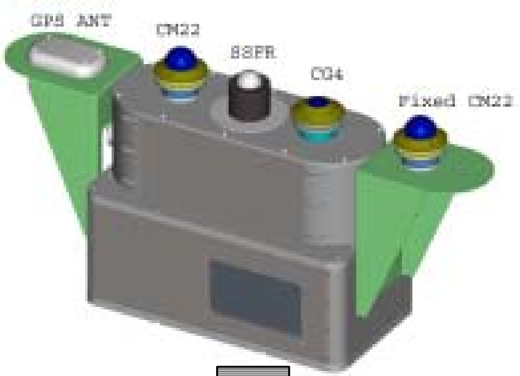
VIPS

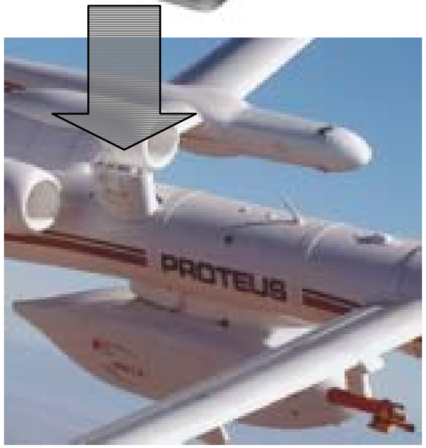
Nevzorov

Stabilized radiometer platform improves measurements

Stabilized radiometer platform prevents small-scale angular motion

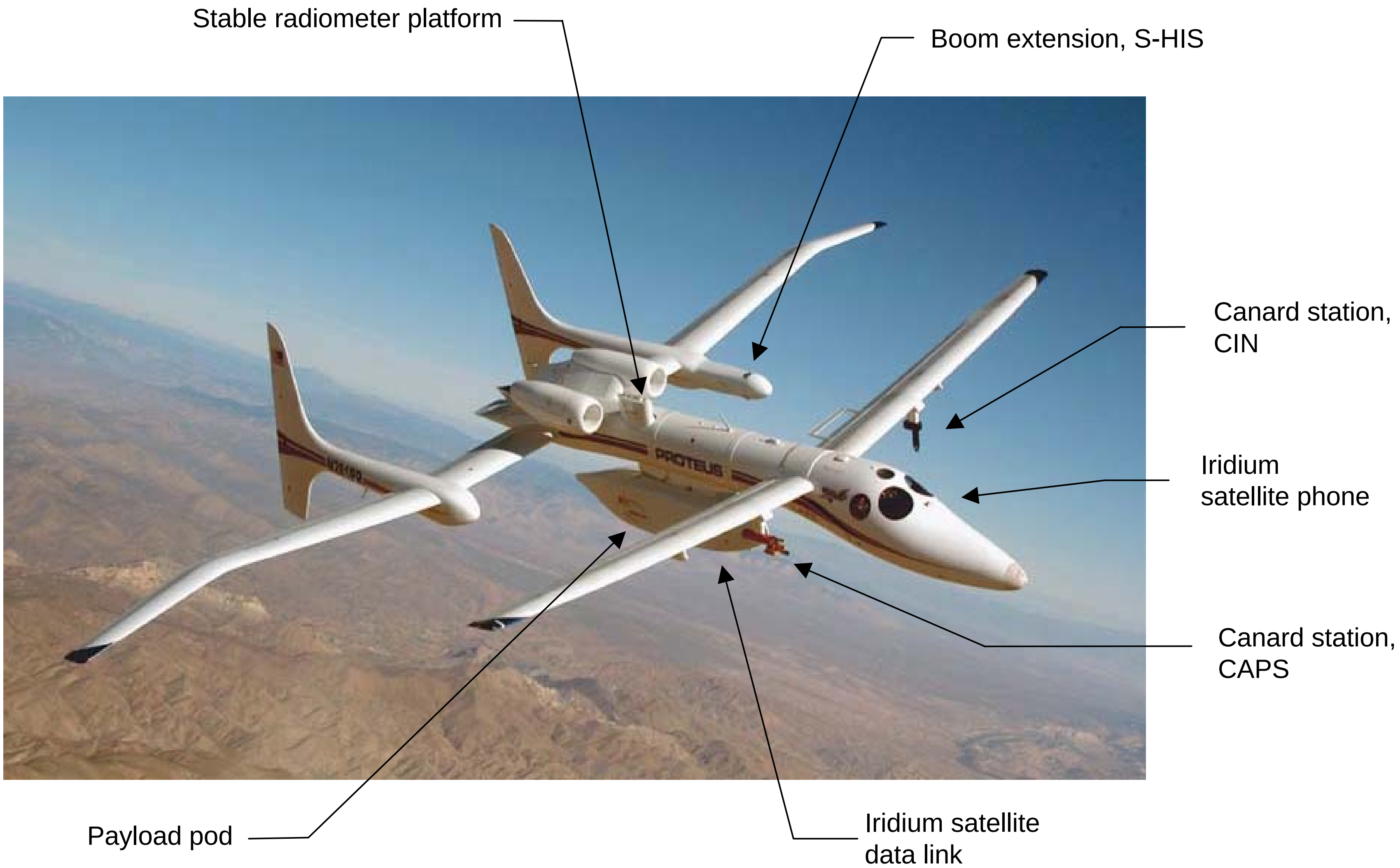




