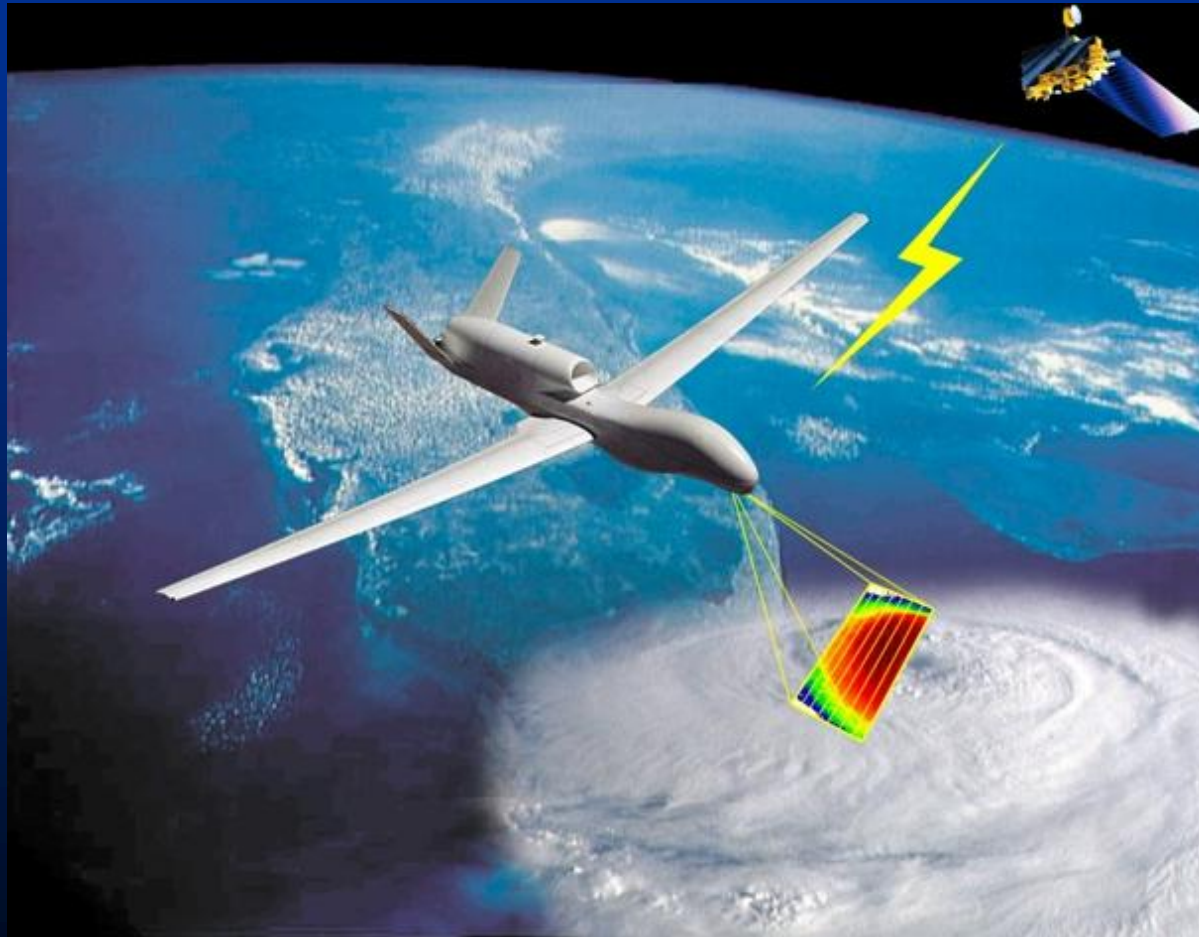


# NASA Airborne Infrared Remote Sensing Systems

## Thermal Imaging Workshop

Naval Postgraduate School, Monterey, CA

September 14, 2009



Jeff Myers

UCSC

NASA Ames

UARC



Airborne Sensor Facility  
Ames Research Center



# Outline

- The NASA Airborne Science Program and Airborne Sensor Facility
- NASA IR Facility Sensor Overview
- Instrument Characteristics and example Data
- Instrument Calibration
- Data and Instrument Access

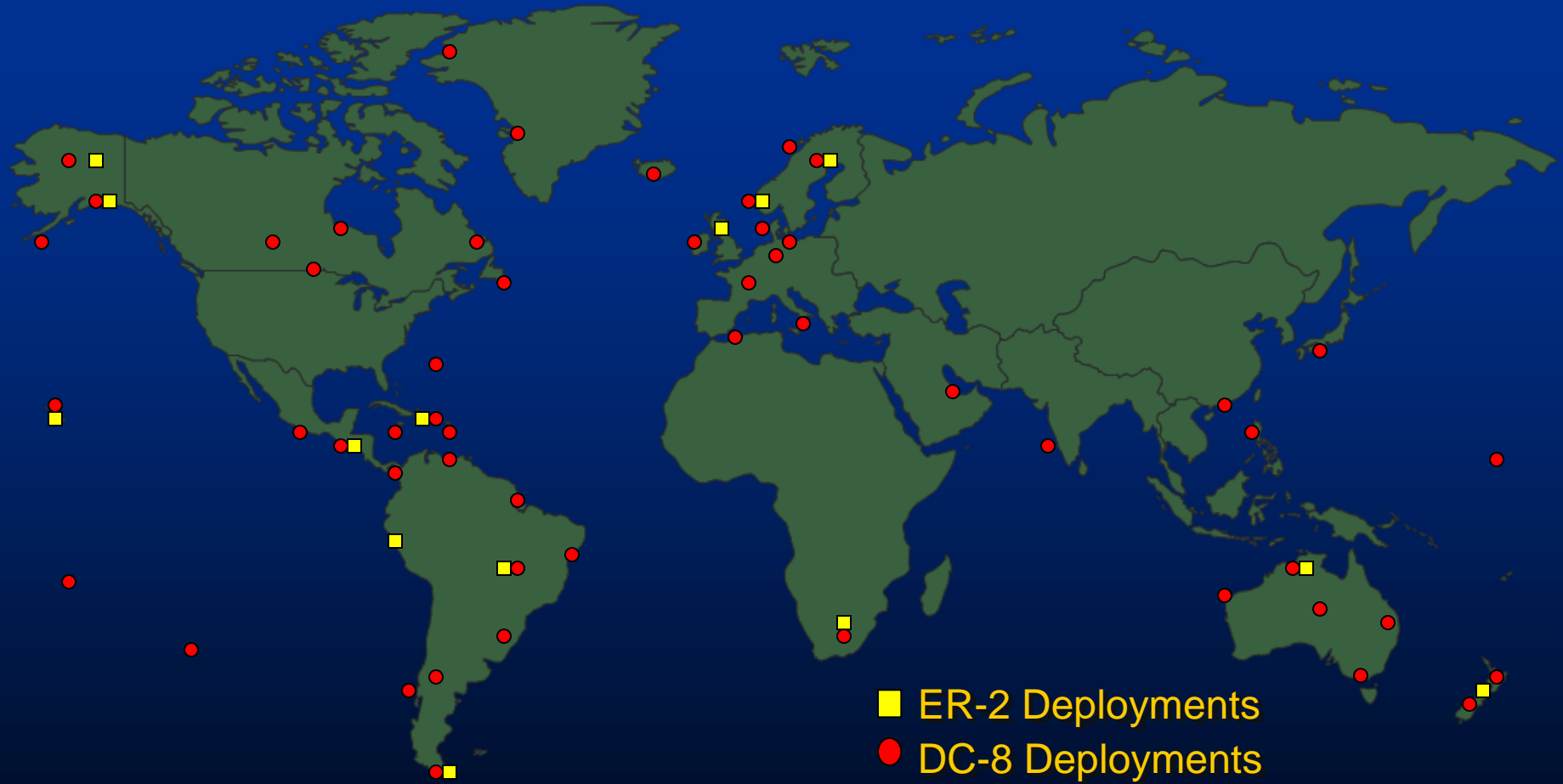
# The NASA Airborne Science Program



- **Supports the Earth Science Division, Research and Analysis Program at NASA H.Q.**
- **Conducts Remote Sensing and In Situ Airborne Missions for Satellite Cal/Val & Process Studies**
- **Provides “Flying Laboratories” to Host NASA, Univ. & Other Govt. Agency Experiment Packages**
- **Maintains a Suite of Calibrated Remote Sensing Devices for Community Use.**

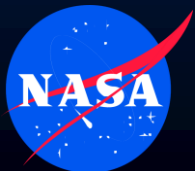


# Airborne Science Program International Deployment Sites



# Airborne Sensor Facility

- **Resides at the University-Affiliated Research Center under the NASA Ames Earth Science Division**
- **Staffed by Univ. of California, Santa Cruz**
- **Joint funding from the Airborne Science and EOS Programs**
- **Provides Earth science mission support through:**
  - **Instrumentation Development and Operations**
  - **Sensor Maintenance and Calibration**
  - **Enabling technologies for UAS Programs**
  - **Data Processing and Software Development**



Ames Research Center



# ASF: Recent and Ongoing Projects



J-31 CAR Integration



Global Hawk Payload Data System



AMS Ikhana UAS (Wildfire)



Network Server



Interface Panels



Payload Power Controller



Telemetry and Payload Computer

# NASA Core Science Platforms



WB-57F (2 at JSC)



ER-2 (2 at DFRC)



P-3B (WFF)



DC-8 (UND/DFRC)

# NASA UAS Platforms for Airborne Science



**Global Hawk (operational 2010)**



**G.A. Altair UAS**



**Ikhana Predator-B UAS  
(operational)**

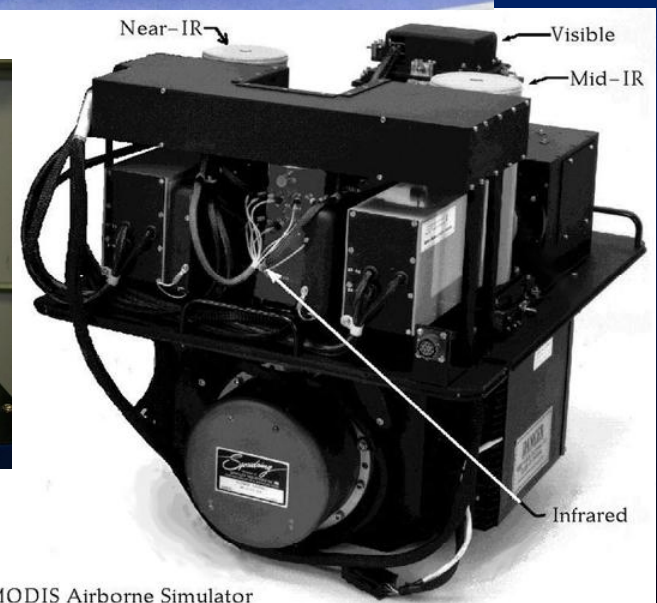
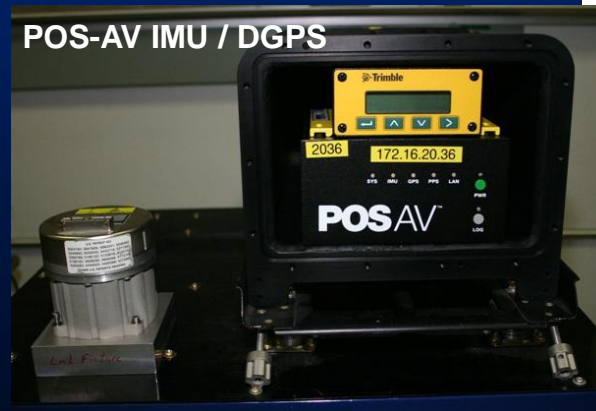
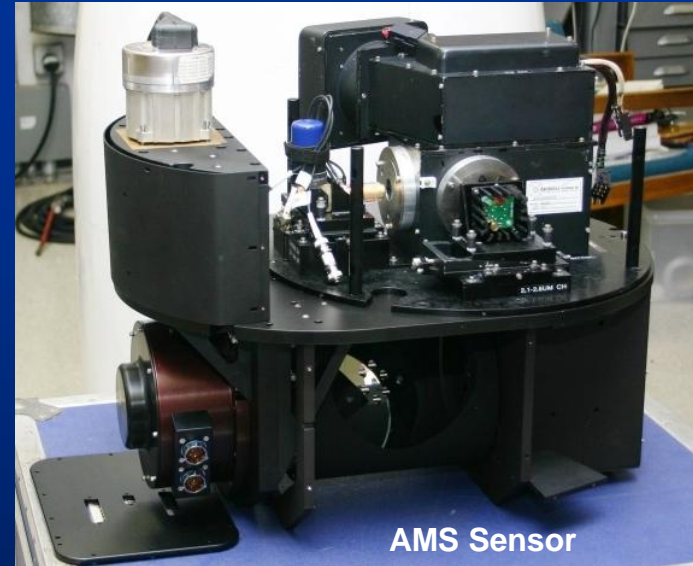


**SIERRA UAS  
(operational 2009)**

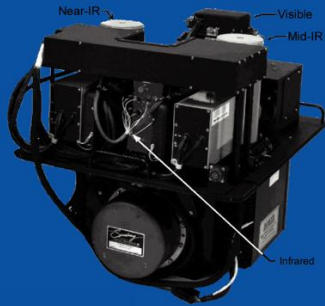


# NASA Facility Instrumentation at the Ames Airborne Sensor Facility

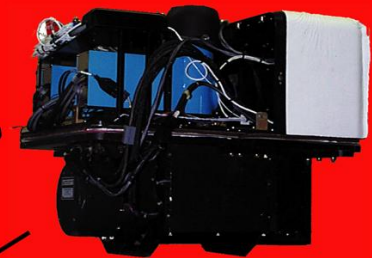
- MODIS and ASTER Airborne Simulators (MAS & MASTER)
- UAS AMS (Autonomous Modular Sensor System)
- Precision Geo-Positioning Hardware (Applanix POS-AV 510 & 610)
- Electro-Optic and Film Cameras



# ER-2 TERRA Validation Configuration



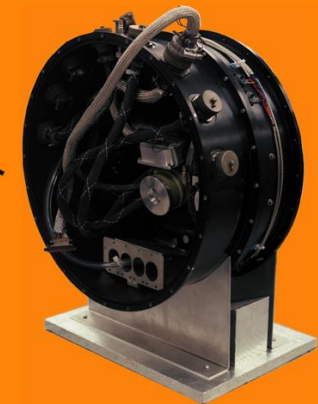
**MODIS Airborne Simulator (MAS) Superpod**



**MODIS/ASTER Airborne Simulator (MASTER)**



**Airborne Visible-Infrared Imaging Sensor (AVIRIS) Q-bay**

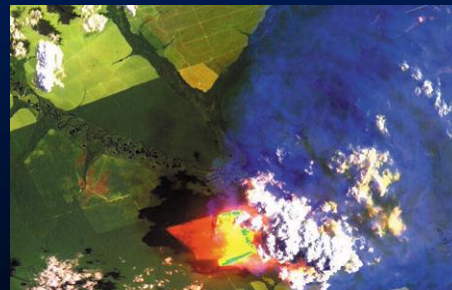
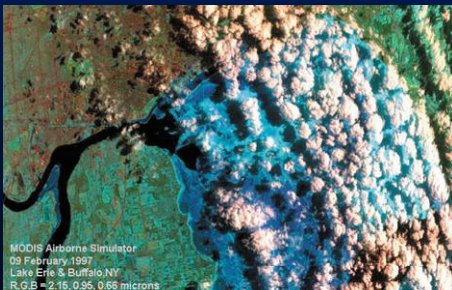
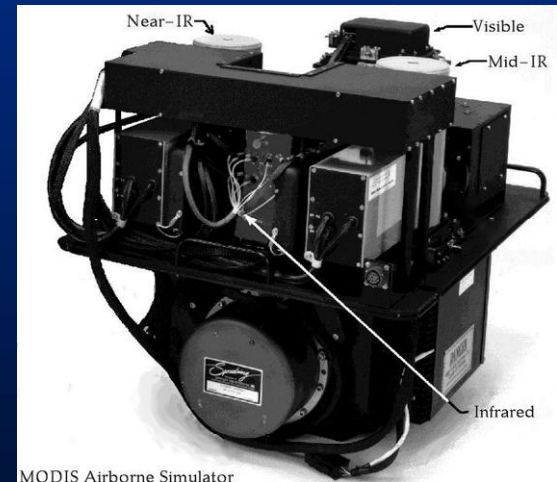


