
# Imaging Spectroscopy in The United States with the Airborne Visible and Infrared Imaging Spectrometer

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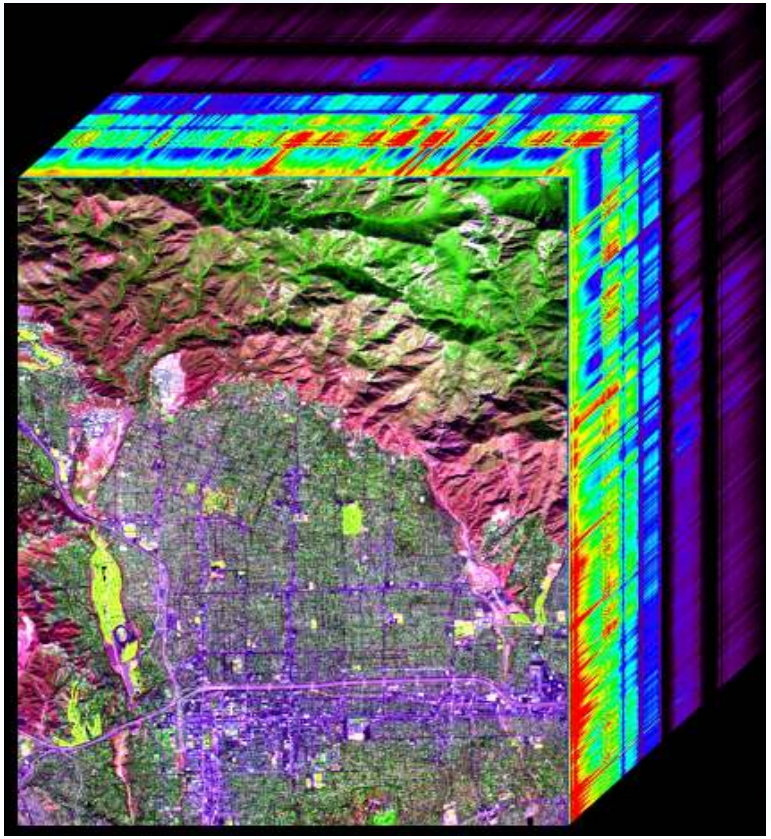

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# Understanding Worlds with Imaging Spectroscopy


## Airborne Imaging Spectrometer (AIS), Earth-1983

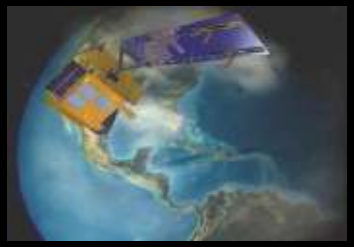
### Space Science

Near-Infrared Mapping Spectrometer (NIMS) on Galileo 1989

Visual and Infrared Mapping Spectrometer (VIMS) on Cassini 1997

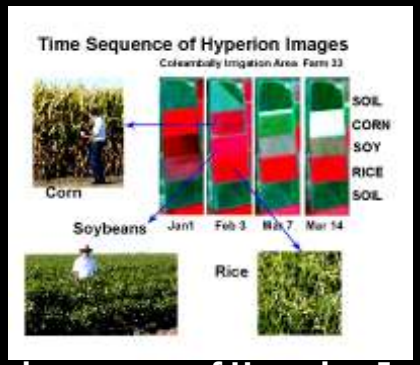
Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) 2005

### Earth Science

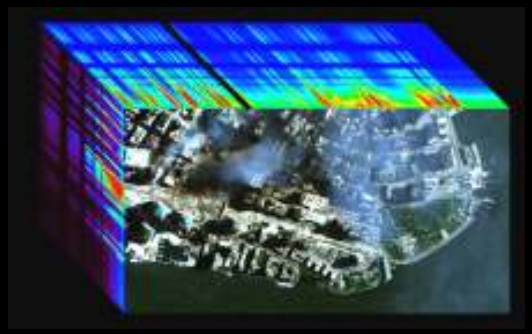


New Millennium EO-1 (Hyperion)1st Earth Space-borne Imaging Spectrometer, 2002

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) Earth-1987




Timed sequence of Hyperion Images Observing crops over time



AVIRIS captures 9/11 aftermath

# Historical Overview


- Sensor began flying in 1987 on NASA ER-2
- Has been collecting data annually for 15 years
- The Jet Propulsion Laboratory operates, maintains, and calibrates the sensor for NASA
- AVIRIS is a research and development system for both applications and sensor development
- Originally created as a experimental test sensor for Space Shuttle and Satellite missions
  - AVIRIS was the only sensor built from original proposal
- Because AVIRIS is a research sensor, it has been able to be upgraded every year

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# Design Characteristics


- 200 µm detectors
- F/1 Optics
- High Precision SNR
- 4 Spectrometers
- 4 Focal Plane Arrays

- **Stable, Uniform, and Calibrated in:**

| | Spectral | Radiometric | Spatial |
|---|---|---|---|
| **Range** | **370 to 2510 nm** | **0 to Max Lambertian** | **33 degrees (FOV)** |
| **Sampling** | **10 nm** | **12 bits** | **1 mrad (IFOV)** |
| **Accuracy** | **0.5 nm** | **96 Percent** | **1 mrad** |

Recent Instrument Upgrades:

- Thermal control 1997
- Low Altitude 1998
- INU/GPS 1998
- Geo rectification 1998
- Onboard calibrator 1999
- Detector arrays 2000
- Digital signal chain 2001
- Onboard data storage 2001
- 33° Field of View in 2002
- New Onboard Calibrator 2003
- New Foreoptics in 2004
- 370 – 2510 nm Range in 2004

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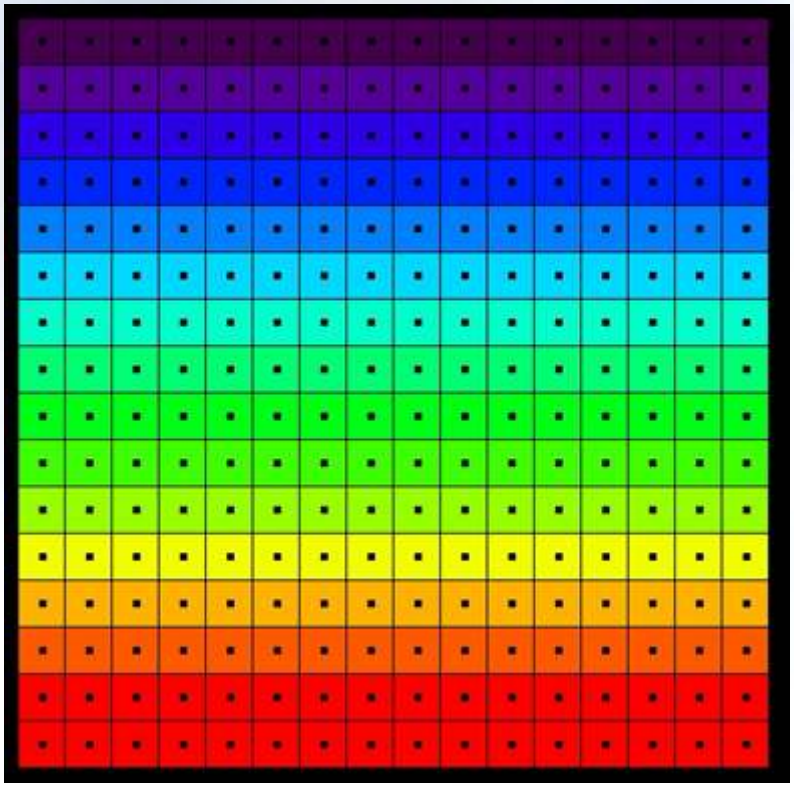
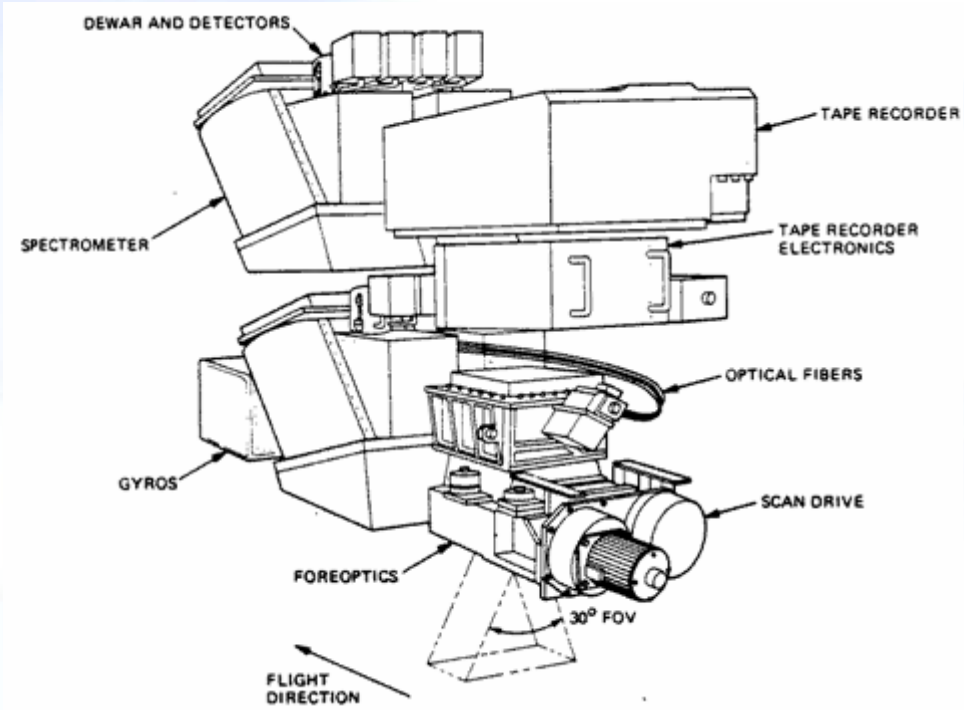
# Whiskbroom Imaging Spectrometer