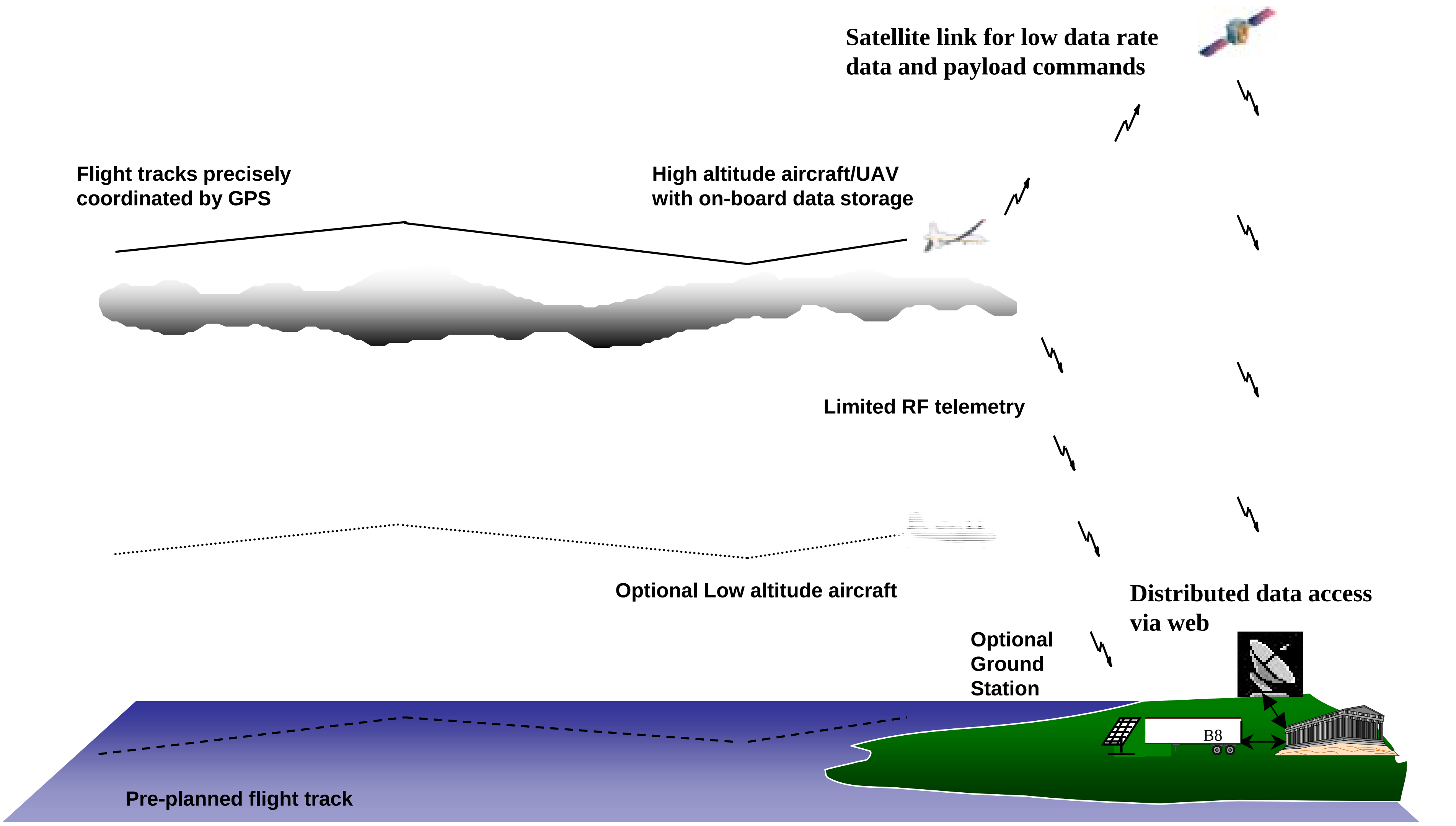


Angular stability is important for radiometric measurements

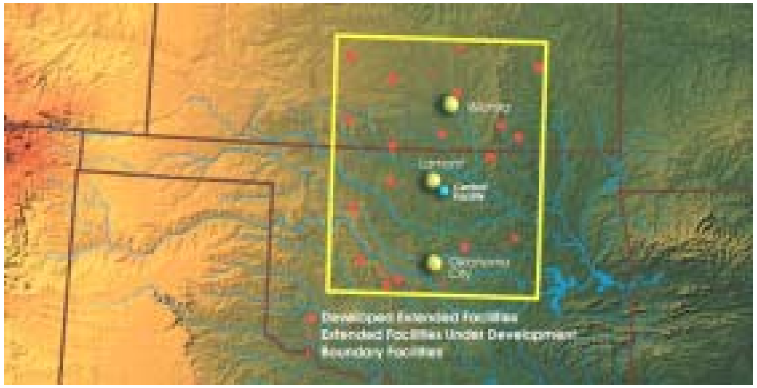
ARM-UAV/Proteus payload arrangement



Arrangements for recent and future ARM-UAV deployments