**Airborne Multi-angle Imaging SpectroRadiometer (AirMISR) Nose pod**

# MODIS Airborne Simulator

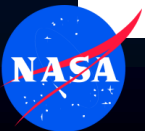
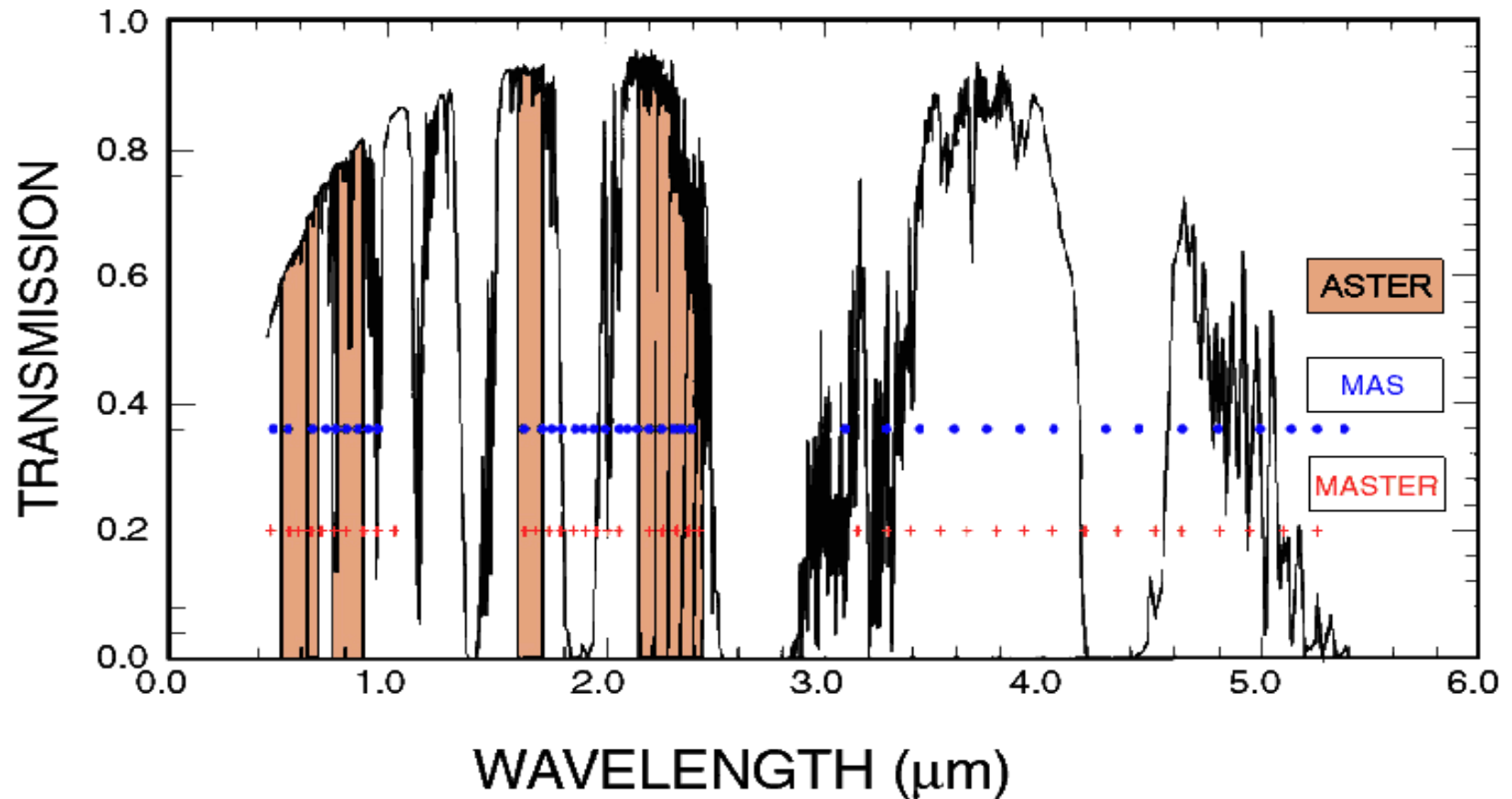
- Simulates the EOS Moderate Resolution Imaging Spectrometer (Terra & Aqua)
- Supports the MODIS Science Team and other multi-disciplinary investigations
- Flown on ER-2 aircraft

Spectrometer	Spectral Range $\mu\text{m}$	Number of Bands	Nominal Bandwidth $\mu\text{m}$
1	0.445 - 0.967	9	0.040
2	1.620 - 2.420	16	0.050
3	3.040 - 5.440	16	0.150
4	8.340 - 14.430	9	0.500



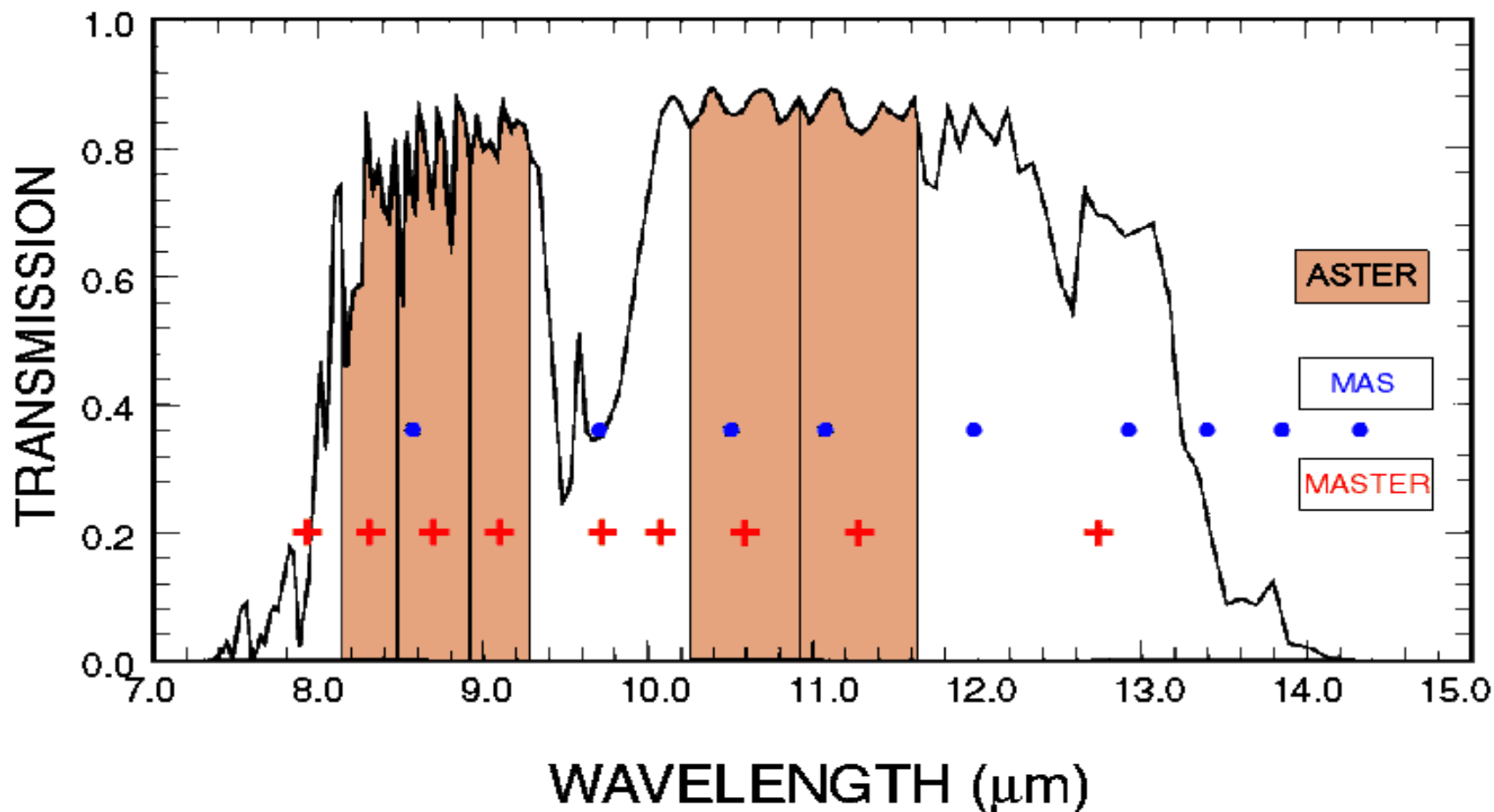
# MAS & MASTER Spectral Band Positions (Vis-MWIR)

## Atmospheric Transmission from 0.0 to 6.0

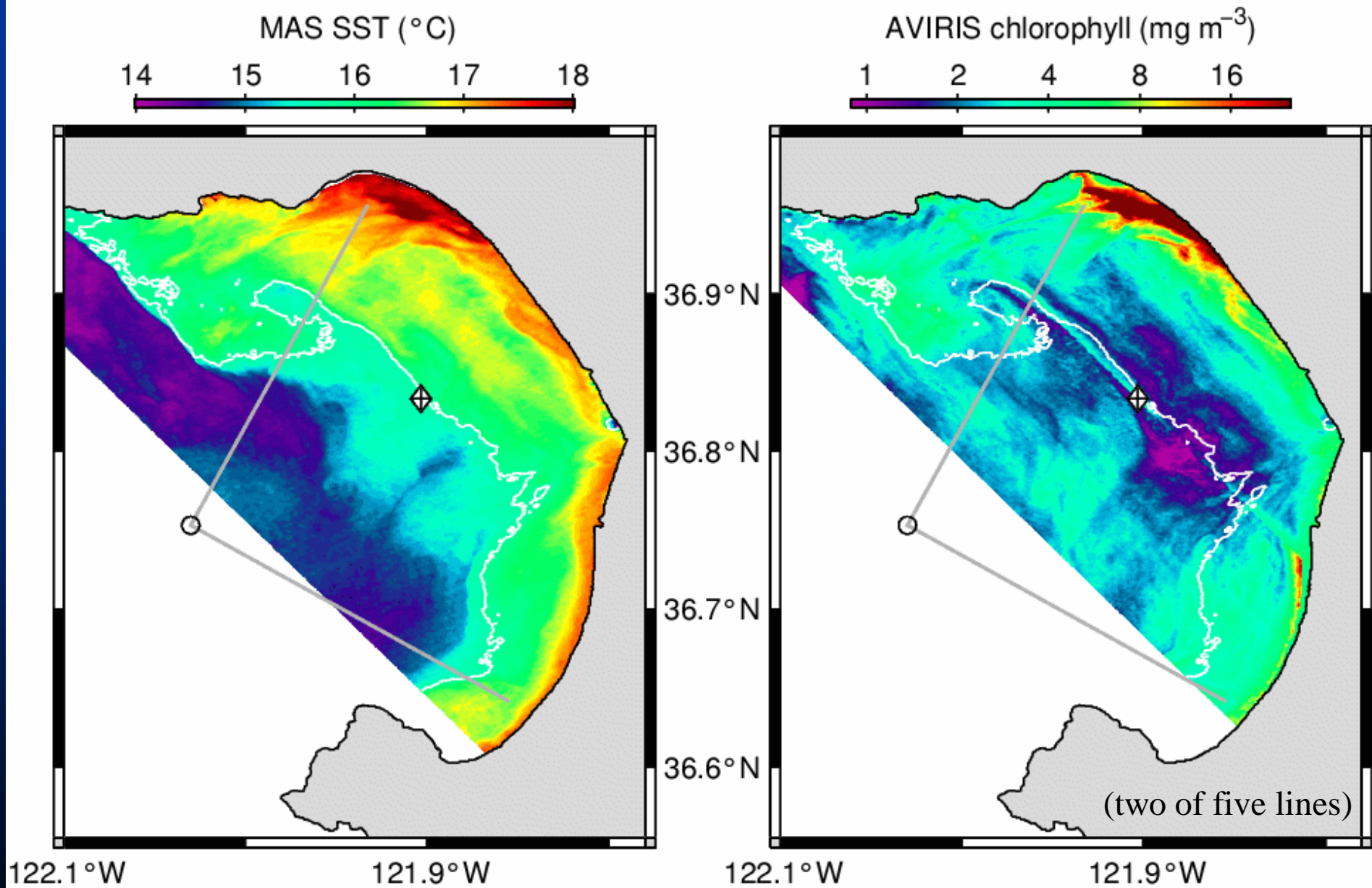


# MAS & MASTER Spectral Band Positions (Thermal IR)

## Atmospheric Transmission from 7.0 to 15.0

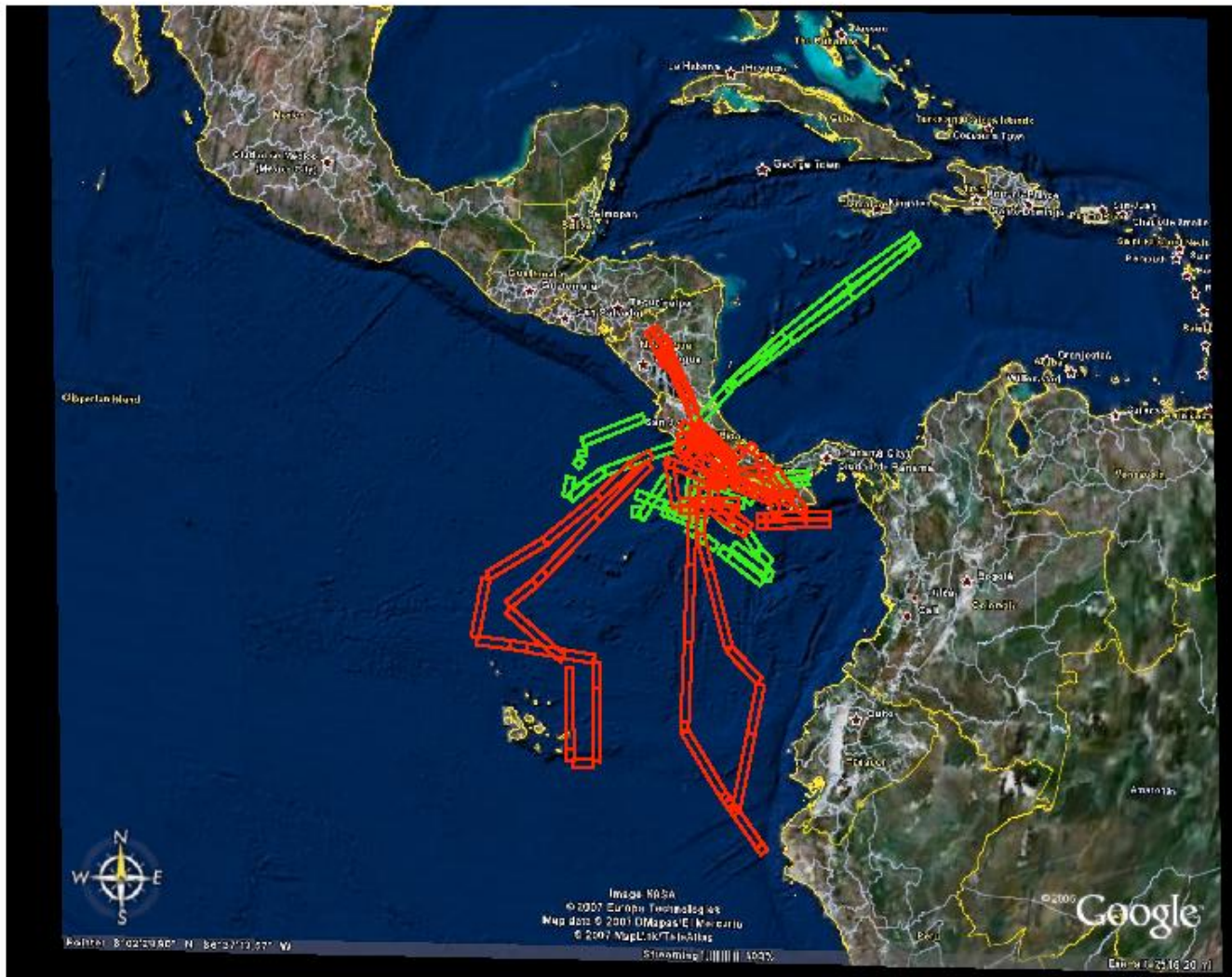


# August 26, 2004: AVIRIS & MAS acquisitions



(Courtesy J. Ryan)