Cross Track Sample

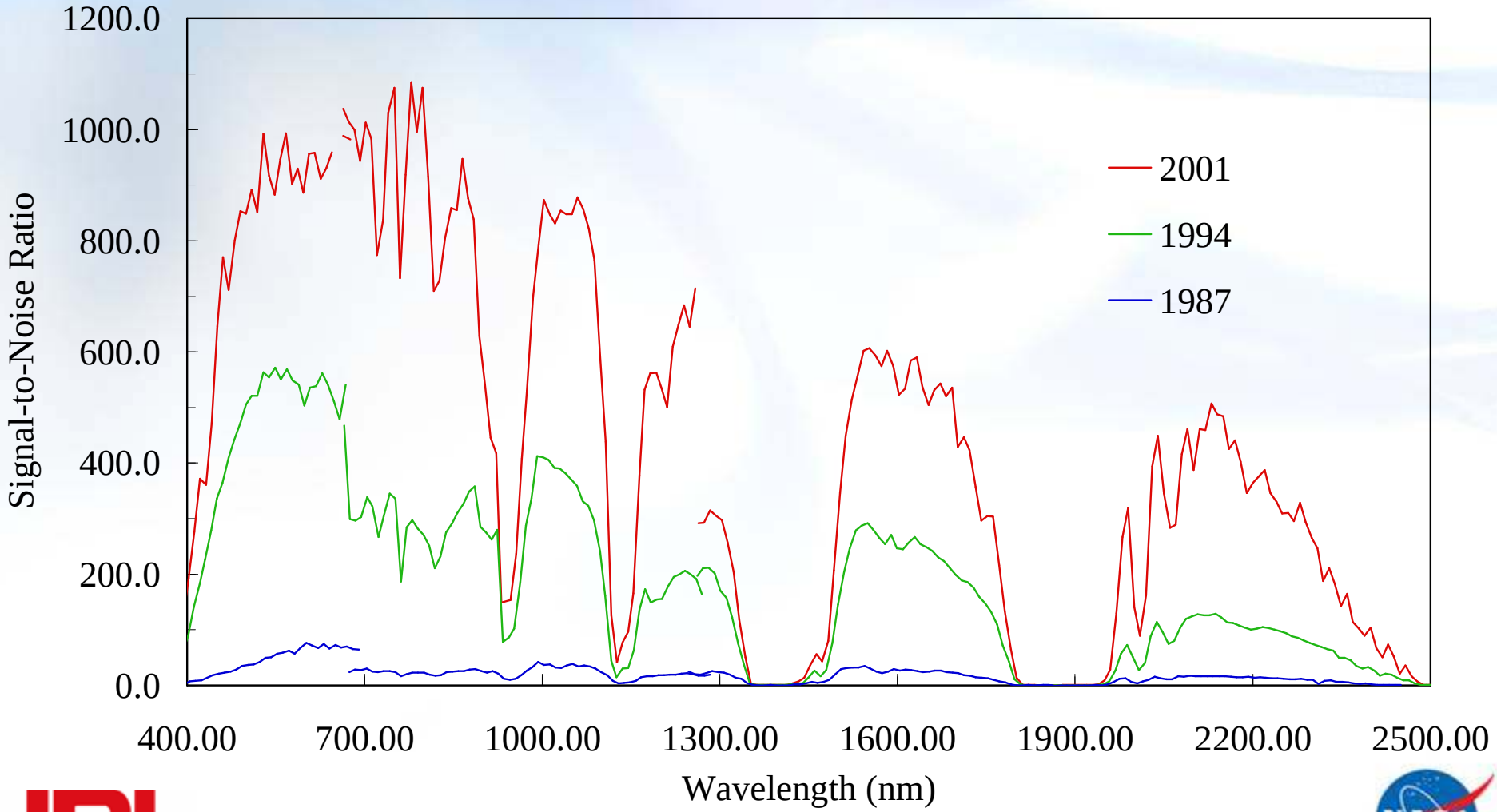


Wavelength



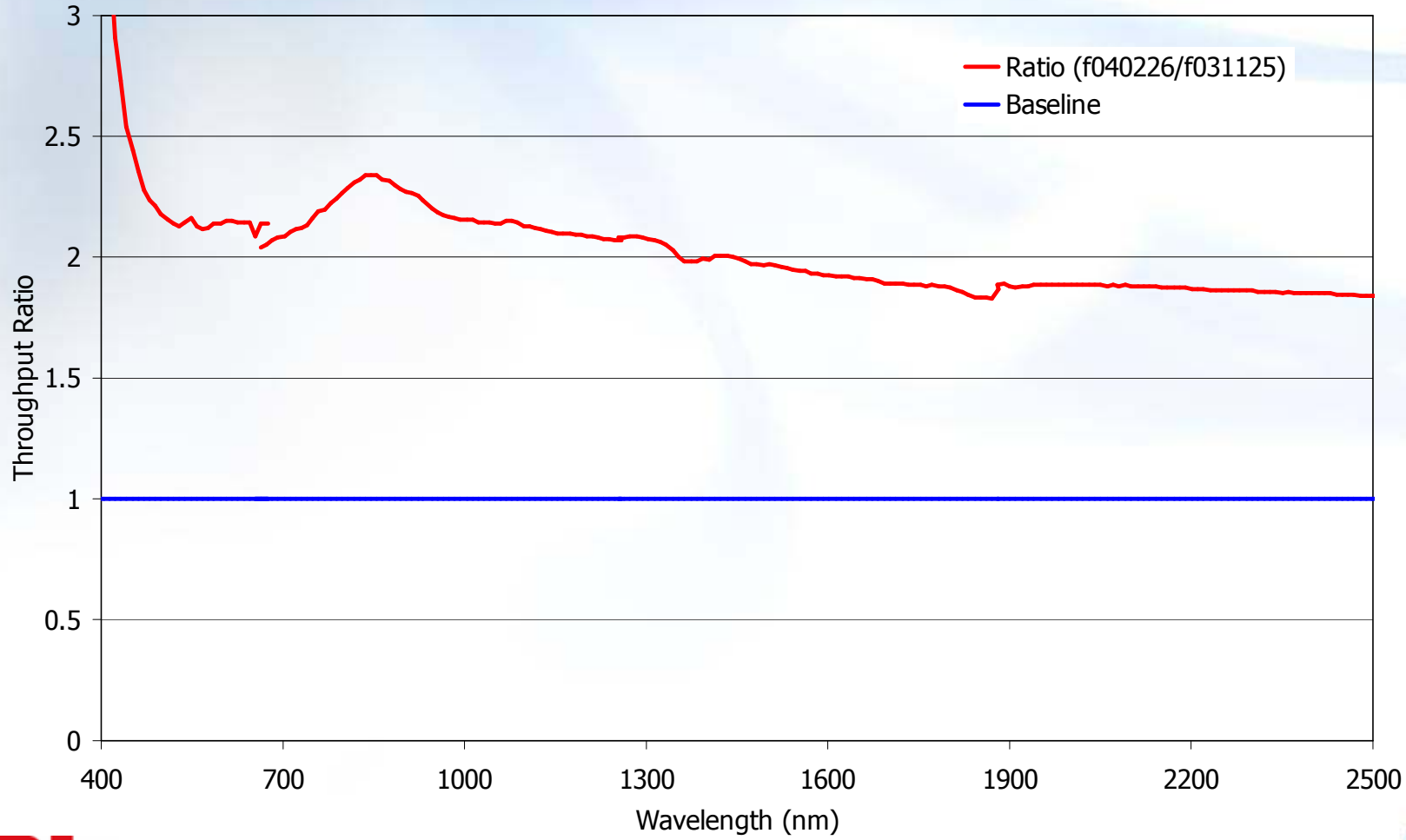

- Grid is the Focal Plane
- Dots are IFOV centers
- Colors are Wavelengths
- All Spectra are Directly Intercomparable