The ARM-UAV “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:

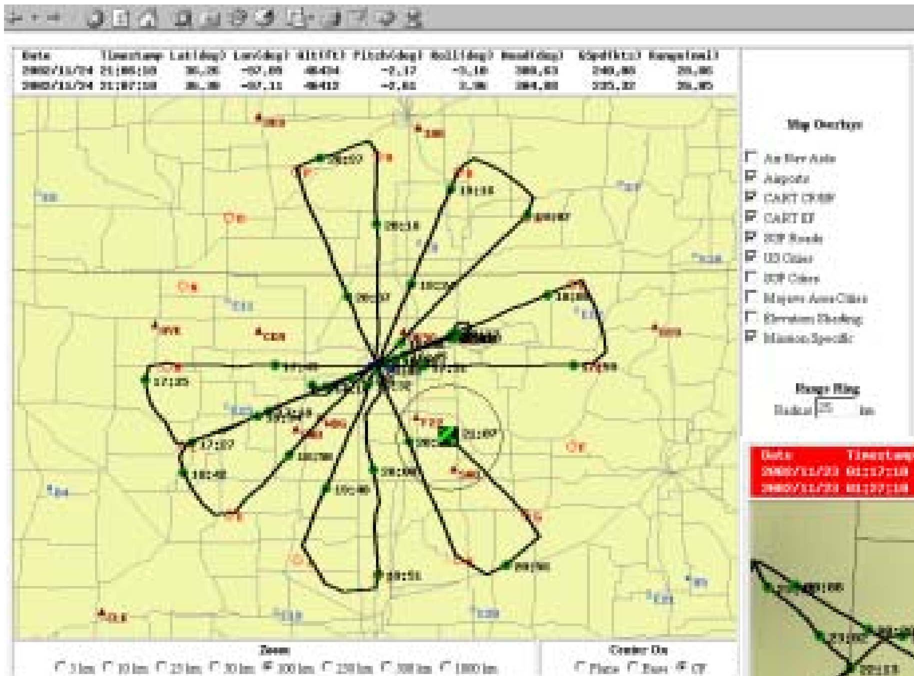
- **Ethernet direct connection (hangar/ramp only)**
- **RF modem (line-of-sight, $\leq$ about 30 miles from base)**
- **Low data rate/low cost satellite data link (Iridium)**