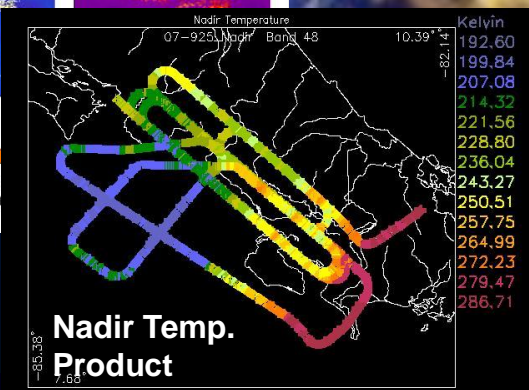
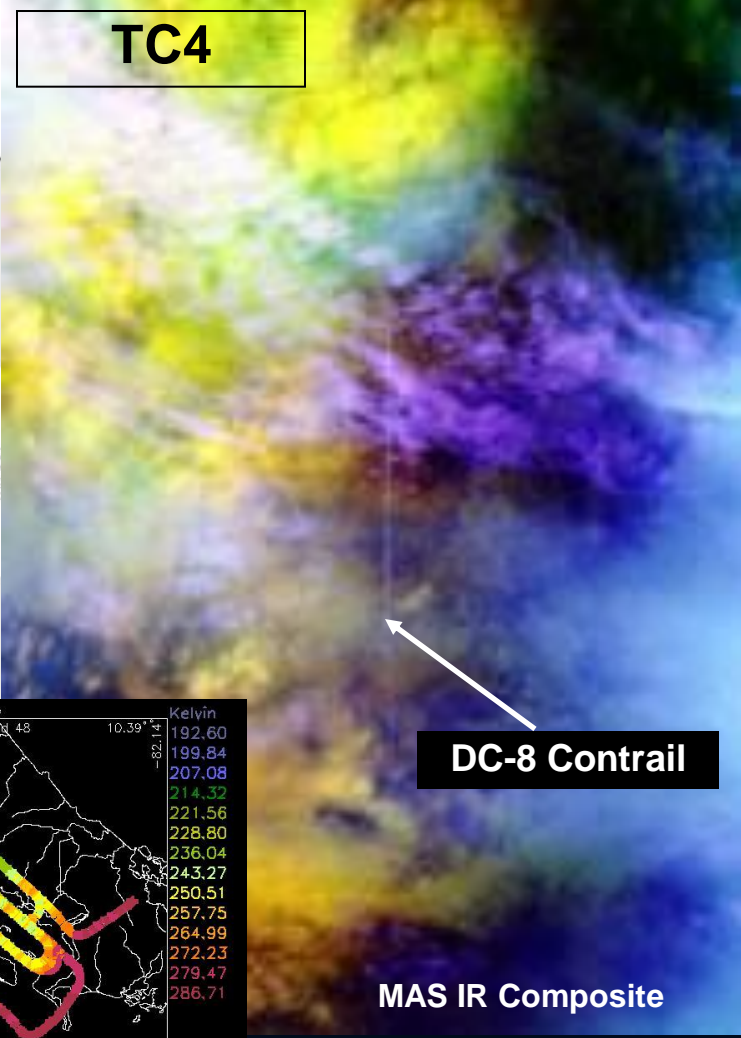
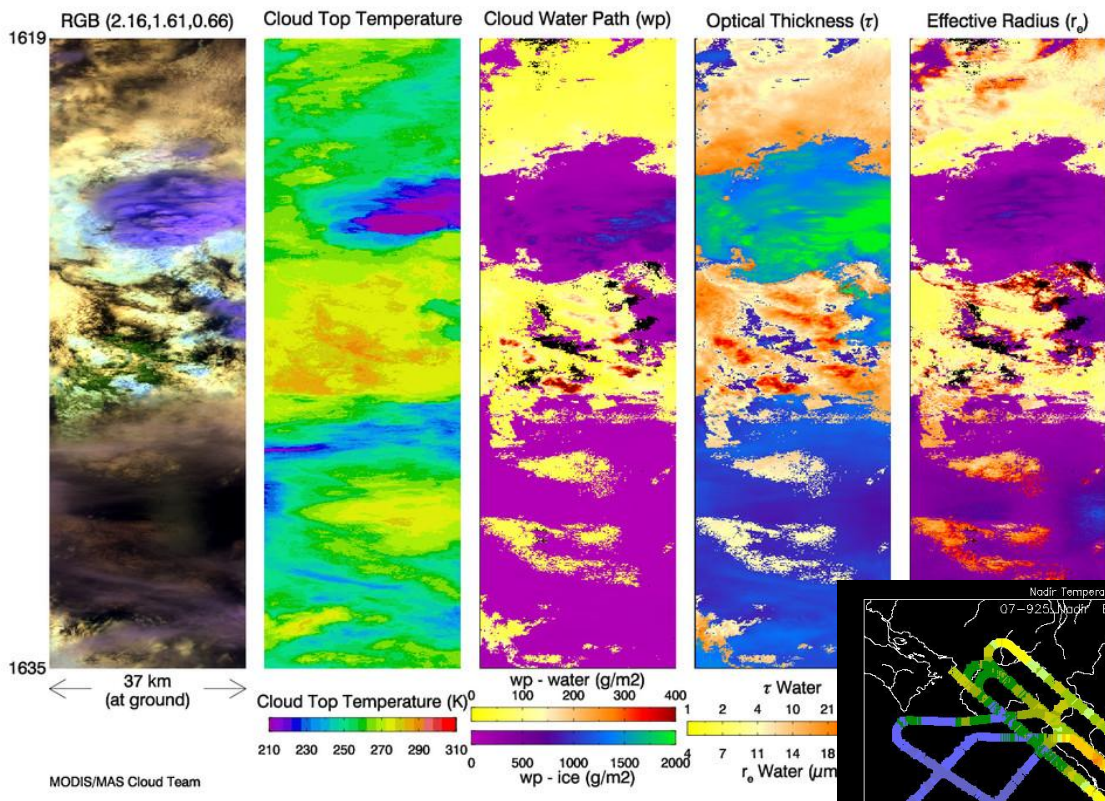
# TC4 MAS + MASTER Coverage (ER-2) July – Aug. 2007





# MAS & MASTER Data Collections: Costa Rica TC4

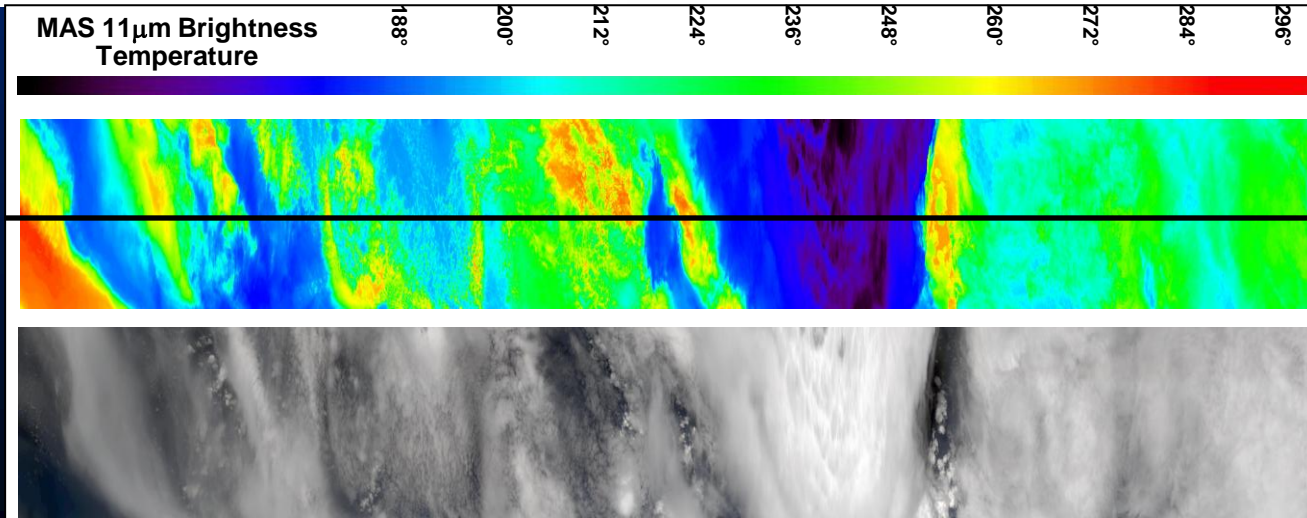
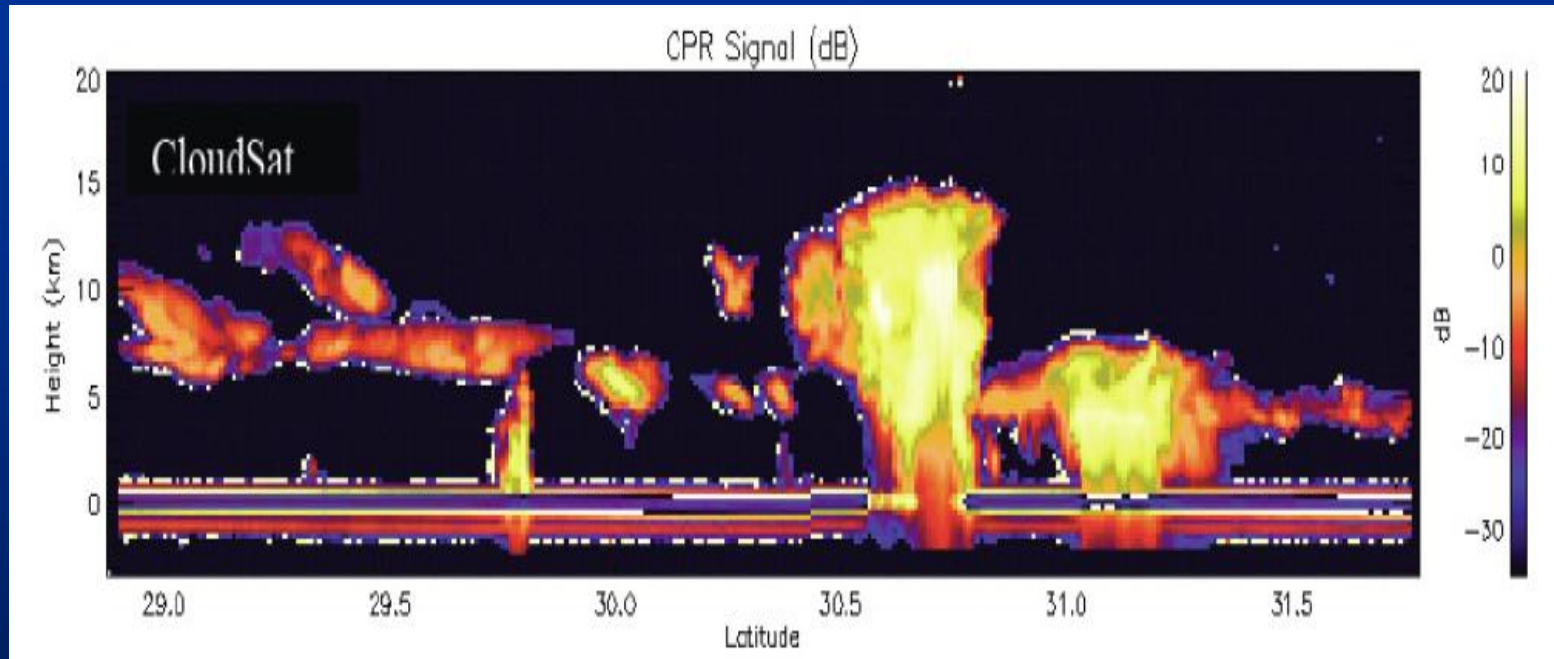
MASTER (ASTER) Airborne Simulator 03 August 2007 Flight # 07926 Track #11  
(TC4 Preliminary Retrievals - Pre-deployment Calibration)



**Field-Generated Level-2  
Data Products  
(with GSFC MODIS Cloud Team)**



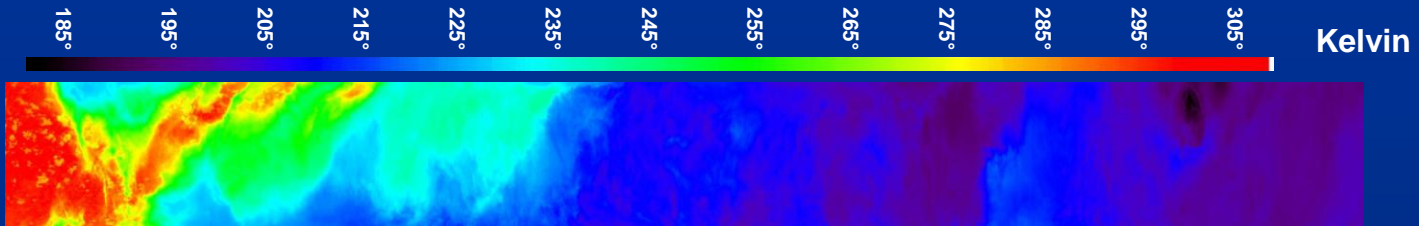
# MAS Data Collections: CCVEX



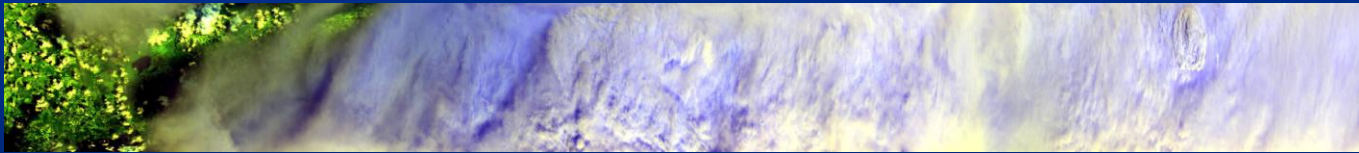
7-30-06 18:19  
- 18:45 UTC

# Data Collections: MAS CCVEX (w/ CRS)

MAS  
11.0um

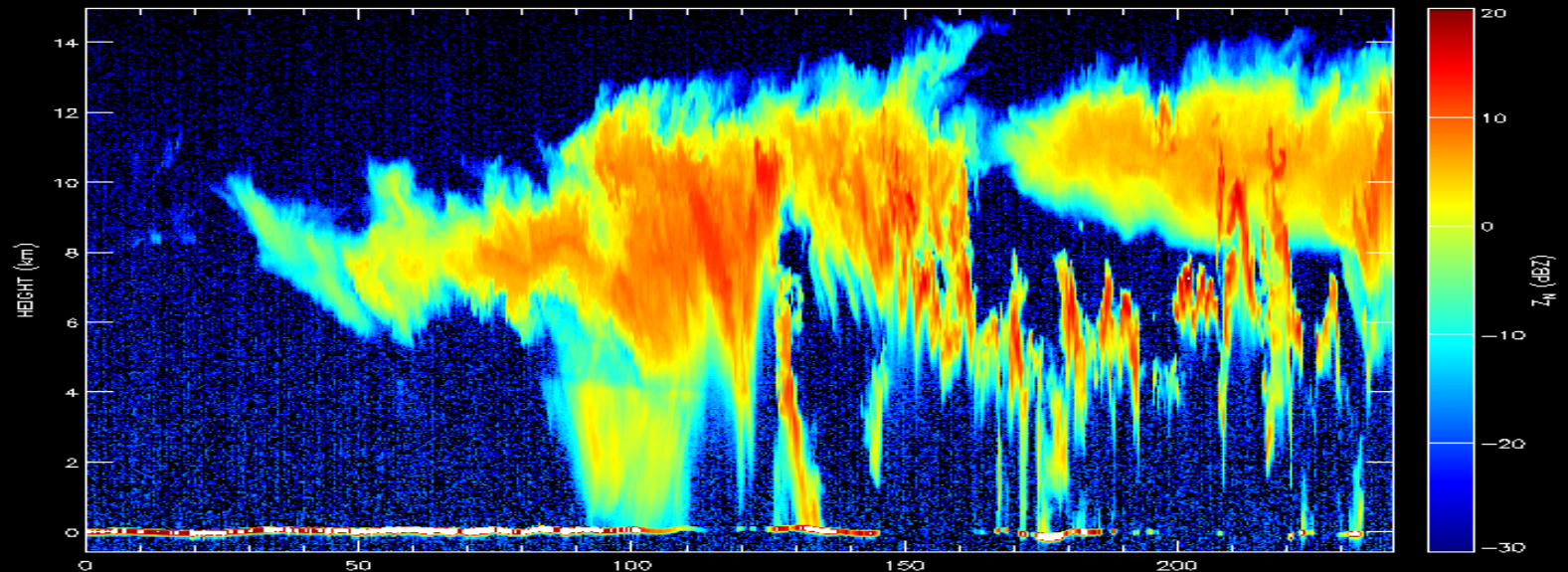


VIS



GSFC Cloud Radar 28 July 2006

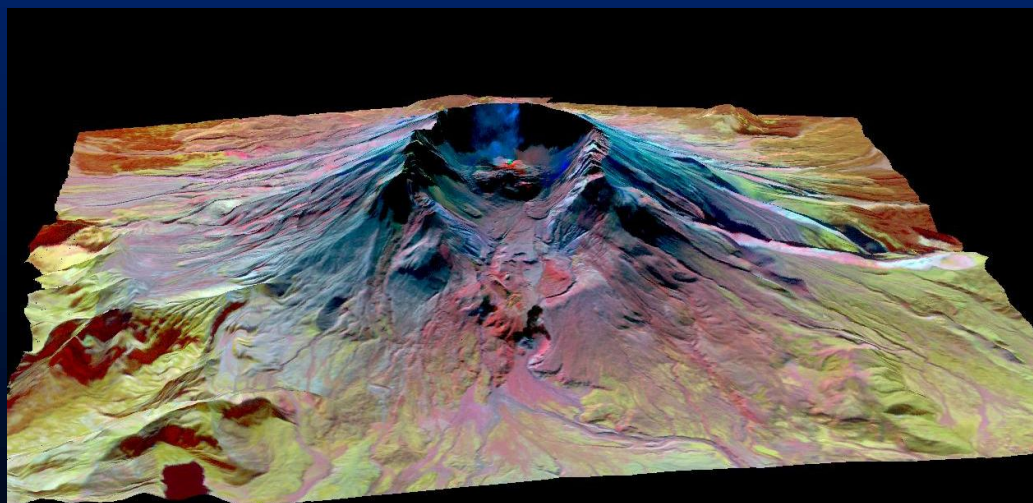
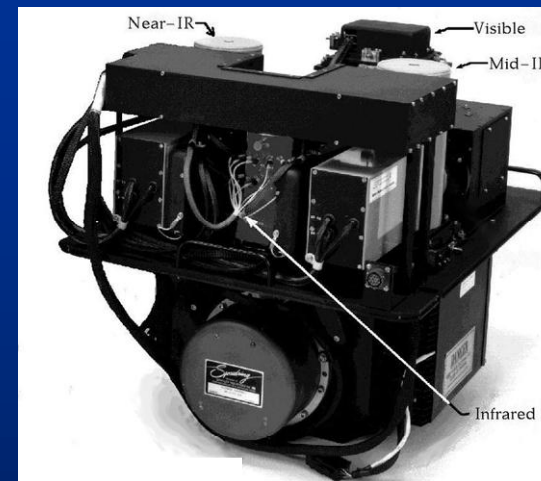
19:21 – 19:39 UTC