# Signal-to-Noise Ratio at Reference Radiance

# Factor of 2 Throughput Increase in 2004

AVIRIS 2004 Performance Improvement
Following Completion of Foreoptics Refurbishment



# Aircraft


| Aircraft | 1st Year | Altitude | Spatial Resolution | Swath Width |
|---|---|---|---|---|
| NASA's ER-2 | 1987 | 20 km | 20 m | 11 km |
| Low Altitude ER-2 | 2001 | 9 km | 9 m | 5.4 km |
| Med Altitude ER-2 | 2002 | 13 km | 13 m | 8 km |

# NASA ER-2


NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: EC99-45225-2 Date: October 1999 Photo by: Jim Ross

Lockheed ER-2 #809 high altitude research aircraft in flight

# Direction for NASA Aircraft

- Currently moving towards catalog of aircraft
- Getting rid of NASA Owned Aircraft
  - DC-8 is moving to University of North Dakota (UND)
  - Only 1 ER-2 in operation, plan is to cancel it in 2005
- Prefer use of commercially contracted aircraft
  - AVIRIS was ahead in moving to the Twin Otter
- The next direction is to fly remote sensing instruments on Remotely Piloted Aircraft
  - One ER-2 is being converted to optionally piloted
  - Will be 5 years before UAV can fly over US Airspace
  - Mostly Military Technology
  - AVIRIS is performing analysis of possible UAV platform

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# Aircraft


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| Twin Otter | 1998 | 4 km | 4 m | 2.2 km |

# Commercial Twin Otter


# Aircraft


| Aircraft | 1st Year | Altitude | Spatial Resolution | Swath Width |
|---|---|---|---|---|
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| Twin Otter | 1998 | 4 km | 4 m | 2.2 km |
| Scaled Composites Proteus | 2004 | 6 km | 6 m | 3.2 km |

# Scaled Composite's Proteus


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# Scaled Composite's Proteus


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# Scaled Composites

- Burt Rutan's Company
- Alternative Approach to Aircraft
- Using Composite Materials
- Same Company that built and is flying the Space Ship 1 in X-Prize


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# Aircraft


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| Scaled Composites Proteus | 2004 | 6 km | 6 m | 3.2 km |
| NASA's WB-57 | 2005 | 9 km | 9 m | 5.4 km |

# NASA's WB-57

# Direction for NASA Sensors

- **Sensor Fusion:**
  - **AVIRIS has been involved with multi-sensor data collections (LIDAR, SAR, Multi-Angle, Thermal IR)**
  - **NASA Data Collections are for large Multi-Agency, Multi-Sensor, Multi-Discipline Programs**
- **Commercial Hyperspectral data collection:**
  - **NASA is promoting use of commercial sensors**
    - **HyMap (www.hyvista.com)**
    - **CASI (http://www.itres.com)**
    - **TRWIS-III (http://www.northropgrumman.com)**
    - **HyperSpecTIR (www.spectir.com) ***

      ** Not Officially Promoted by NASA*
  - **NASA Sponsored a Intercomparison Study with AVIRIS and HyVista Corporations HyMap Sensor in June, 2004**

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# AVIRIS vs. HyMap


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# Current Research and Applications

- **Cryosphere Studies**
  - **AVIRIS acquired data in 2002 and 2003 in support of:**

# Cryosphere Example Study

## • MEMSCAG Products

- Multiple Endmember Snow-Covered Area and Grain Size
  - ***Painter, Dozier, et al. 2003 RSE***
- Multiple Endmember Spectral Mixture Analysis
  - **Number of endmembers varies pixel-by-pixel**
  - **Endmembers vary pixel-by-pixel**
  - **Snow endmembers generated with RT model DISORT**
- Products
  - **Fractional SCA**
  - **Fractional VCA**
  - **Fractional Grain Size (grain size of fractional snow cover)**

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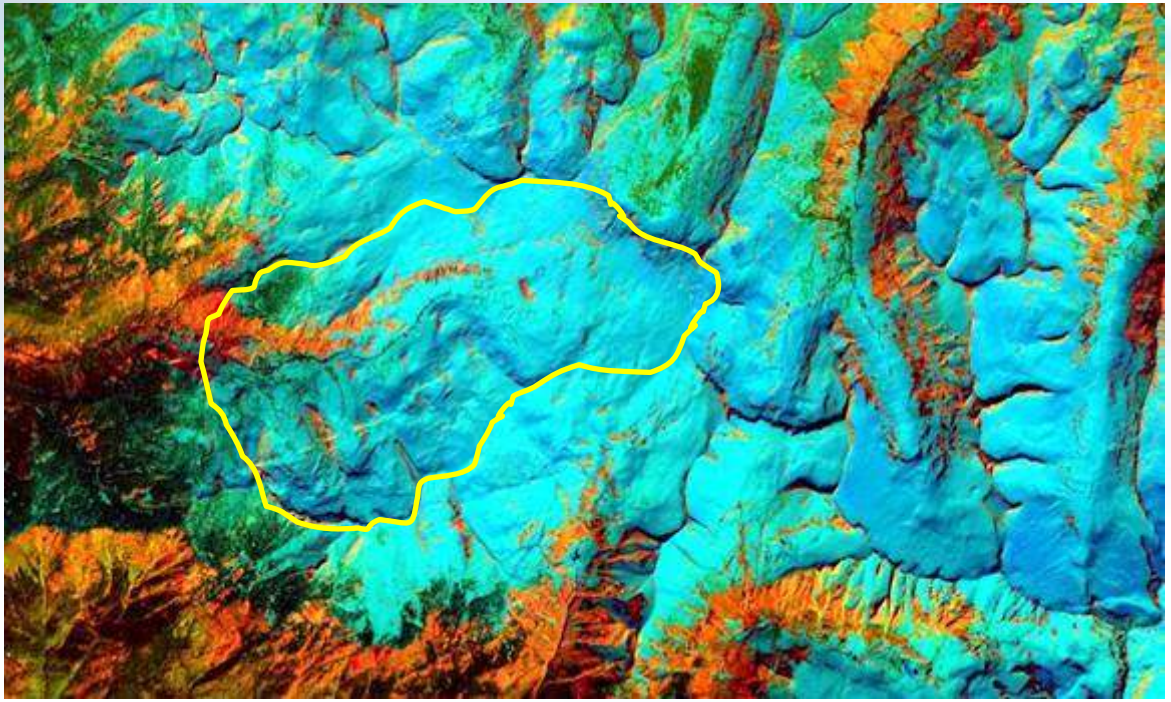
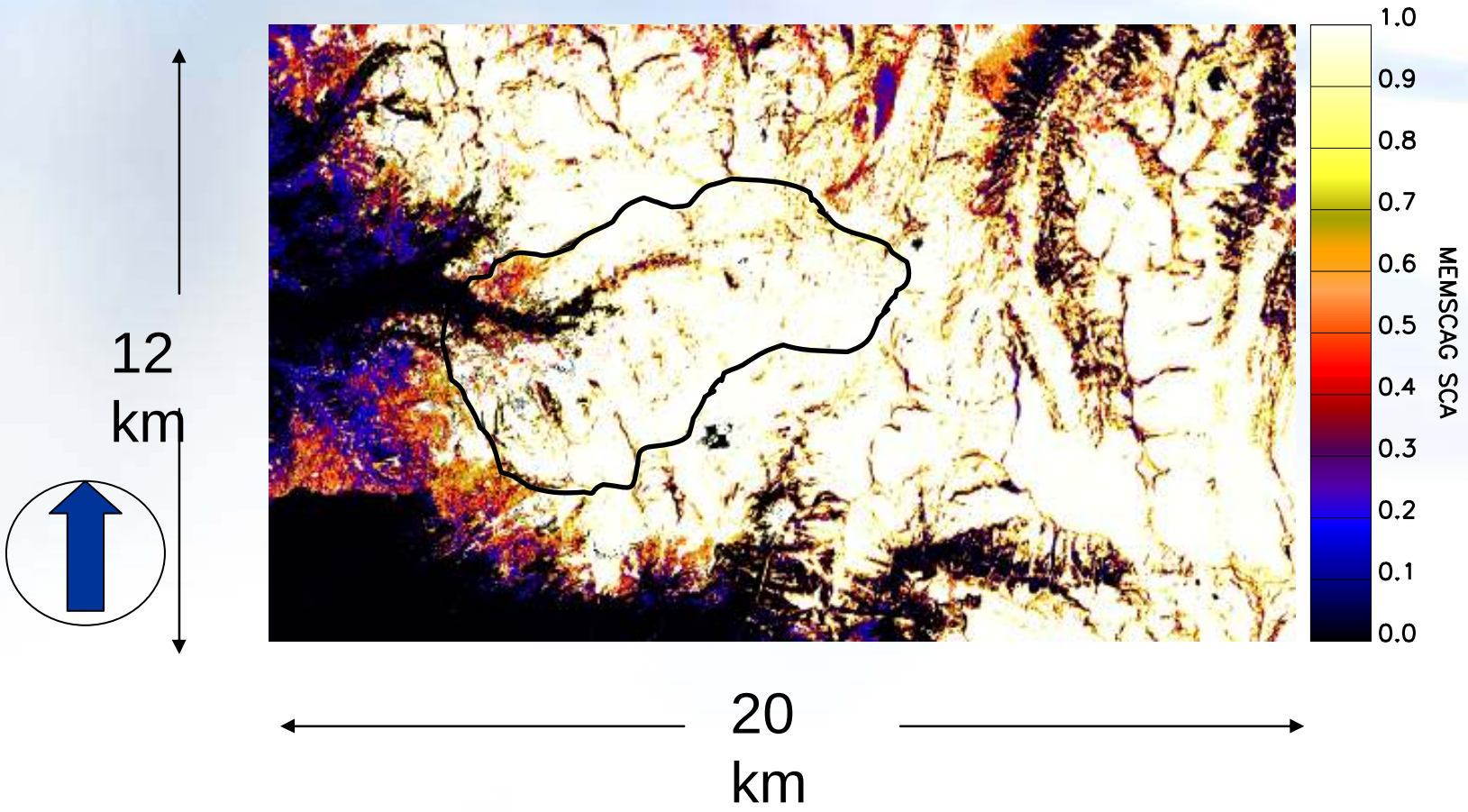
# Tokopah Basin, Sequoia N.P.