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**

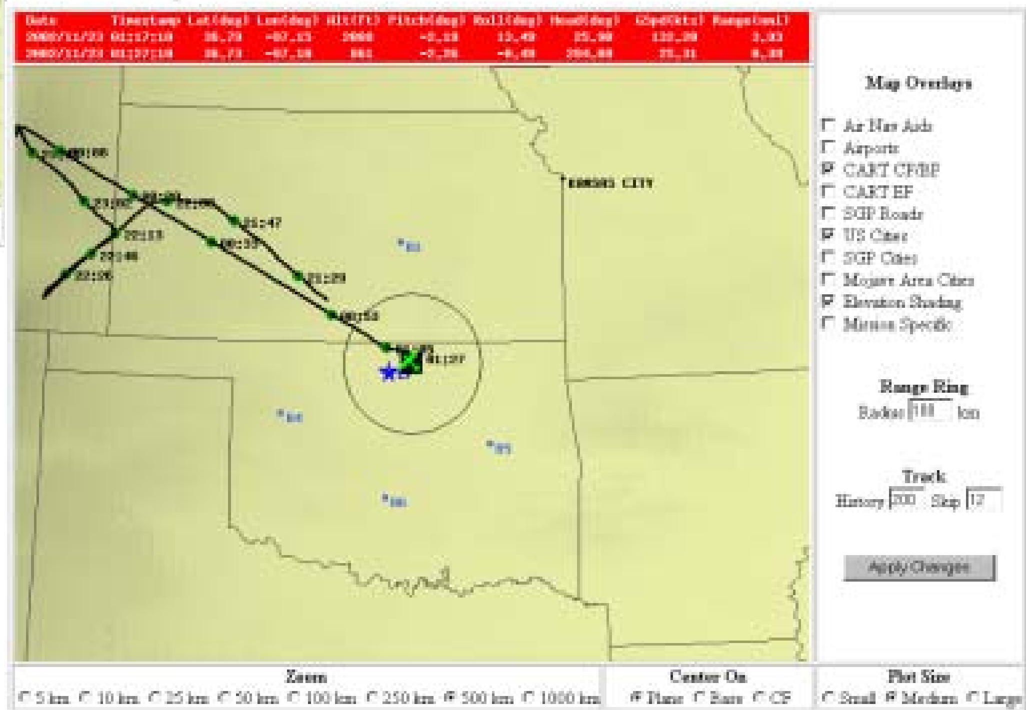
ARM-UAV mission control and display capabilities