# MASTER: The MODIS-ASTER Airborne Simulator

- Simulates both the EOS Advanced Spaceborne Thermal Emission Reflection Radiometer and MODIS
- Automated Geo-Location/Rectification
- Flown on B-200, ER-2, Caravan, WB-57, DC-8 aircraft

Spectrometer	Spectral Range $\mu\text{m}$	Number of Bands	Nominal Bandwidth $\mu\text{m}$
1	0.440 - 0.965	11	0.040
2	1.600 - 2.427	14	0.050
3	3.075 - 5.325	15	0.150
4	7.700 - 13.000	10	0.500



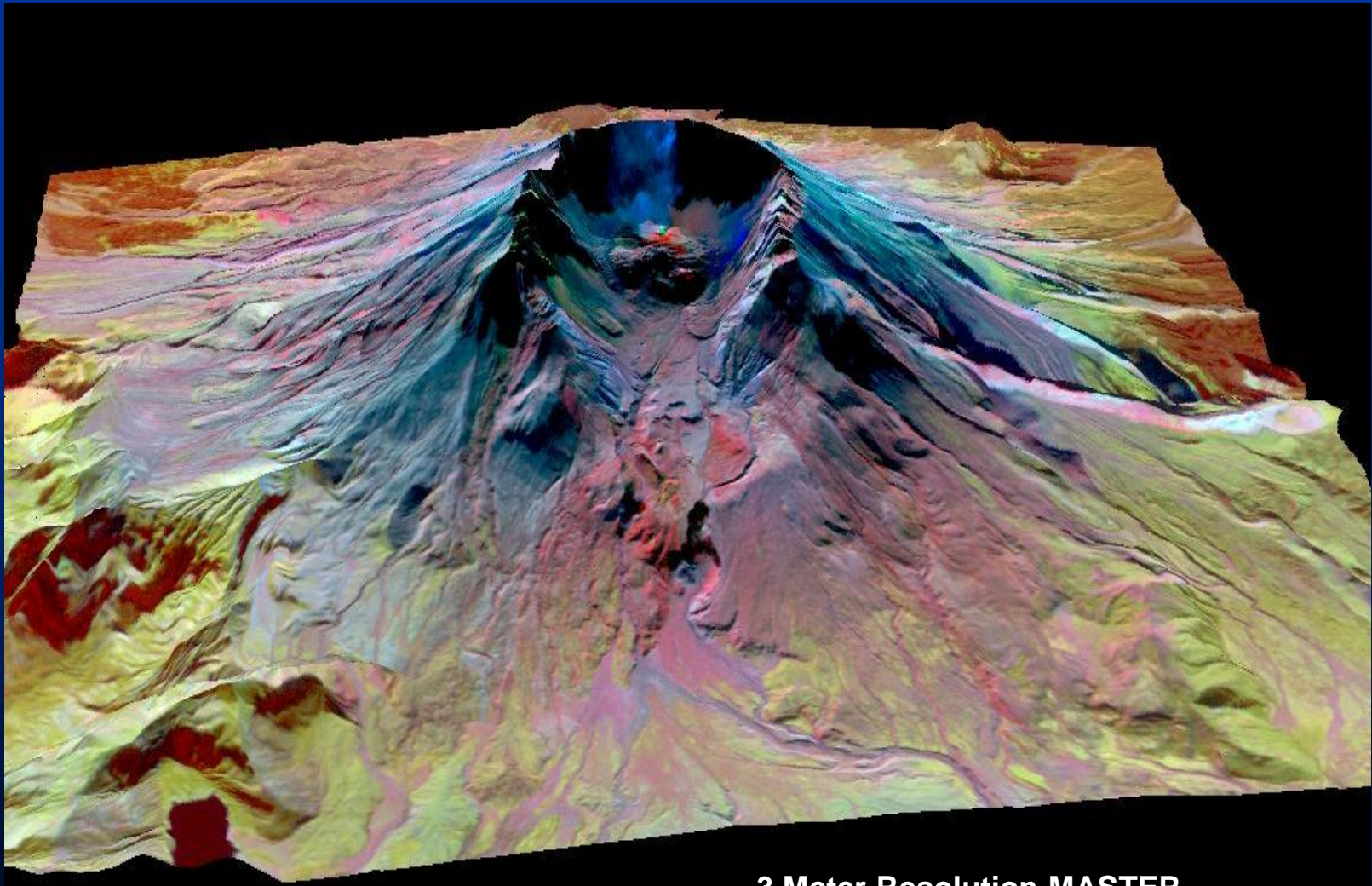
Mount St. Helens: 3 meter MASTER Data + 1 meter LIDAR DEM

# MASTER Instrument Characteristics

<b>Wavelength range</b>	<b>0.4-13 micrometers</b>
<b>Number of channels</b>	<b>50</b>
<b>Number of pixels</b>	<b>716</b>
<b>Instantaneous Field of View</b>	<b>2.5 milliradians</b>
<b>Total Field of View</b>	<b>85.92 degrees</b>
<b>Platforms</b>	<b>D.O.E. Beechcraft B200, Sky Research Cessna Caravan, NASA ER-2, DC-8, WB-57</b>
<b>Pixel size DC-8</b>	<b>10-30 m</b>
<b>Pixel size ER-2</b>	<b>50 m</b>
<b>Pixel size B200</b>	<b>5-20 m</b>
<b>Pixel size Caravan</b>	<b>3-15 m</b>
<b>ER-2 Range</b>	<b>3000 nautical miles</b>
<b>B200 Range</b>	<b>900 nautical miles</b>
<b>Caravan Range</b>	<b>1000 nautical miles</b>
<b>DC-8 Range</b>	<b>5400 nautical miles</b>
<b>Scan speeds</b>	<b>6.25/12.5/25 rps</b>
<b>Products</b>	<b>Radiance at sensor (Level 1B)</b>
<b>Calibration VIS-SWIR</b>	<b>Laboratory Integrating Sphere</b>
<b>Calibration MIR-TIR</b>	<b>2 On-board Blackbodies</b>
<b>Data Format</b>	<b>Hierarchical Data Format (HDF)</b>
<b>Digitization</b>	<b>16-bit</b>

# Mt. St. Helens MASTER + LIDAR

10/14/04 (Bands 44-12-2)

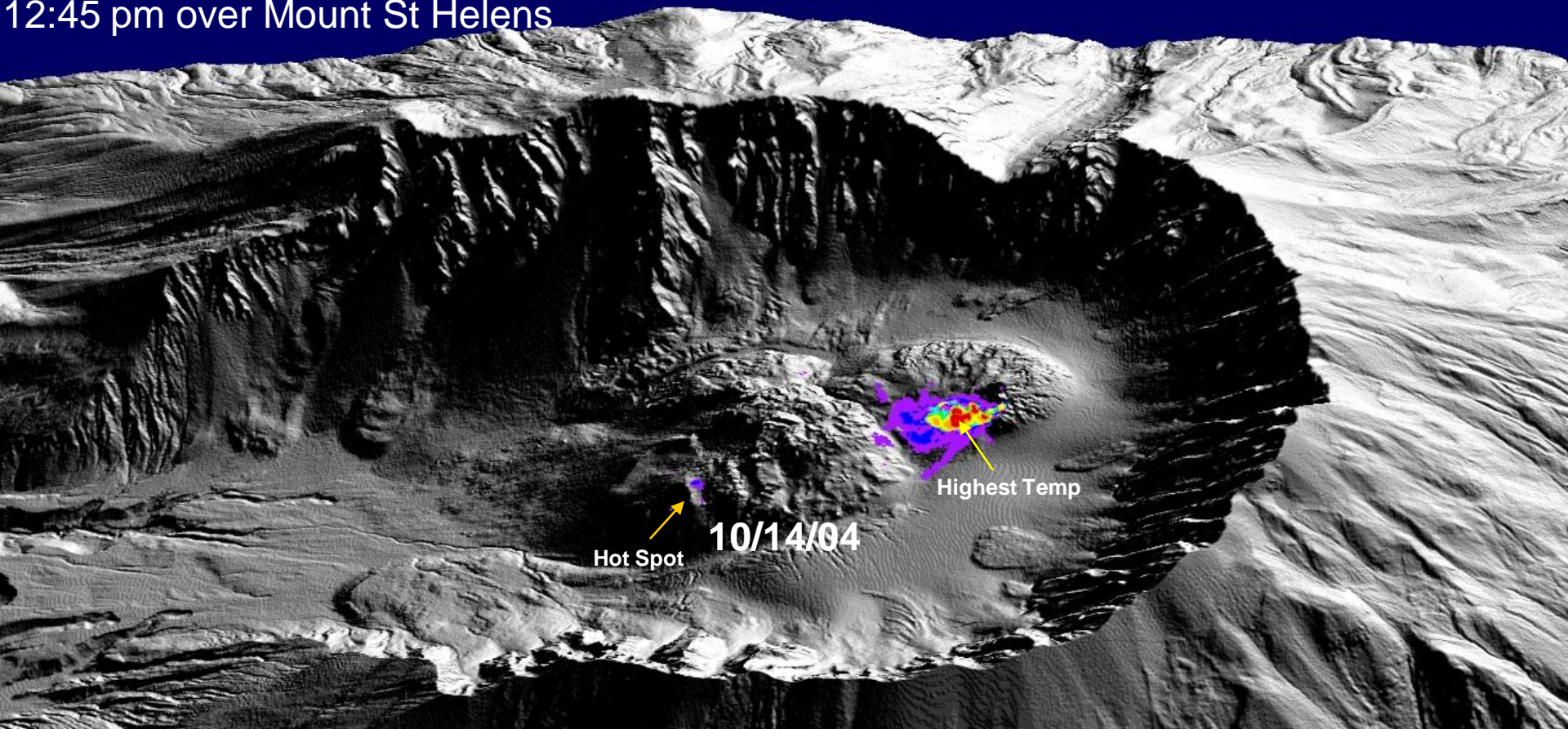


3 Meter Resolution MASTER  
1 Meter resolution Optech LIDAR DEM  
Automatic Ortho-Rectification



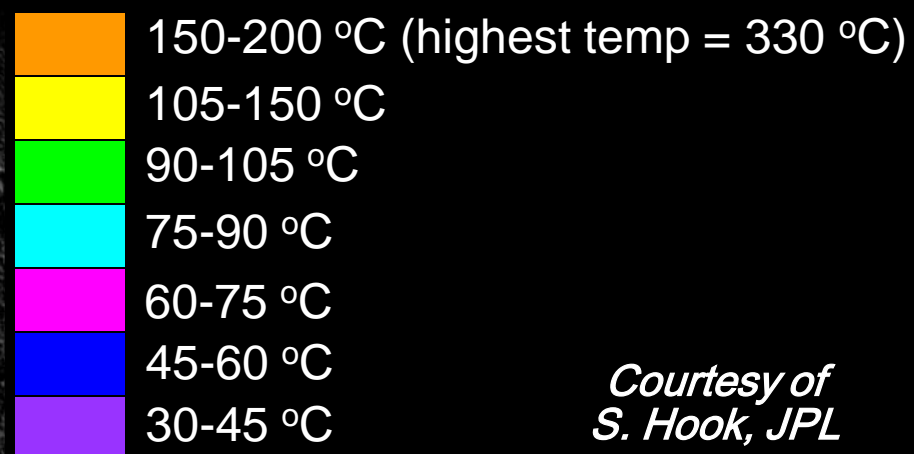
Ames Research Center  
Earth Science Division

Combined LIDAR (topography) and MASTER (temperature) data acquired 10-14-2004 at 12:45 pm over Mount St Helens



Hot Spot  
10/14/04

Highest Temp



MASTER 5 m spatial resolution  
LIDAR 2.5 m spatial resolution

*Courtesy of  
S. Hook, JPL*

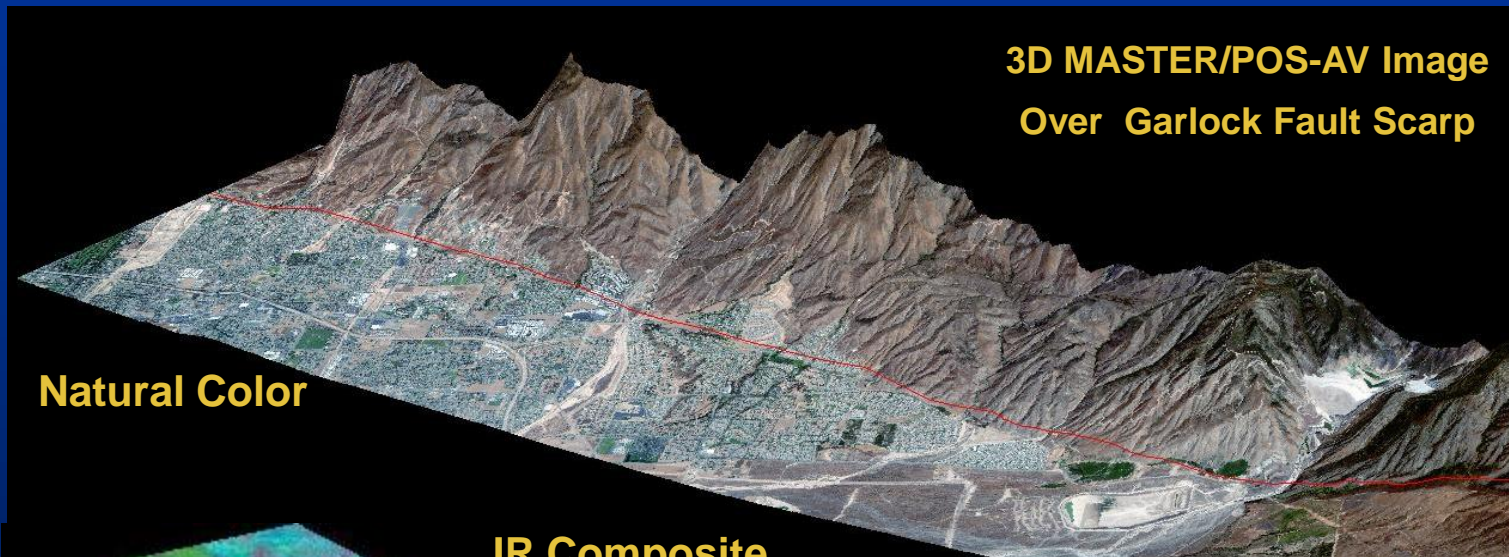
# MASTER (WB-57)



Arenal, Costa Rica (bands 42-22-6, March, 2003)

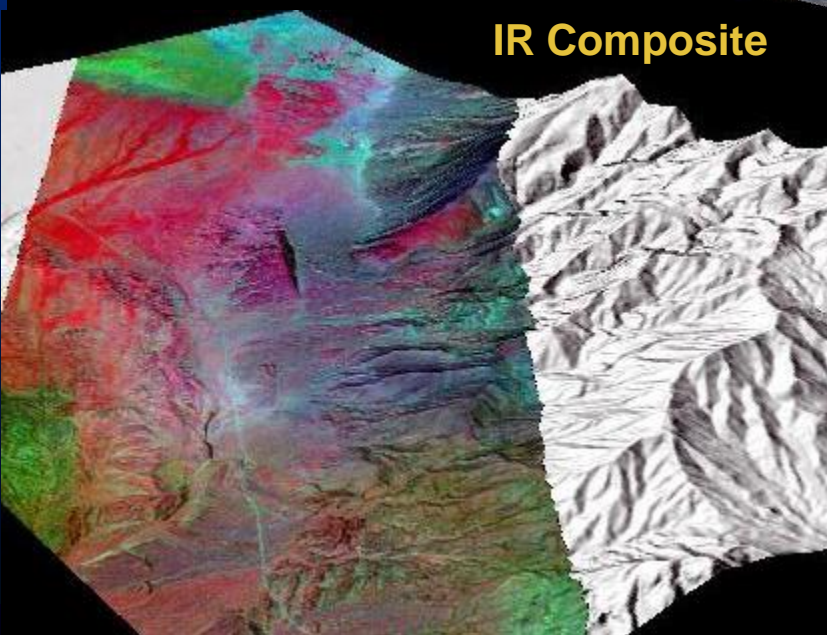
# MASTER DATA Collections: Calif. Fault Systems

(Day/Night Repeat-Pass Coverage)