12 km

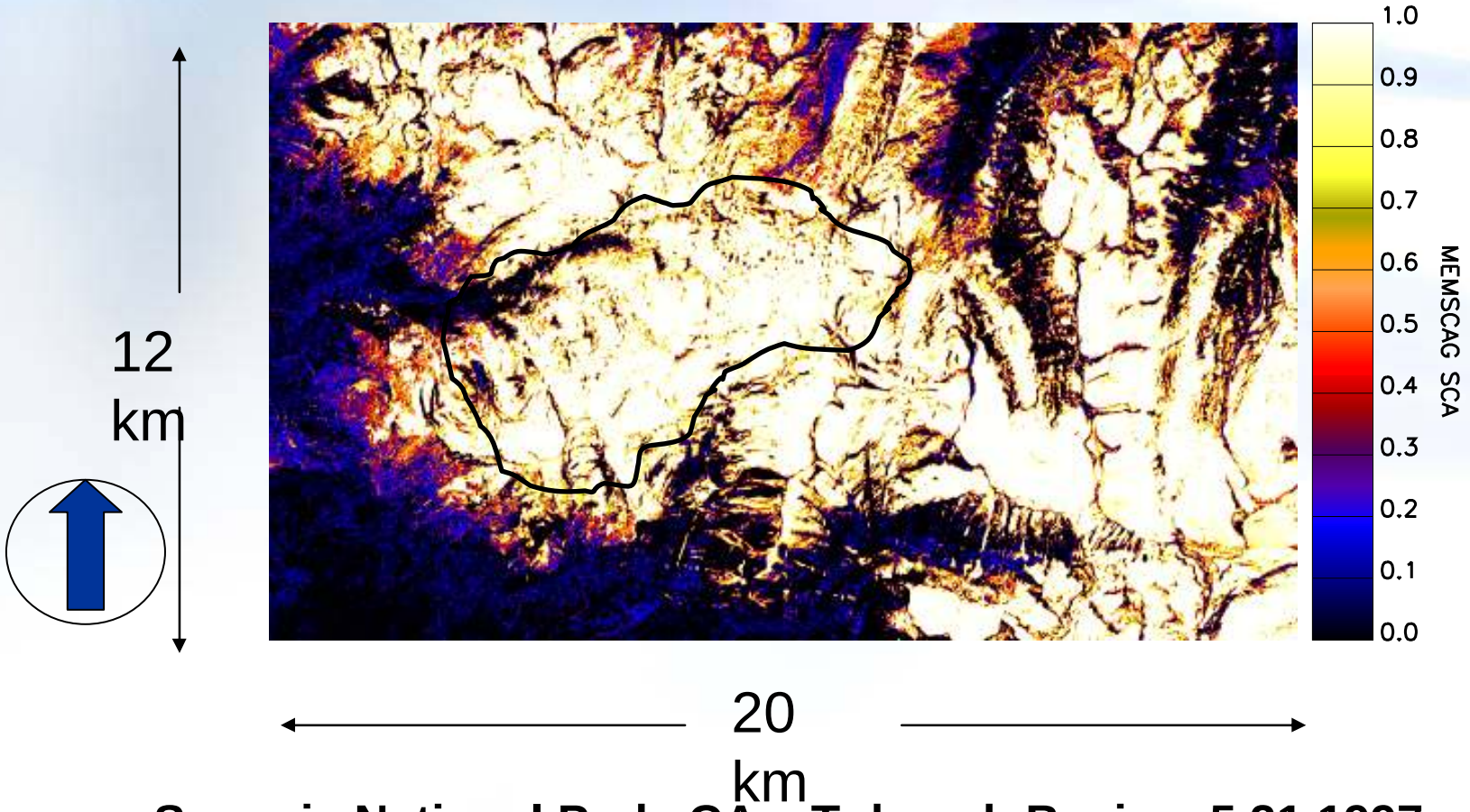
20 km

# MEMSCAG Results - SCA



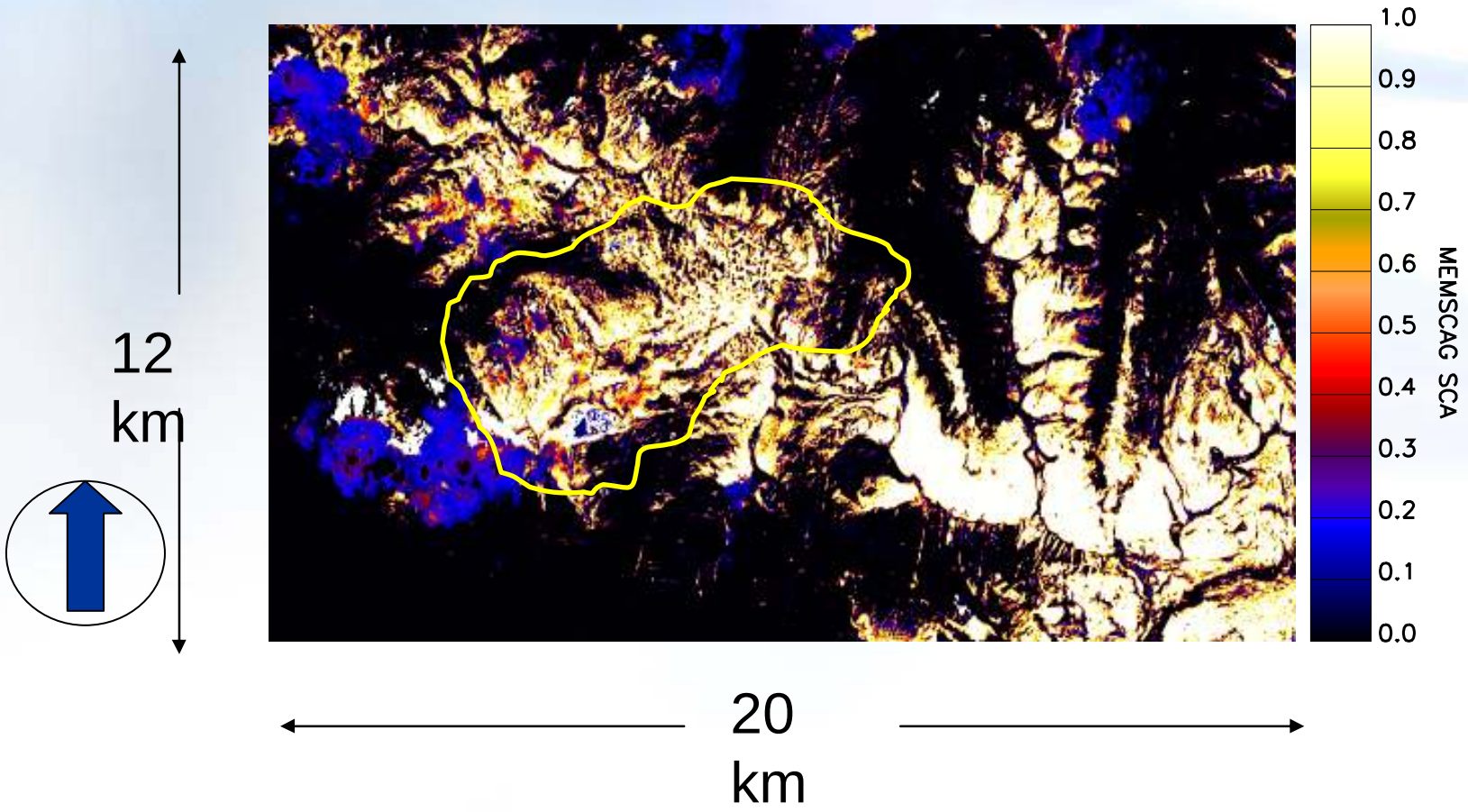

**Sequoia National Park, CA – Tokopah Basin – 5.5.1997**

# MEMSCAG Results - SCA



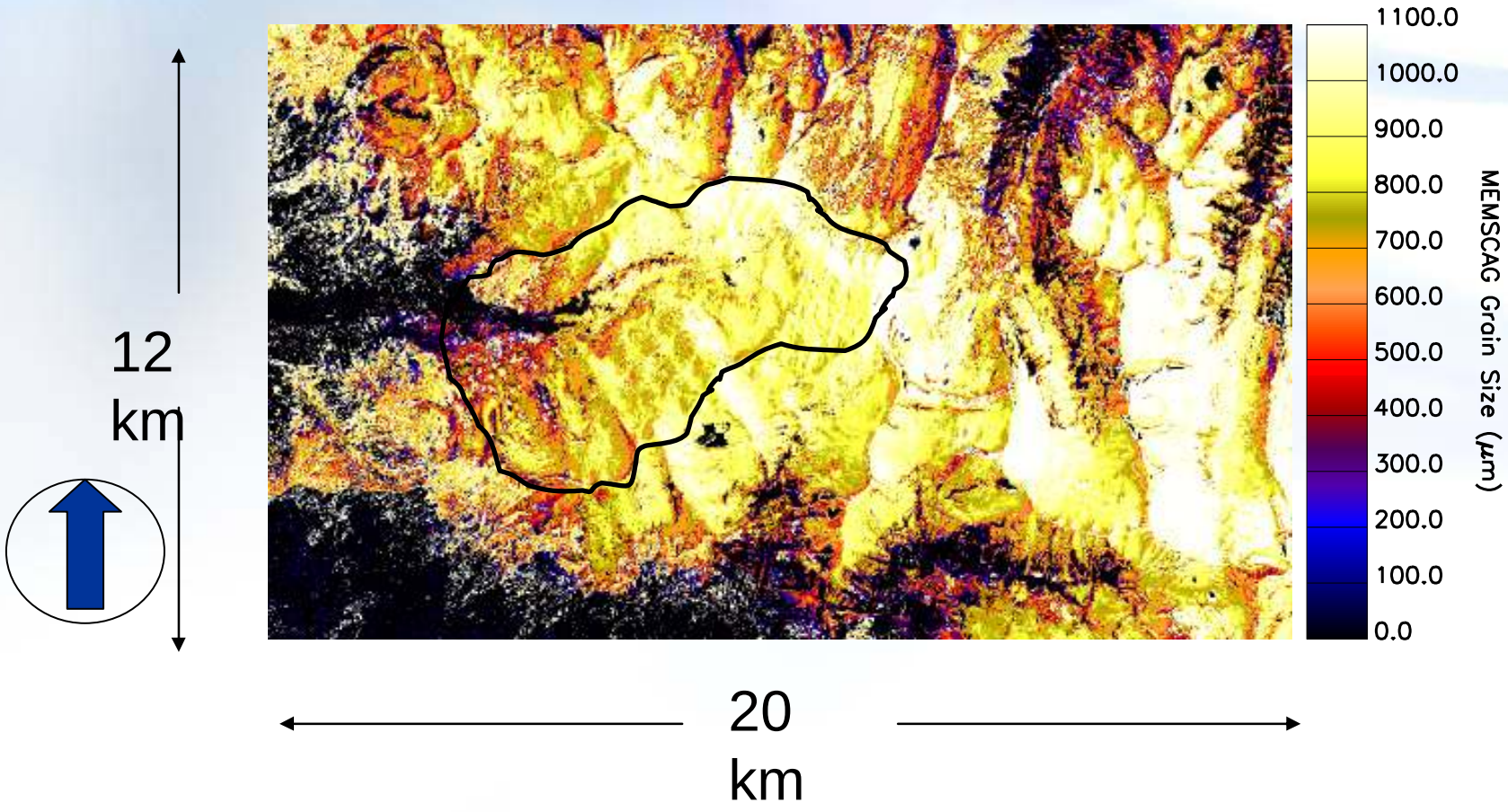

**Sequoia National Park, CA – Tokopah Basin – 5.21.1997**

# MEMSCAG Results - SCA



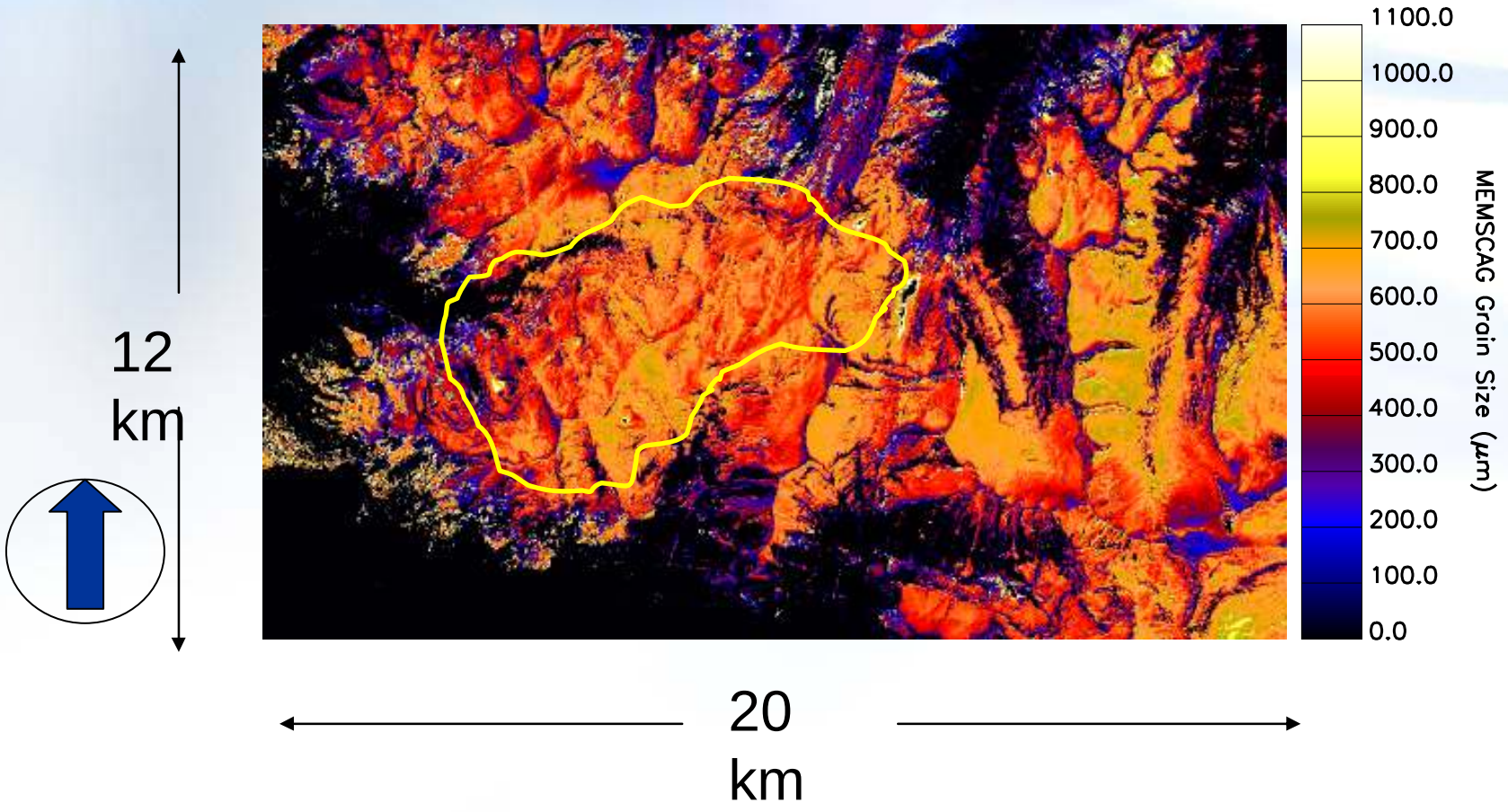