100 km range

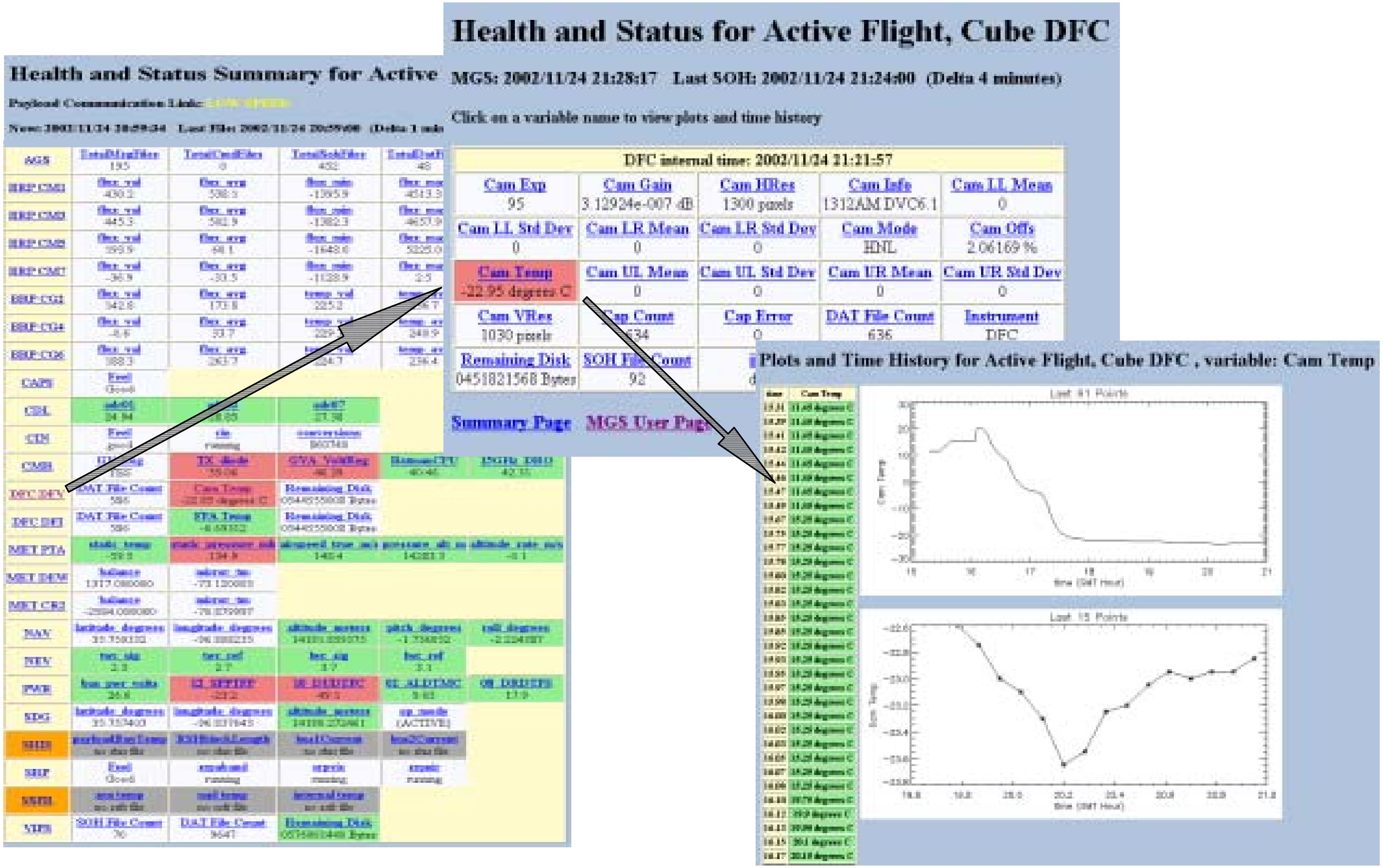
Map display allows monitoring flight path in near real time