3D MASTER/POS-AV Image  
Over Garlock Fault Scarp

Natural Color



IR Composite



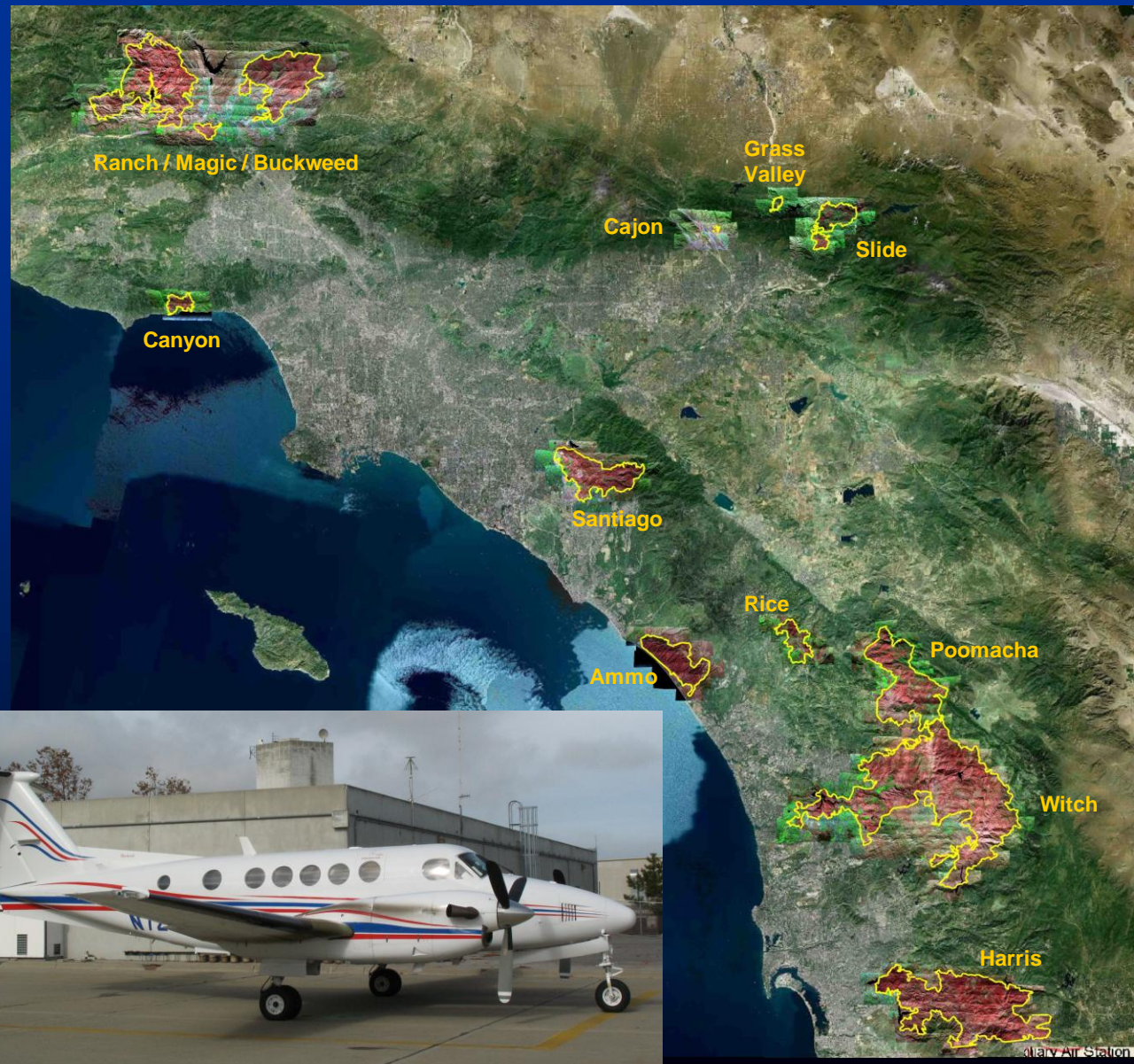
B200 Flight Lines

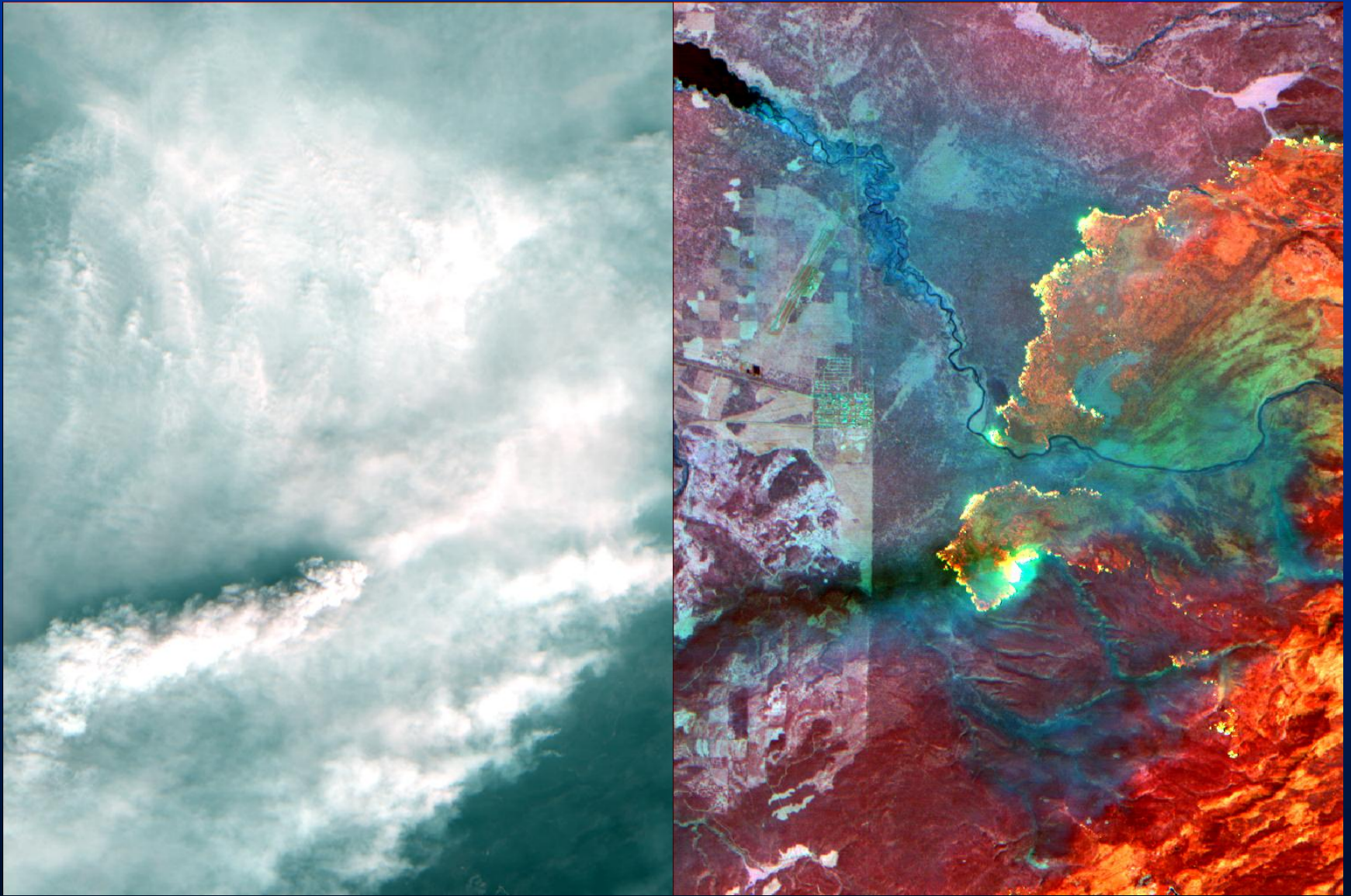


# MASTER DATA Collections: Post-Fire Assessment

Acquisition Dates  
November 5 – 15, 2007

- 5m Resolution
- 79 Flight lines
- 950 Nautical miles
- 54 Gbytes data



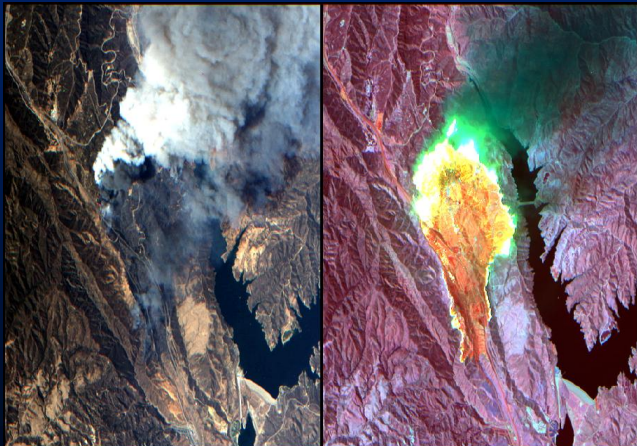


## Yellowstone Fire – 1988

ER-2 TM Simulator with LOS Down-Link

# AMS: The UAS Autonomous Modular Sensor

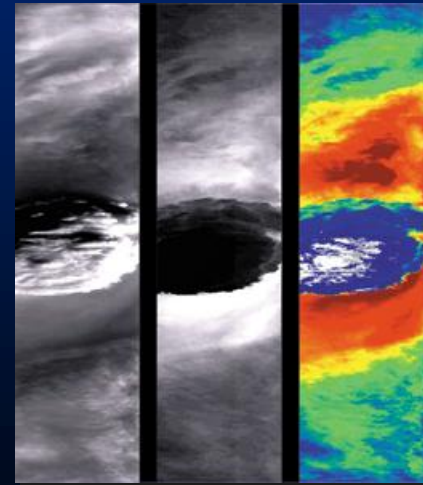
- Configurations for Land Surface, Ocean Color, and Atmospheric Mapping
- Embedded precision navigation system
- Onboard data product generation
- Real-Time data telemetry
- Compatible with large UAS (Predator-B, Altair, Global Hawk) or conventional aircraft



Wild Fire Research



Ocean Color / Coral Reef Research

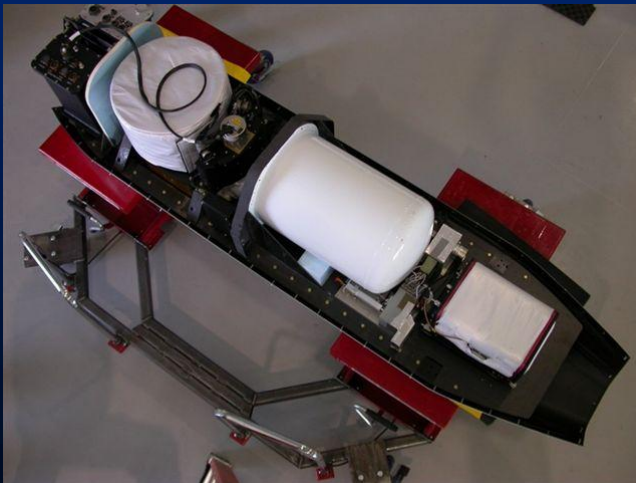


Hurricane and Atmospheric Studies



# The Autonomous Modular Sensor (AMS) a test-bed for future sensor web concepts

- Configurations for Land Surface/Fire, Ocean Color, and Atmospheric Mapping
- Onboard data product generation
- Embedded precision navigation system
- Real-time data telemetry interface
- Hardware development funding from the NASA HQ Airborne Science Program



AMS Sensor Components on Pod Tray



Pod Tray Prepared for Upload

# UAS - AMS

## (Wildfire – Land Surface Configuration)

<u>Band</u>	<u>Wavelength <math>\mu\text{m}</math></u>
1	0.42- 0.45
2	0.45- 0.52 (TM1)
3	0.52- 0.60 (TM2)
4	0.60- 0.62
5	0.63- 0.69 (TM3)
6	0.69- 0.75
7	0.76- 0.90 (TM4)
8	0.91- 1.05
9*	1.55- 1.75 (TM5) <i>1.88<math>\mu\text{m}</math> alternate</i>
10*	2.08- 2.35 (TM7)
11*	3.60- 3.79 (VIIRS M12)
12*	10.26-11.26 (VIIRS M15) <i>6.7<math>\mu\text{m}</math> alternate</i>

*\*Redundant High-Gain Recording (bands 13 - 16)*

Total Field of View: 42.5 or 85.9 degrees (selectable)

IFOV: 1.25 mrad or 2.5mrad ( “ ” )

Spatial Resolution: 3 – 50 meters (variable)



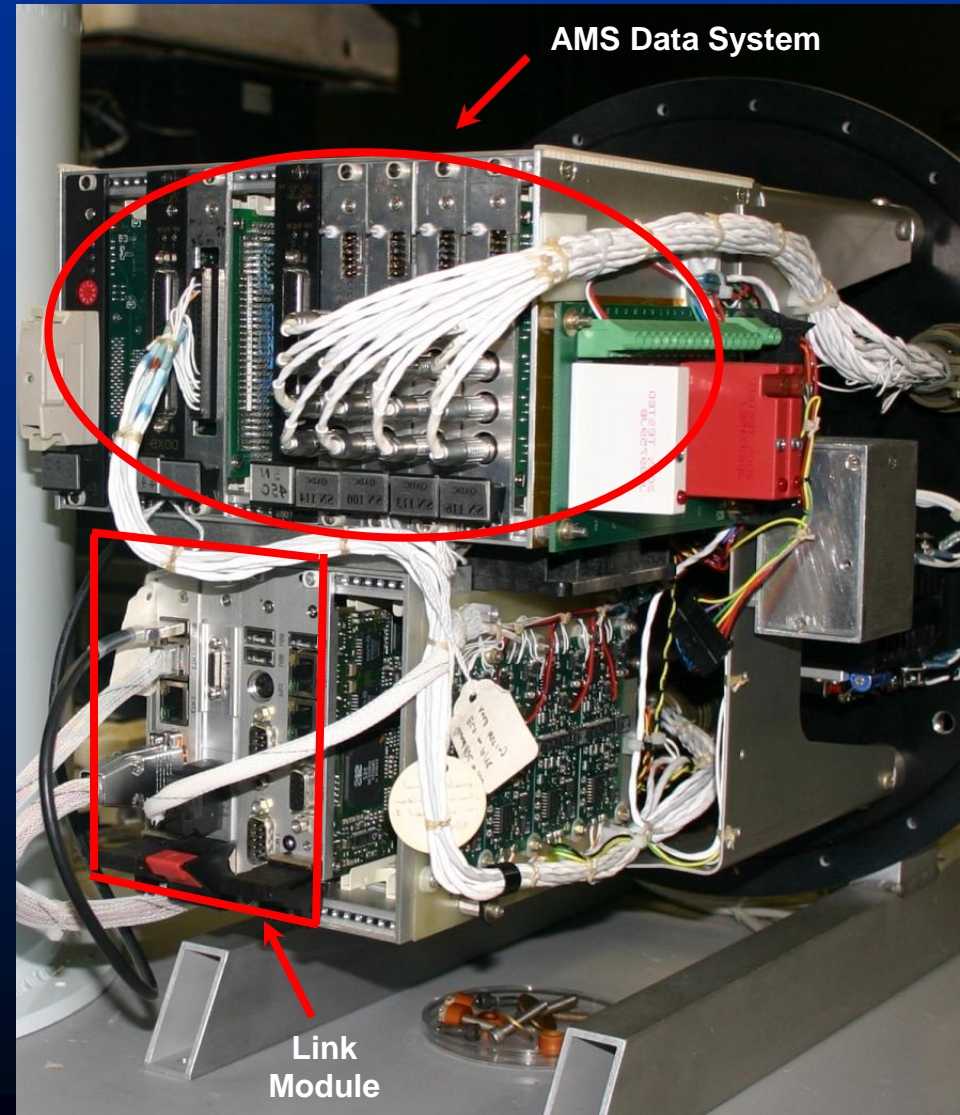
# UAS-AMS Sensor Features

- Pressurized Electronics Packaging
- 16-bit Digitizer w/ Auxiliary CPU
- Customized AADS-1268 Spectrometer
- Sterling & TE-Cooled IR Detectors
- Solid State Storage Media
- Integrated Applanix POV-AV Nav System
- High-speed serial interface for telemetry
- Rapid Portability Between Platforms