**Sequoia National Park, CA – Tokopah Basin – 6.18.1997**

# MEMSCAG Results – grain size



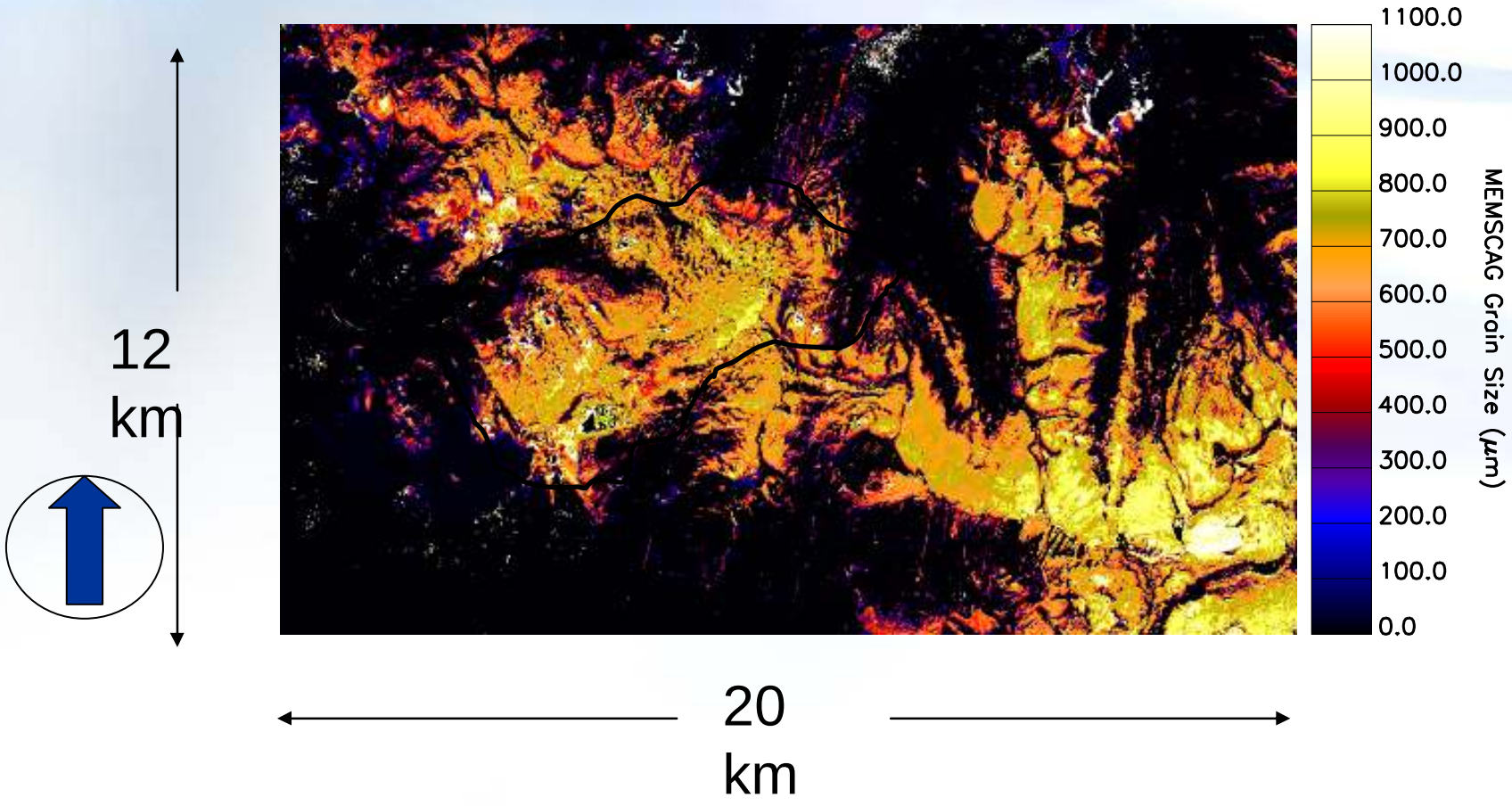

**Sequoia National Park, CA – Tokopah Basin – 5.5.1997**

# MEMSCAG Results – grain size




**Sequoia National Park, CA – Tokopah Basin – 5.21.1997**

# MEMSCAG