500 km range



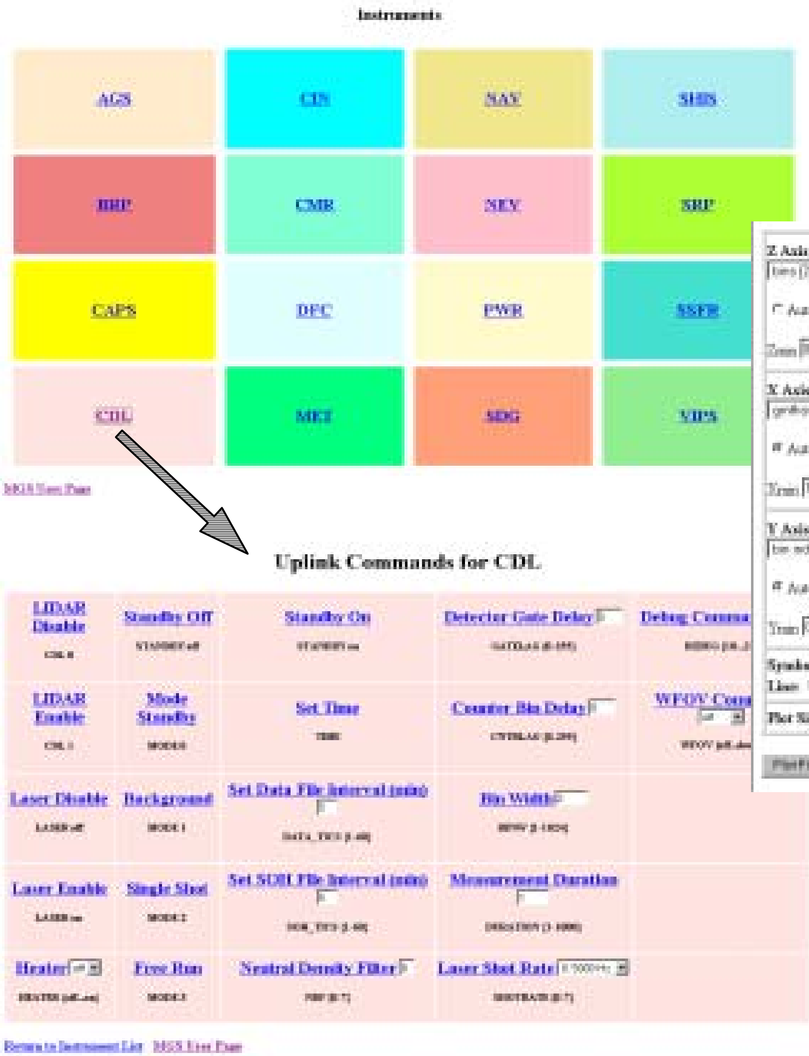
Mission control and display capabilities