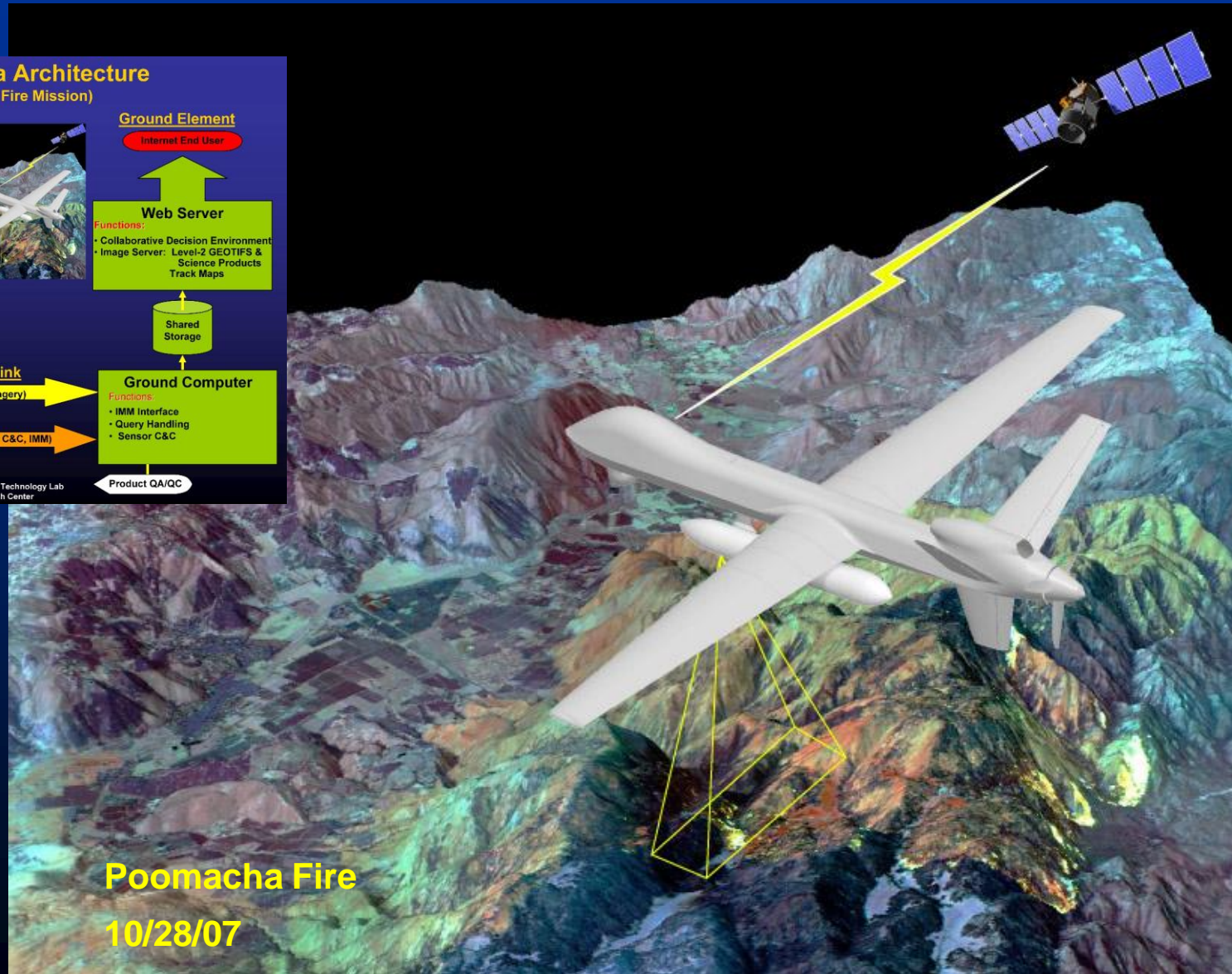
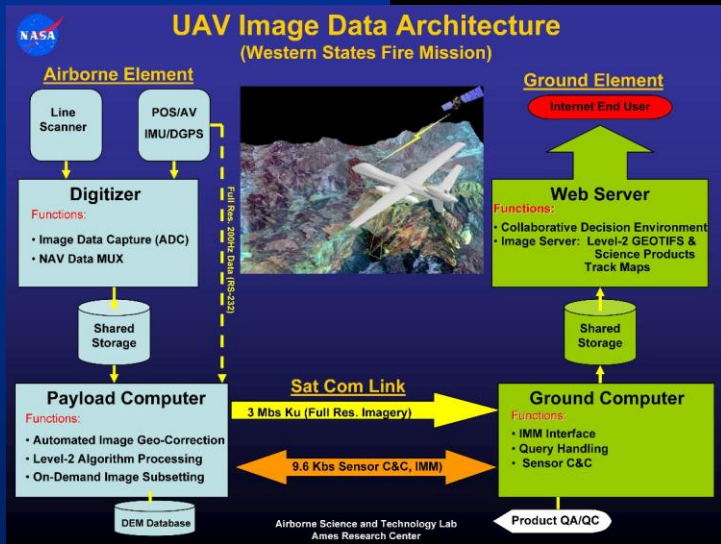


# AMS Data System: Telemetry Link Module

- A universal Interface for science payloads to broad band telemetry systems (Ku, S, C, L)
- Inputs for >20 instruments using standard protocols
- 40 Mbs max. throughput (link speed limited)
- Experimenter CPU & mass storage for science data reduction & recording
- Real-time on-board generation of Level-1 & 2 geophysical products
- Interfaces to ground-based IMM & Collaborative Decision Sensor Web Environment
- Packaged in AMS data system enclosure
- Stand-alone version for Global Hawk



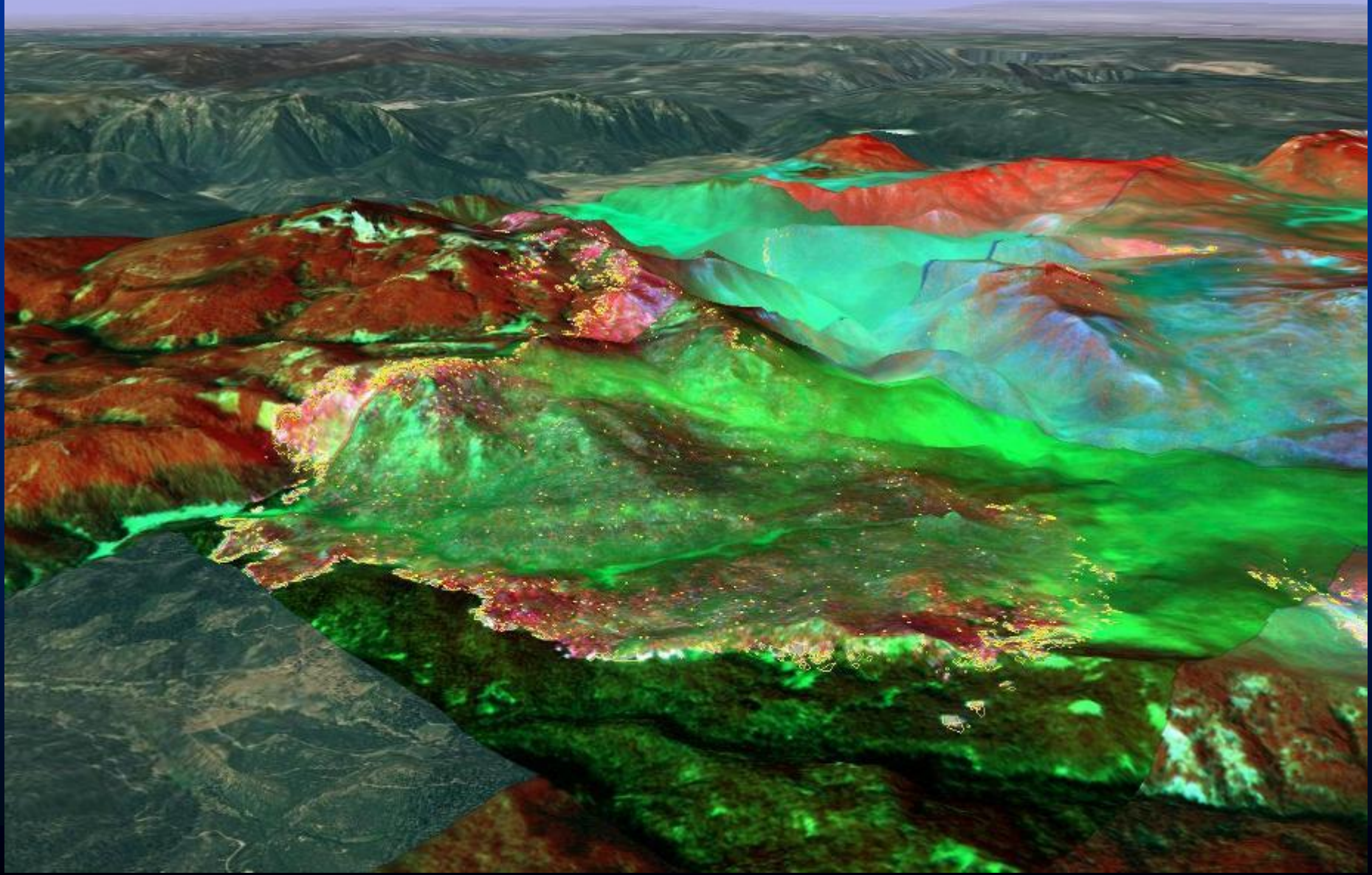
# Autonomous Modular Sensor: Western States Fire UAS Missions



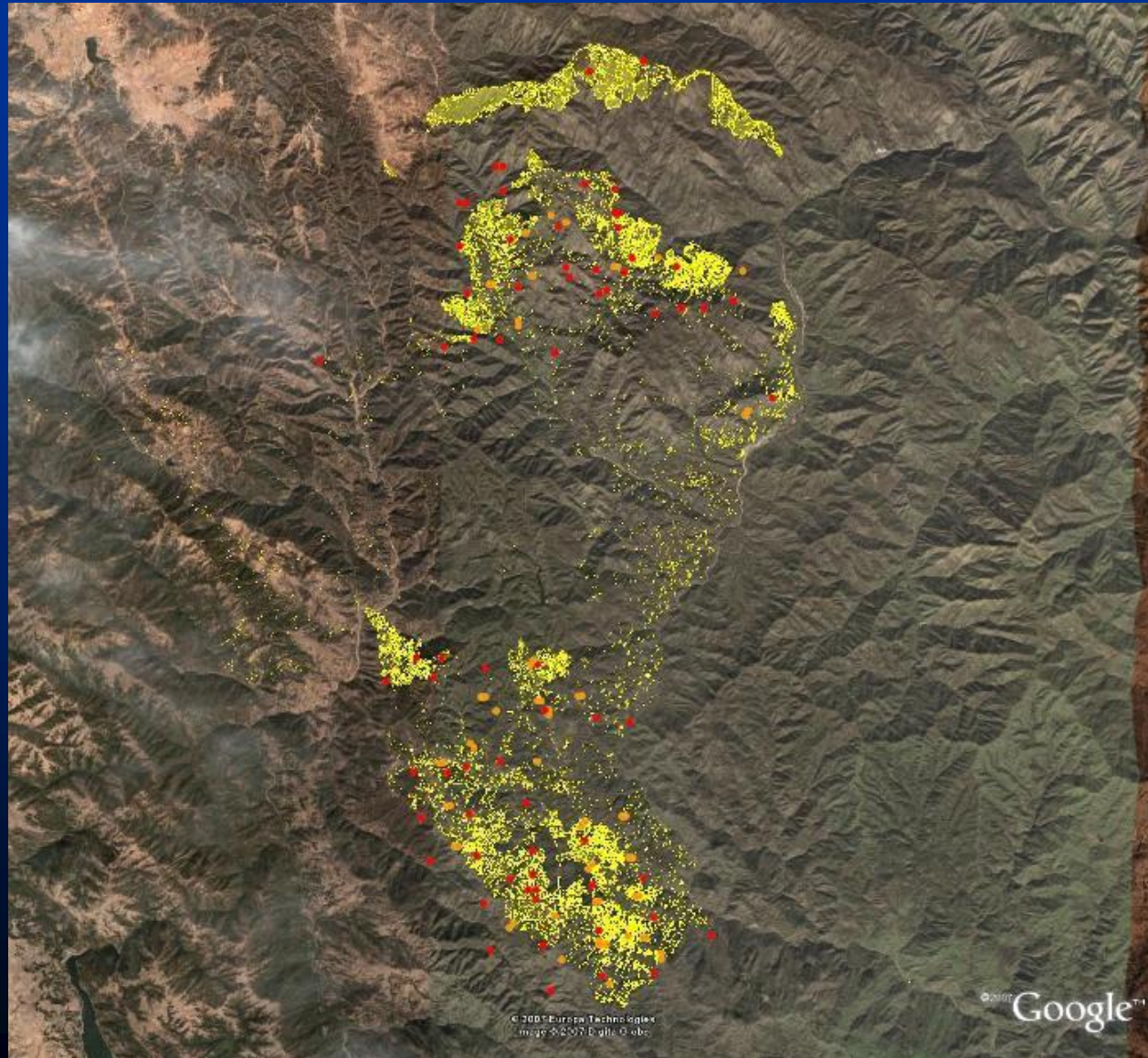


# Moonlight Fire

WSFM #4 (9/8/07)



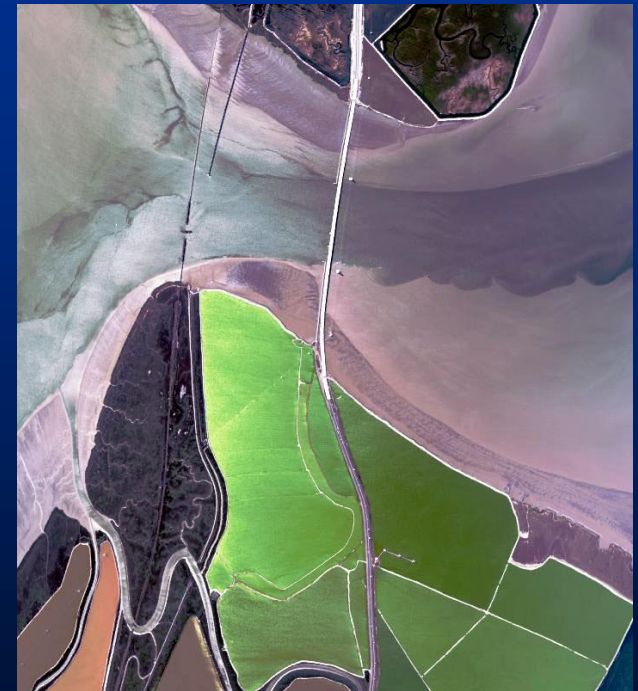
# AMS (yellow) & MODIS (red) Automated Fire Detects on Google Earth (9/7-8/07)



# The AMS Ocean Color Imager Configuration

- Includes SeaWiFS Bands + Thermal IR for SST
- Variable Resolution (2 – 50 meters, altitude dependent)
- Highly Calibrated
- Automated Geo-Location and Data Products

<u>Band</u>	<u>Center Wl, nm</u>	
1	412*	
2	443*	
3	490*	
4	510*	
5	555*	
6	620	
7	670*	*SeaWiFS Bands
8	770*	
9	860*	
10	1024	
11	11.5um	



IFOV / FOV: 2.5 mrad / 86 degrees

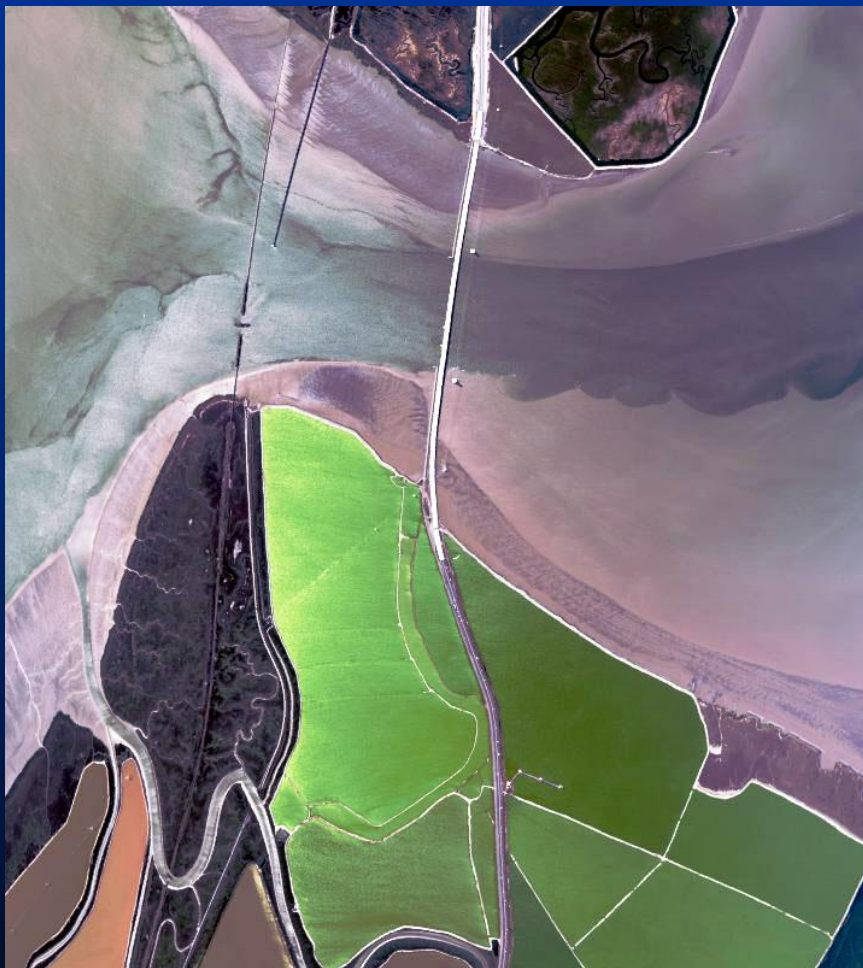
AMS-OCI (San Francisco Bay)