Results – grain size

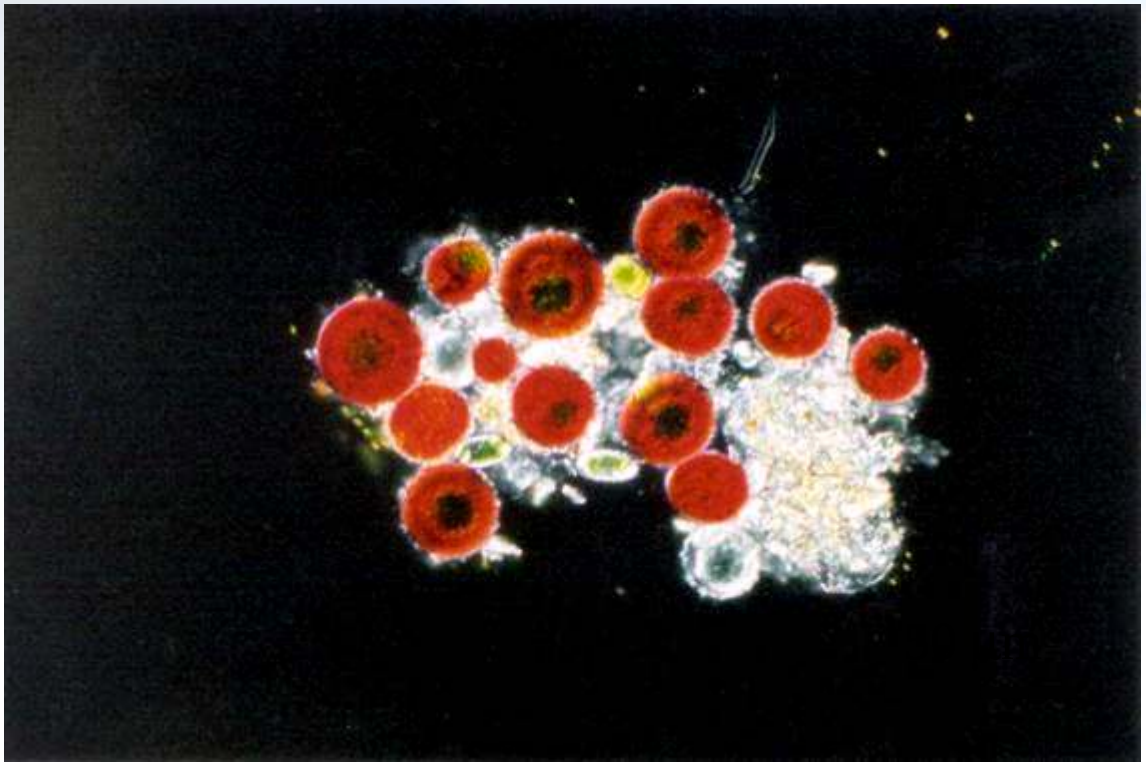



**Sequoia National Park, CA – Tokopah Basin – 6.18.1997**

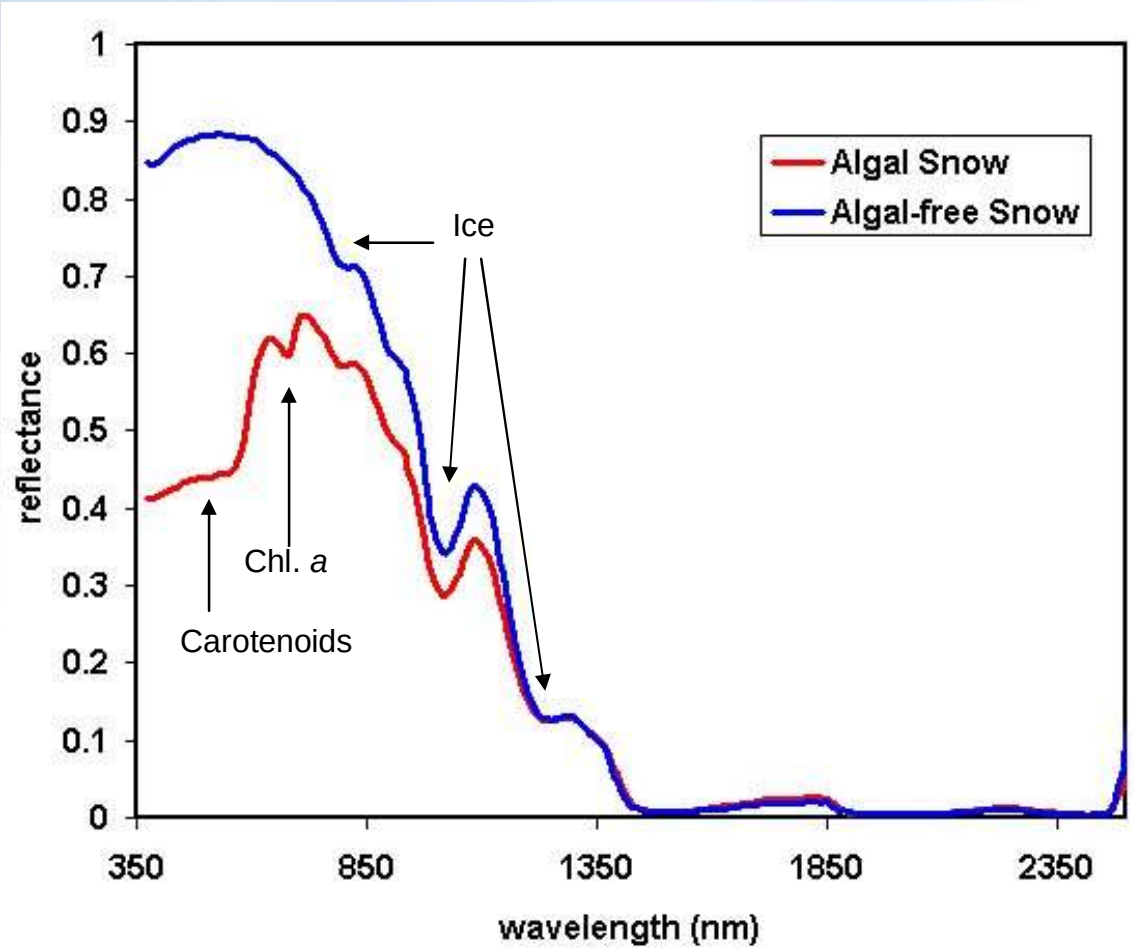
# Snow Algae Concentration

***Painter, T. H., B. Duval, et al. (2001).*** **Detection and quantification of snow algae with an airborne imaging spectrometer.