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

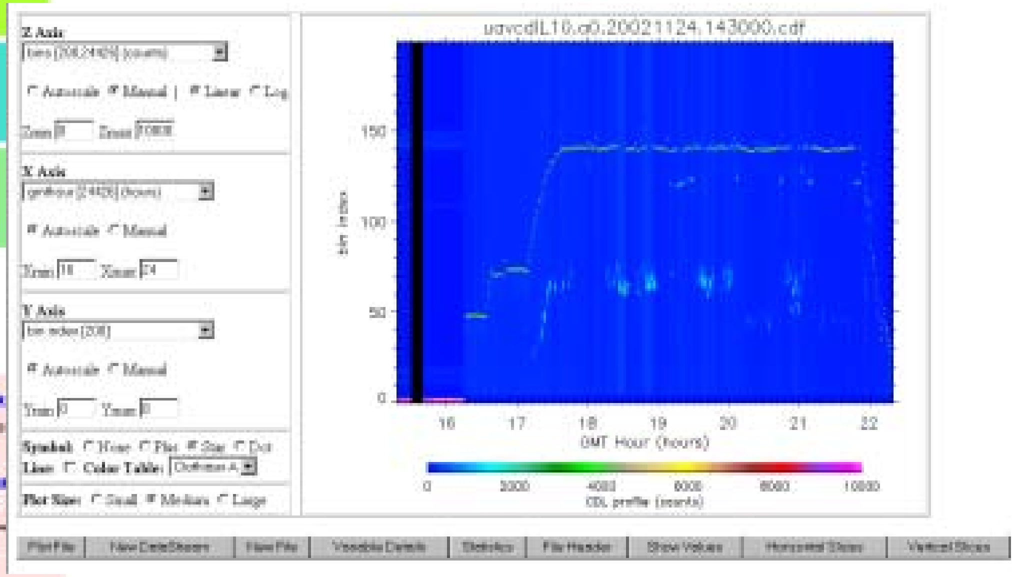


Mission control and display capabilities

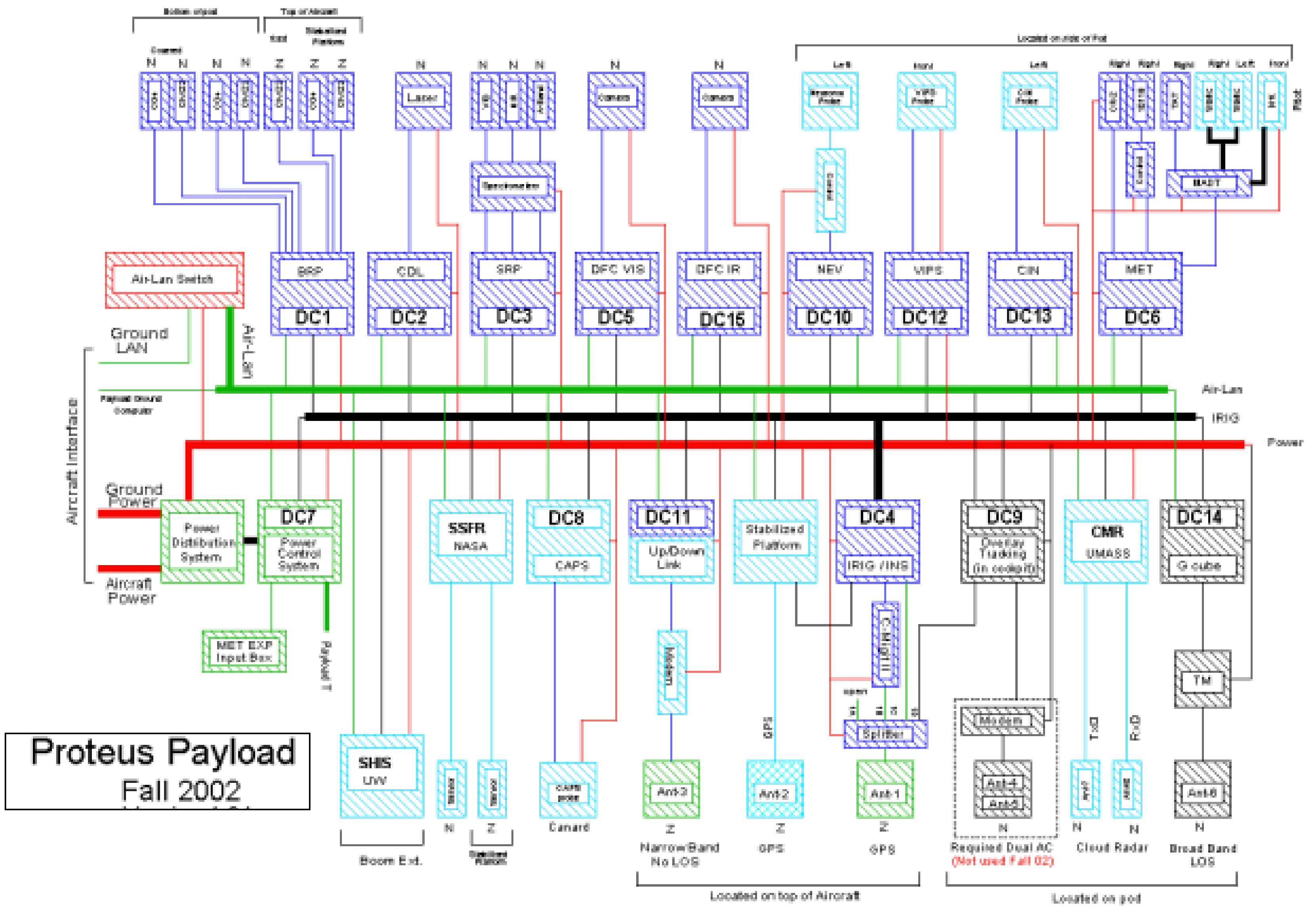
Uplink controls instruments



Interactive plotting allows data access



Payload electrical and data configuration



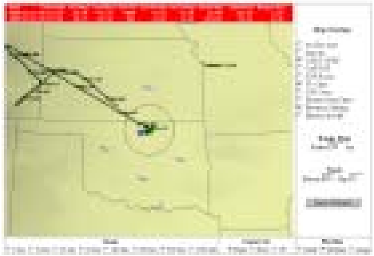
Many elements of the payload approach were notable