## Aircraft Platforms:

Predator-B or Global Hawk UAS, ER-2, WB-57, Beech B200, Twin Otter



# AMS Ocean Color Imager Test Flight Data (4/20/06)



Natural Color



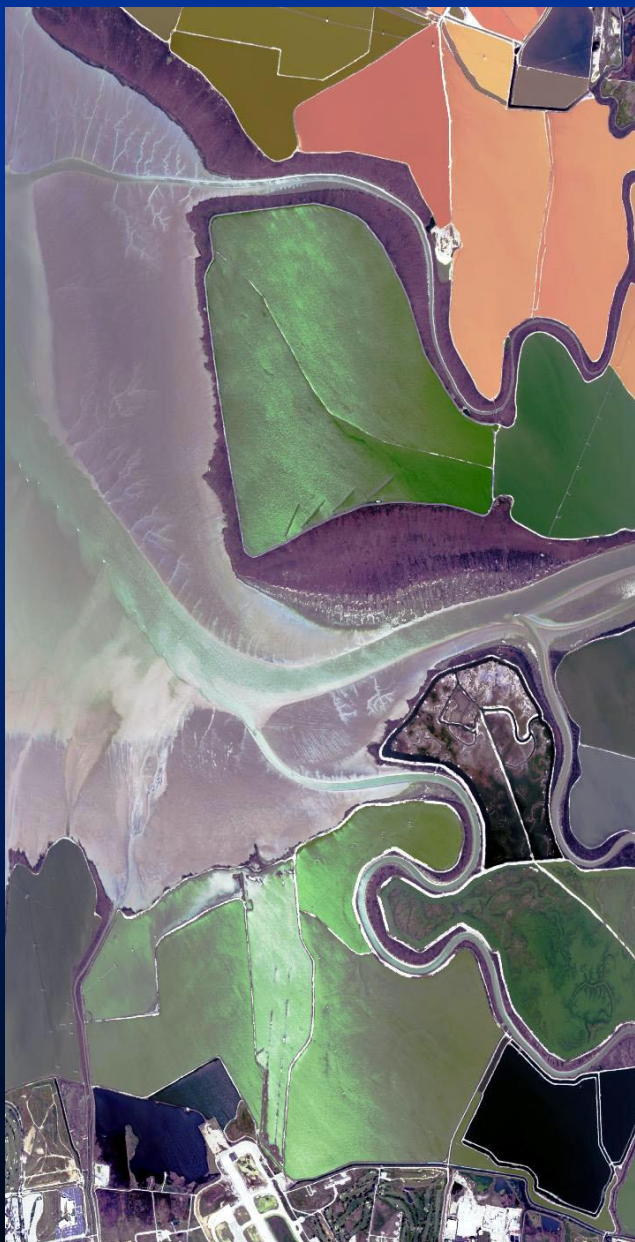
Thermal IR



Airborne Sensor Facility



# Guadalupe Slough (8 m.)



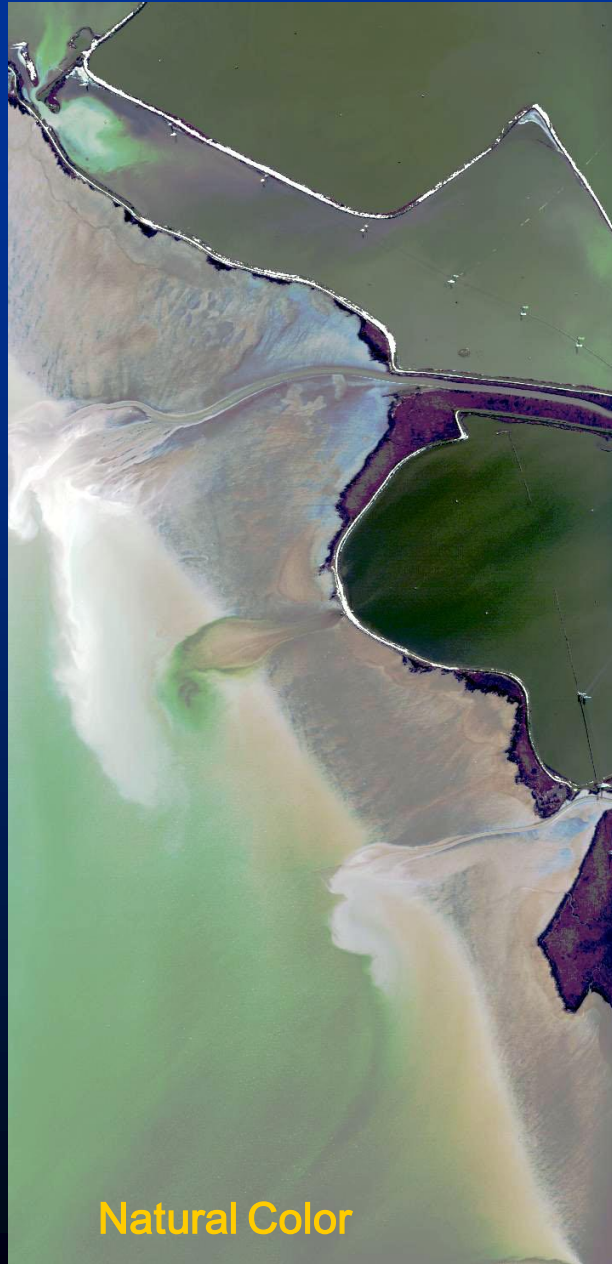
Natural Color



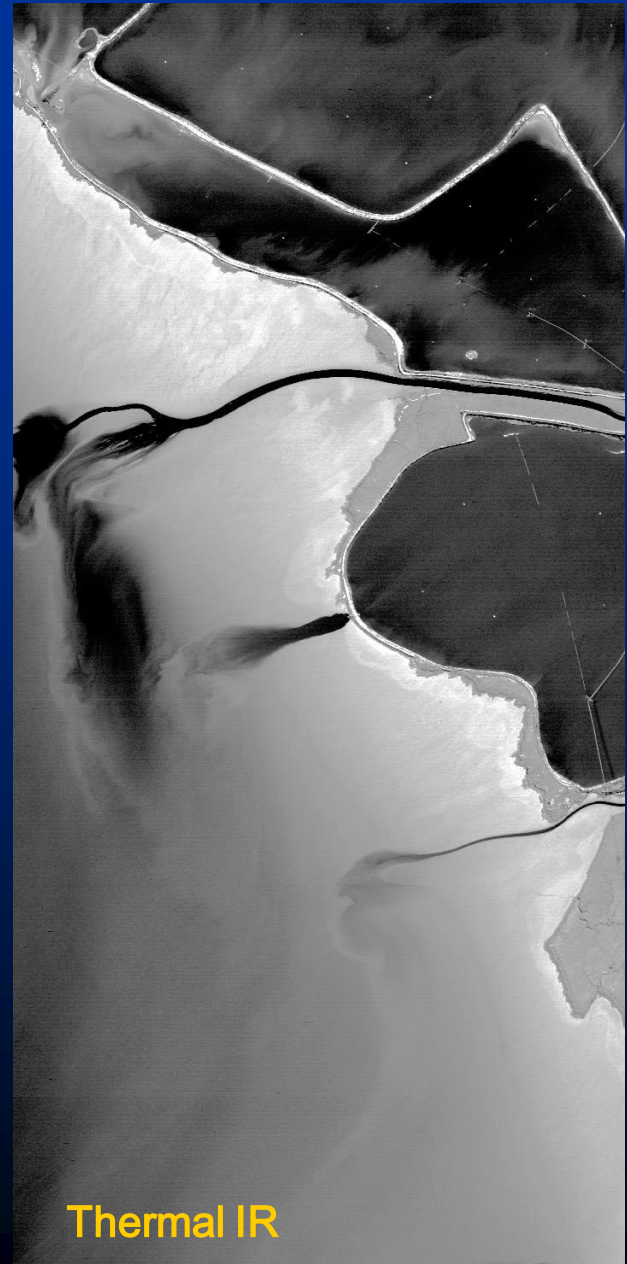
Thermal IR



# Stevens Creek Outlet (8 m.)

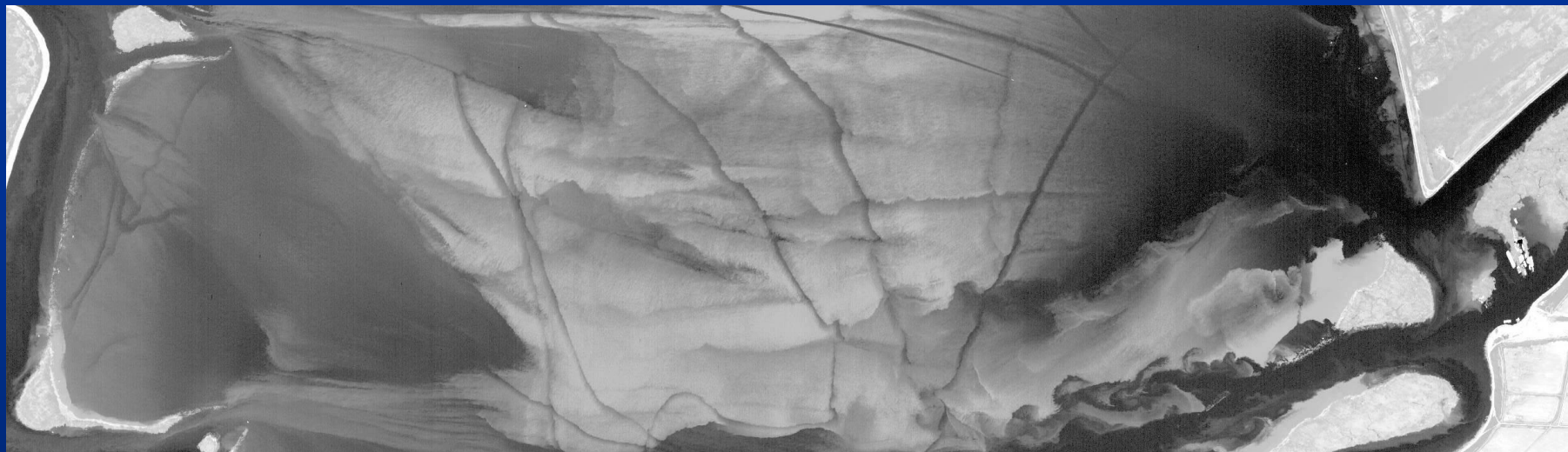


Natural Color

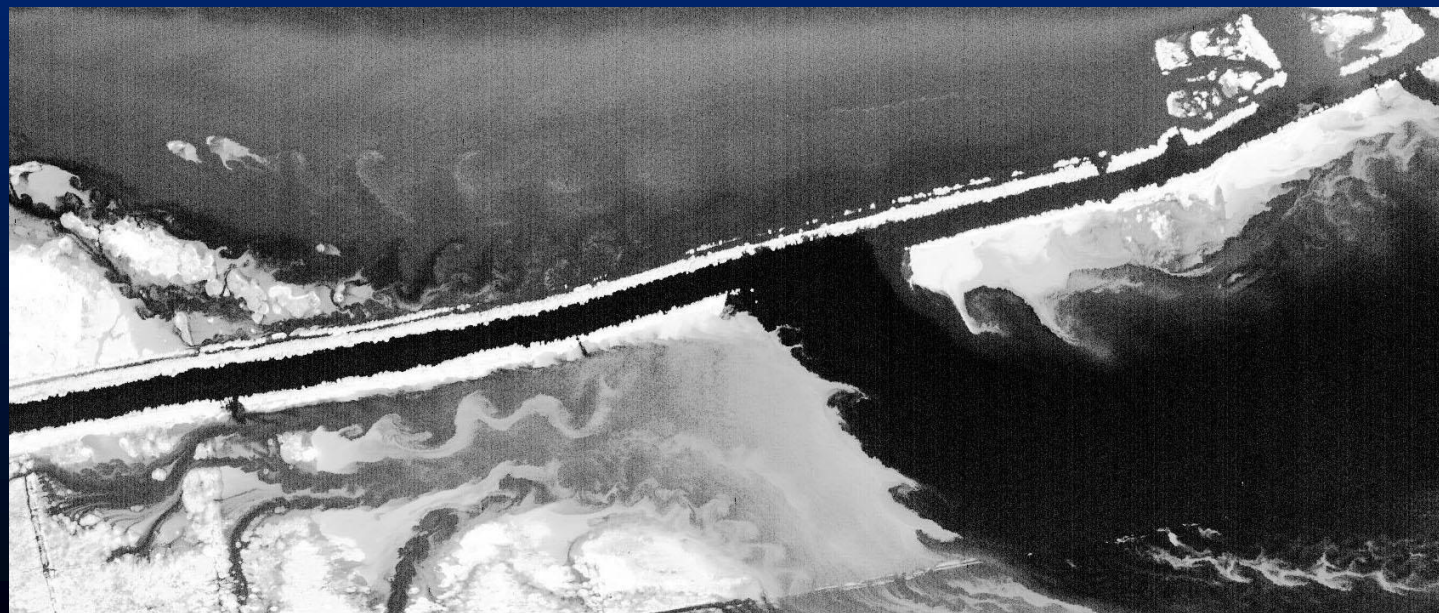


Thermal IR

# AMS Water Surface Thermal Imagery (2 meter res. 4/20/06)



Frank's Tract (above) Liberty Island Levee Breach (below)



Airborne Sensor  
Facility  
Ames Research  
Center



# ASF Sensor Calibration Lab

## ASF Spectral and Radiometric Calibration Facility for Airborne Sensors

Spectral Range = 350nm – 14um

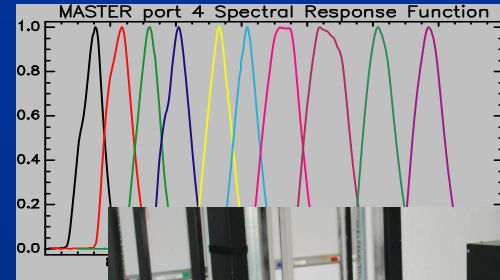
NIST-Traceable, with NASA EOS Program Oversight

Currently supporting:

AMS, MAS and MASTER  
SSFR (Solar Flux Radiometer)  
AATS-14 (Sun Photometer)  
CAR (Cloud Radiometer)  
Field Spectro-Radiometers

NIST Ref. Paper:

*Radiometric Validation of NASA  
ARC Calibration Laboratory, S.  
Brown, C. Johnson, et al. Applied  
Optics/Vol.44, No. 30, Oct. 2005*



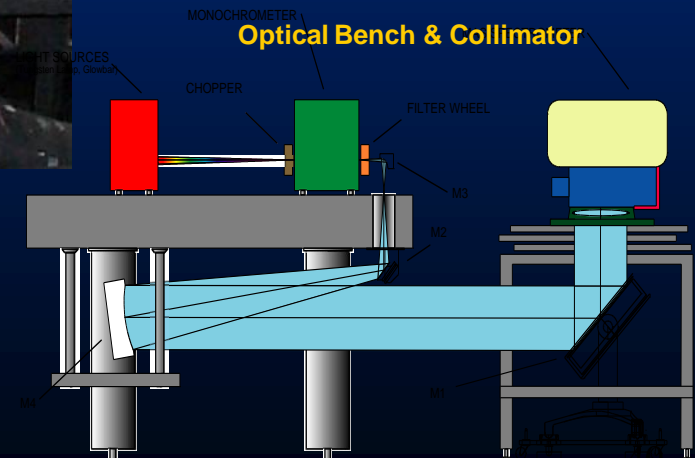
Transfer Radiometer  
Spectral Calibration Configuration