** ***Applied Environmental Microbiology*** ***67****(11): 5267-5272.*

# *Chlamydomonas nivalis*



# Spectral Signature

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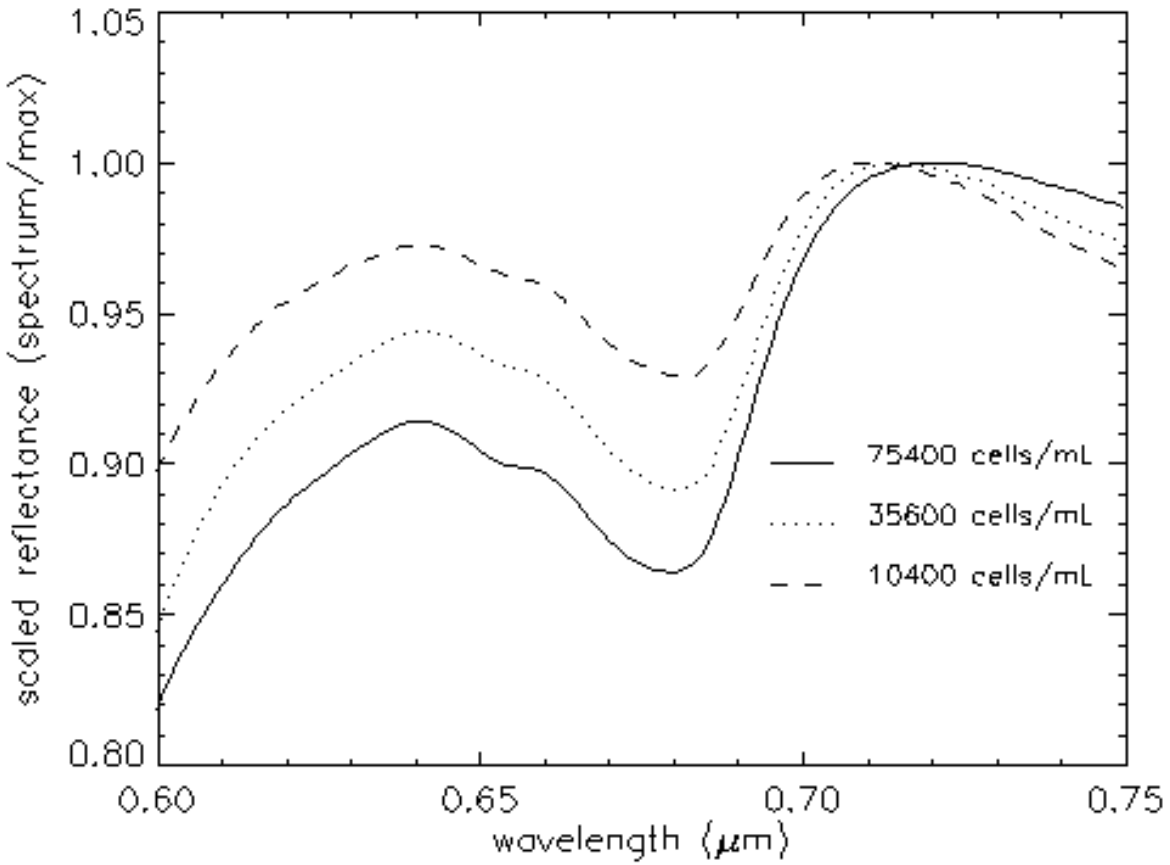
# Chlorophyll Absorption

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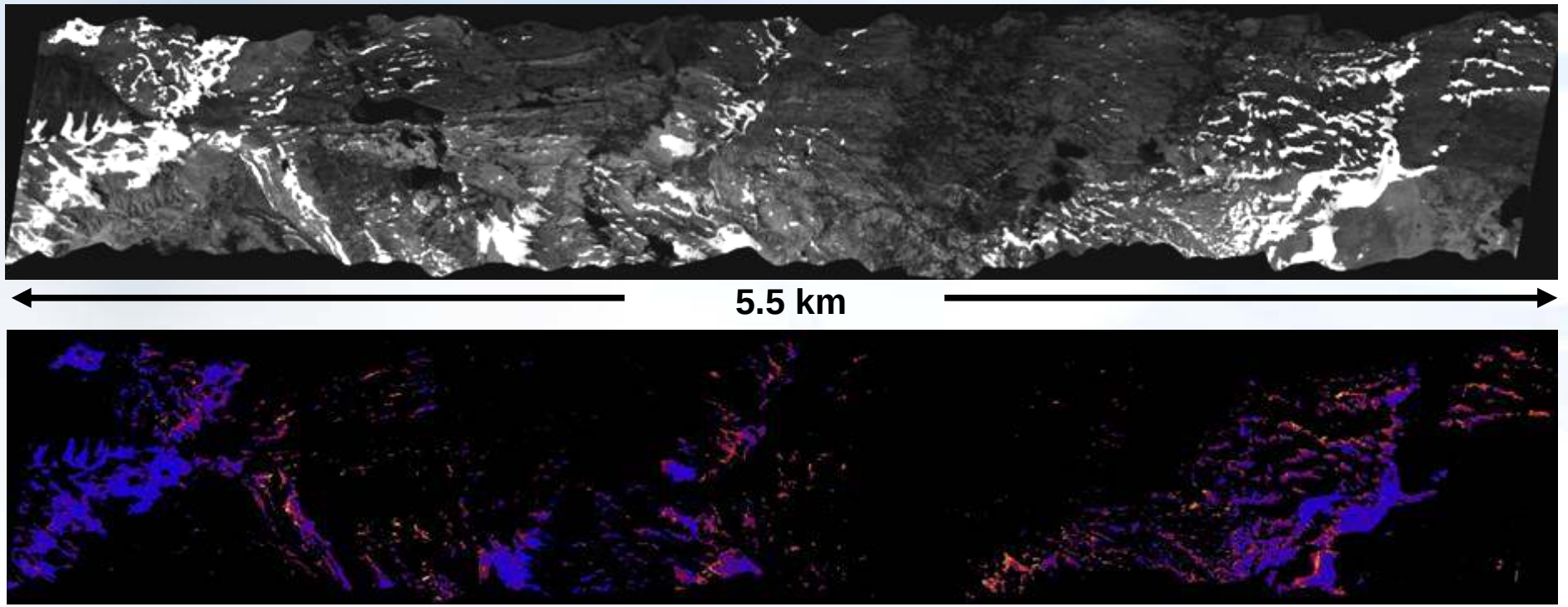
# Algal Concentration