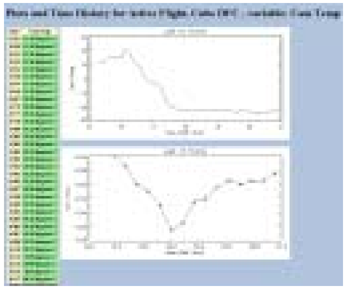
On board storage in dedicated PC-104-based “data cubes”

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

NOAA/NASA/DOE
UAV
Interagency Collaboration

Rickey Petty

March 24, 2004

Proposed NASA/NOAA/DOE Collaboration for Climate Change Research

- There are needs in global climate change observations to augment satellite observations and extend to under-represented regions (e.g, oceans)
- The proposed collaboration between NASA, NOAA, and DOE is intended to address the challenges of an international Earth Observation System using UAVs as an integrated piece of the global system

CCSP Strategic Plan

- Observations:
  - Goal 1; Design, develop, deploy, integrate, and sustain observation components into a comprehensive system.
  - Goal 2; Accelerate the development and deployment of observing and monitoring elements needed for decision support.
  - Goal 3; Provide stewardship of the observing system.

CCSP Strategic Plan (2nd cont)

- Goal 4; Integrate modeling activities with the observing system.
- Goal 5; Foster international cooperation to develop a complete global observing system.
- Goal 6; Manage the observing system with an effective interagency structure.

CCSP Core Science Elements

- Atmospheric Composition
- Climate Variability and Change
- Water Cycle
- Land-Use/Land Cover Change
- Carbon Cycle
- Ecosystems
- Human Contributions & Responses to Environmental Change

CCSP Core Approaches

- Modeling Strategy
- Decision Support Resources Development
- Observing and Monitoring the Climate System
- Data Management and Information

Just an added comment

NACP Science could be a customer with regards to its mission of ascertaining sources and sinks of CO_2.

Addressing Science Issues

Potential scientific issues that could be addressed by this collaboration using UAVs have been identified*:

- Scaling Issues
- Statistics of Cloud and Radiative Properties at Multiple Levels and Locations
- Analysis of Life Cycles of Clouds not Currently Possible

* Greg McFarquhar, "Scientific Rationale for Use of UAVs in Global Unified Profiler Network", draft working paper, September 2003.

Addressing Science Issues 2nd (cont)

- Statistical Analysis of Atmospheric Behavior in a Large Phase Space than Previously Possible
- Atmospheric Statistics in Sparse Regimes
- Critically Needed Data for Large-Scale Model Simulations
- Long Transects for Parameterization Development
- Tropospheric/Stratospheric Exchange

Addressing Science Issues 3rd (cont)

- Aerosol/Cloud Interactions and Indirect Effects
- Indirect Effects in Ice Clouds

The Collaboration Process

The process for establishing the proposed collaboration is now being developed:

- Agreement in principle between the Agencies
- Workshop to establish a well-articulated scientific basis for the collaboration
- Informal collaboration on planned activities
- Develop MOA and establish formal collaboration

Timeline for Collaboration

Possible timeline for establishing the proposed collaboration:

- **Agency coordination teleconference - April 2004**
- **Science Workshop (@ Scripps) - July 2004**
- **Informal collaboration opportunities - 2004-2006**
- **Formal collaboration - 2007 and beyond**

Conclusion

This is an exciting possibility with great potential

There are many issues to be addressed before the collaboration can considered likely

Many will be asked to contribute to the development of the scientific basis and objectives of the proposed collaboration

Please stay tuned for more information