Integrating Spheres

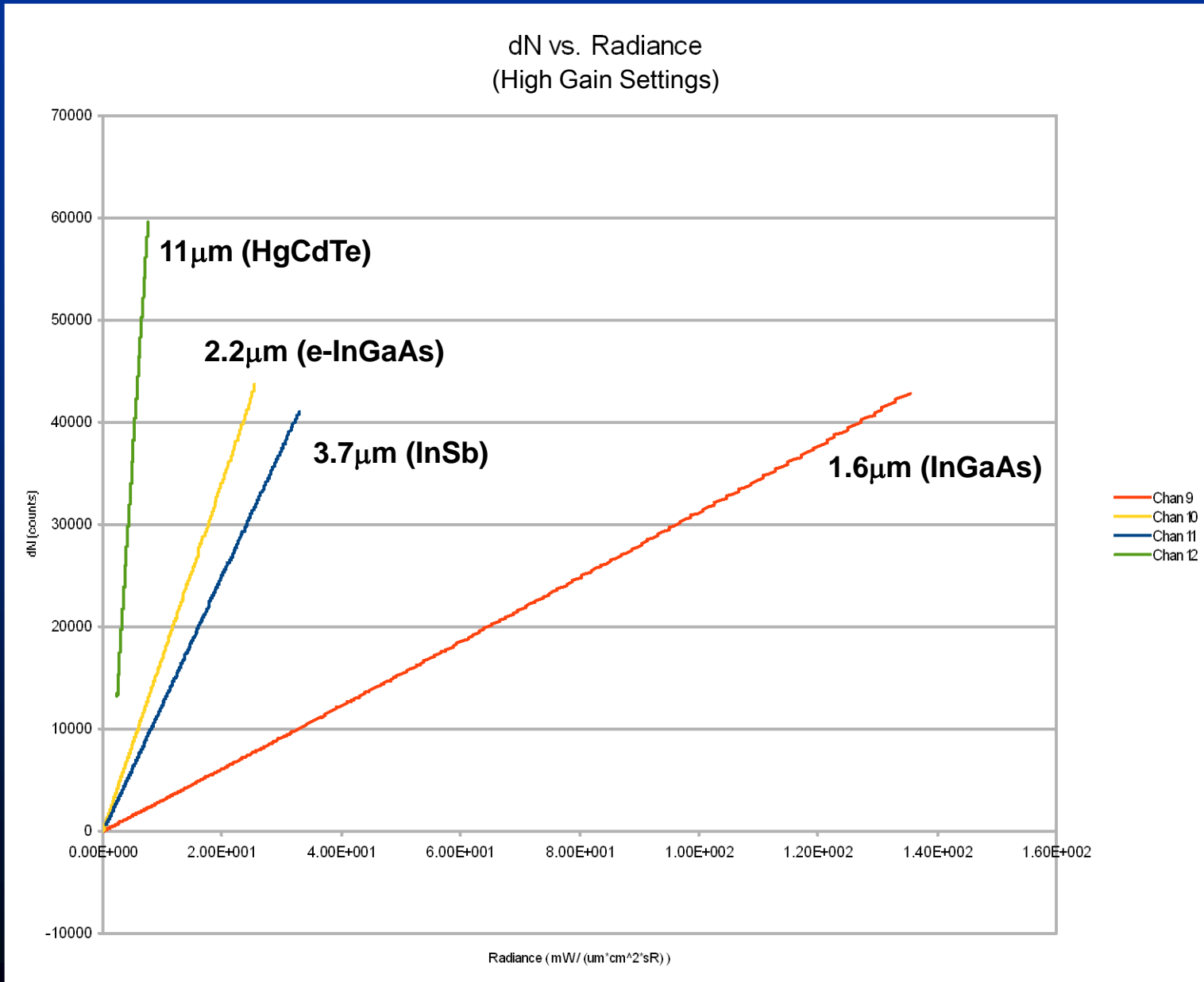


Spectral Sources

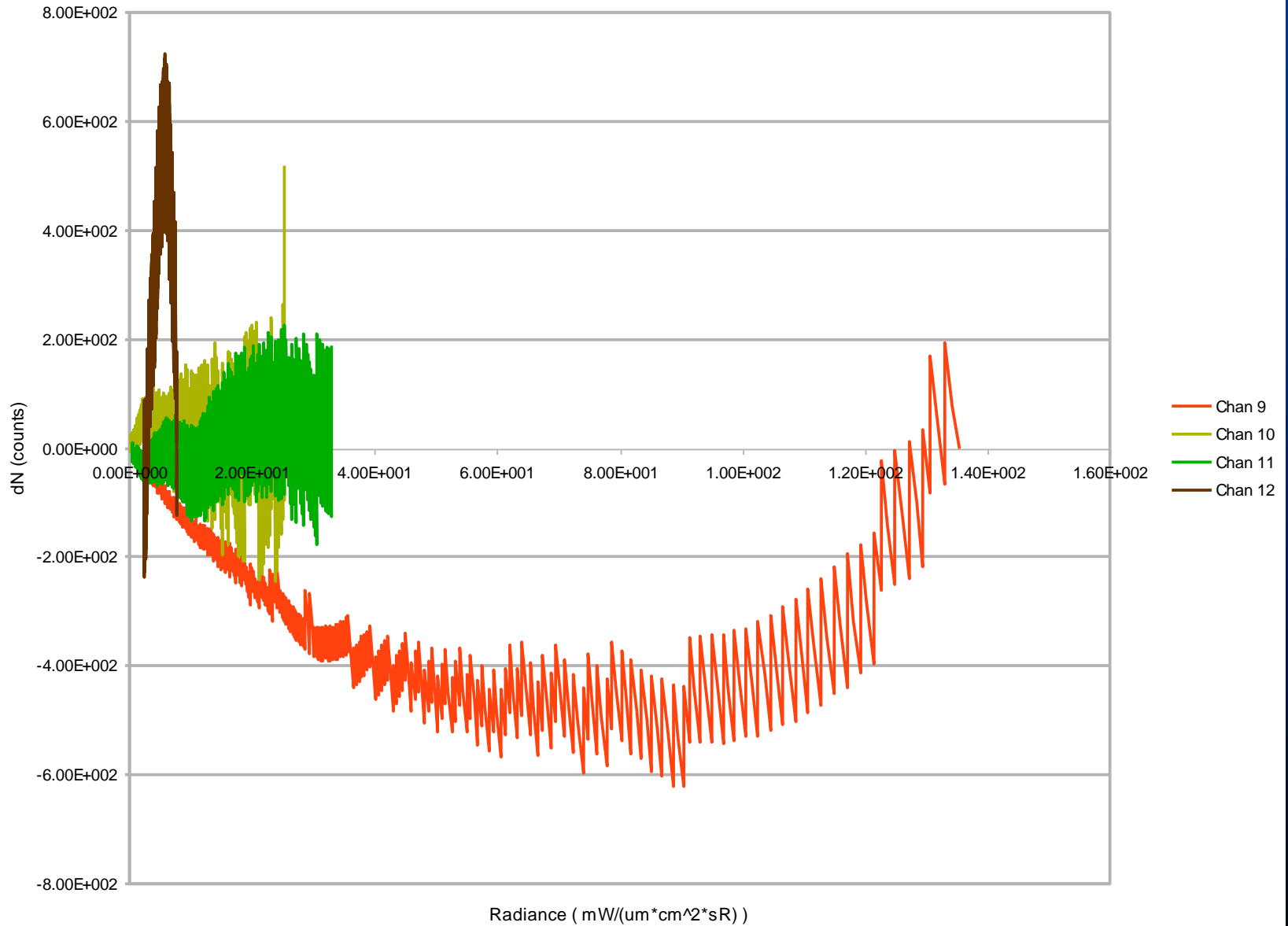




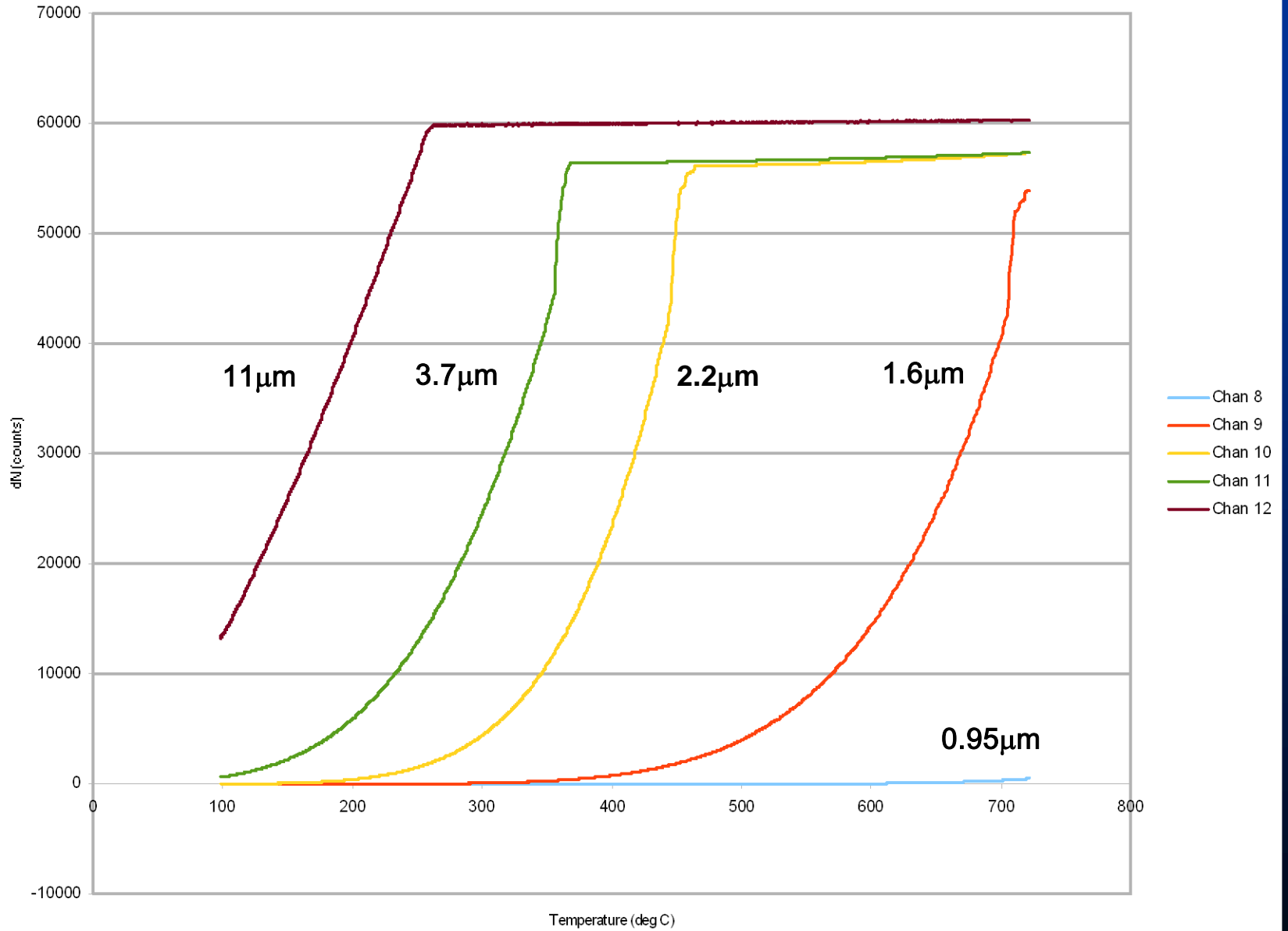
# AMS High-Temperature Blackbody Experiment (8/09)



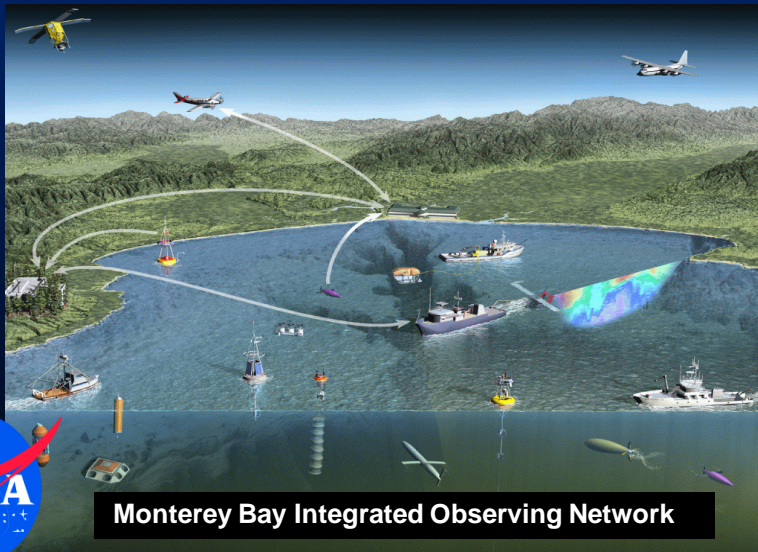
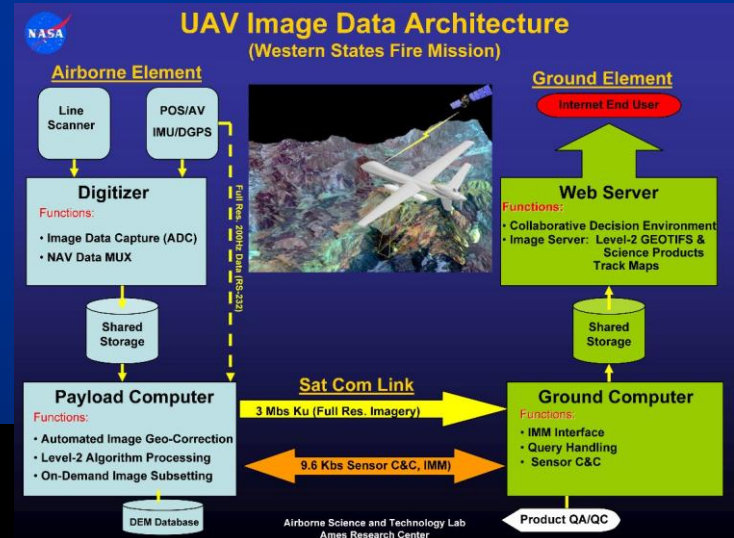
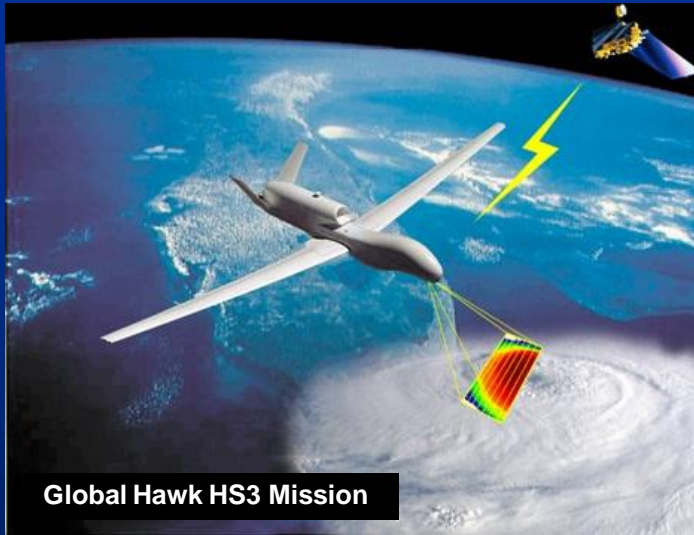
# Deviation from linearity



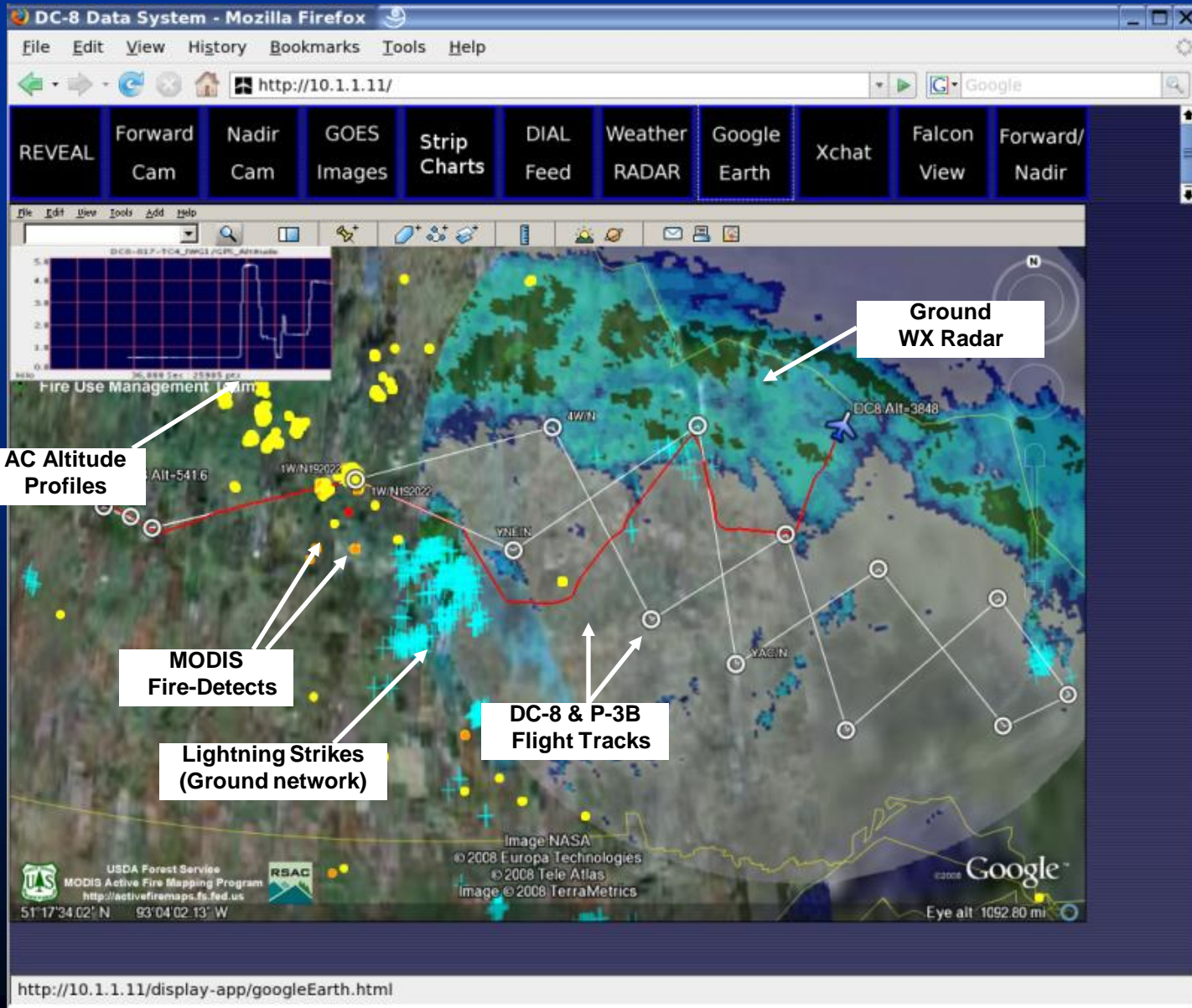
# dN vs. Temperature



# Sensor Webs for the Next-Generation of Airborne Science: onboard processing and extended networks for real-time science



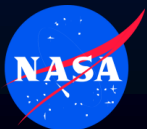
# Real-Time Data Synthesis: Satellite, Aircraft and Ground Data KML Overlays (ARCTAS, 2008)



# Reference Websites



- **General Information & Flight Requests**
  - <http://airbornescience.nasa.gov>
- **MASTER web page**
  - <http://masterweb.jpl.nasa.gov>
- **MAS web page**
  - <http://mas.arc.nasa.gov>
- **Airborne Sensor Facility web page**
  - <http://asapdata.arc.nasa.gov>



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