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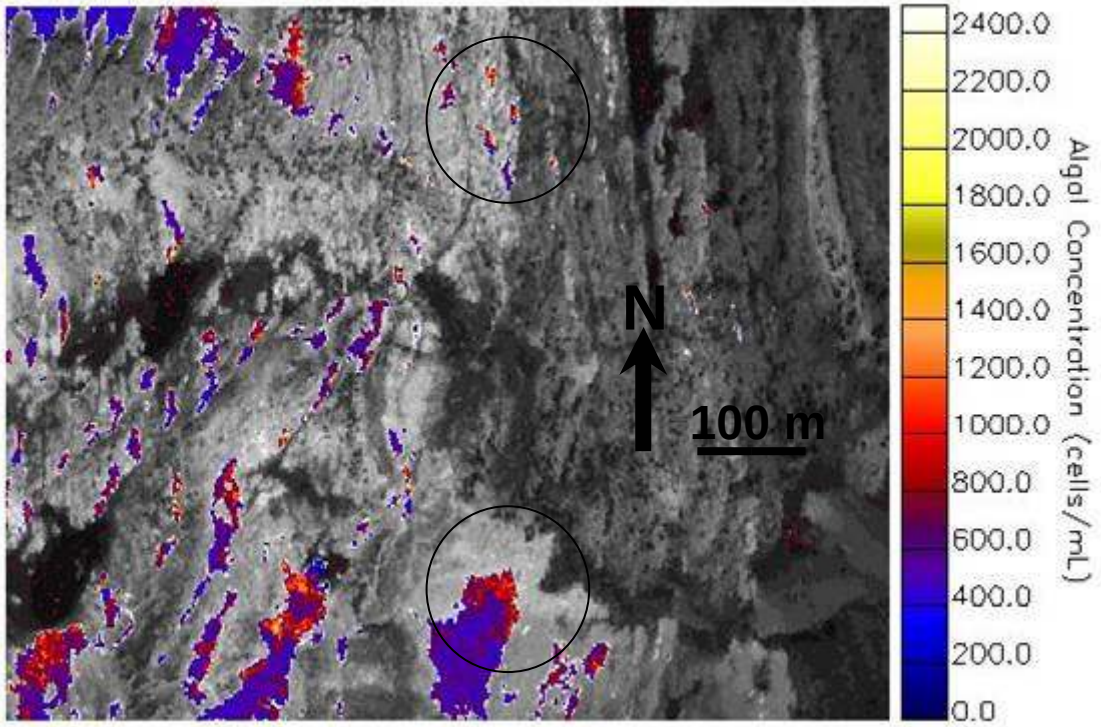
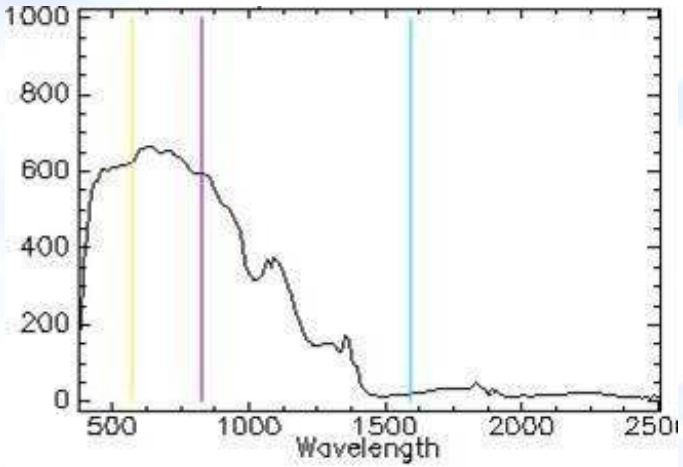
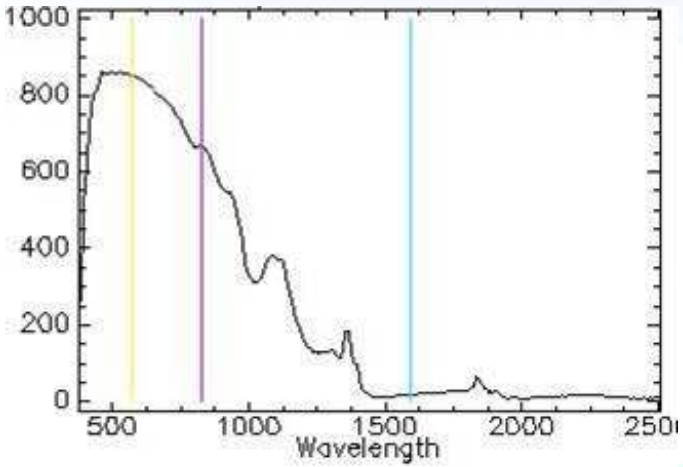
# Algal Concentration – Study Sites



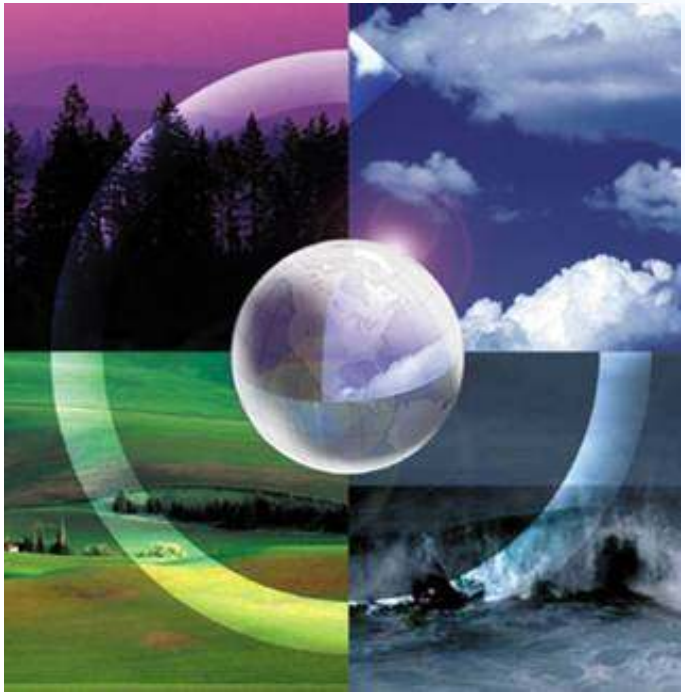



# Current Research and Applications

- **Cryopsphere Studies**
- **Terrestrial Carbon Studies**

# NORTH AMERICAN CARBON PROGRAM

- **In 2003 NASA Head Quarters Terrestrial Ecology Program funded a preliminary Airborne Data Acquisition in Preparation for the North American Carbon Program (NACP)**
- **NACP Proposals were awarded summer 2004**
- **NACP will begin in 2005**



# NACP Preliminary Airborne Data Acquisition

## Summer, 2003

### AVIRIS – Airborne Visible/Infrared Imaging Spectrometer

Gregory Asner and Alfredo R. Huete, "Using Airborne and Spacecraft Remote Sensing to Assess Landscape Transformation by Woody Plants and Invasive Species."

Scott V. Ollinger, Mary E. Martin, Bobby H. Braswell, and Marie-Louise Smith, "Evaluation of Ecosystem Structure and Function Through Hyperspectral Analysis of Foliar Chemistry."

Dar Roberts, "AVIRIS Data Acquisition to Improve Remote Sensing Techniques for Quantification of Forest Biomass and Structure."

### LVIS Laser Vegetation Imaging Sensor

J. Bryan Blair, "Laser Altimetry Used to Assess Forest Structure and Biomass"

### COBRA $CO_2$ Budget and Regional Airborne Study

Steven C. Wofsey, "North America 2003"

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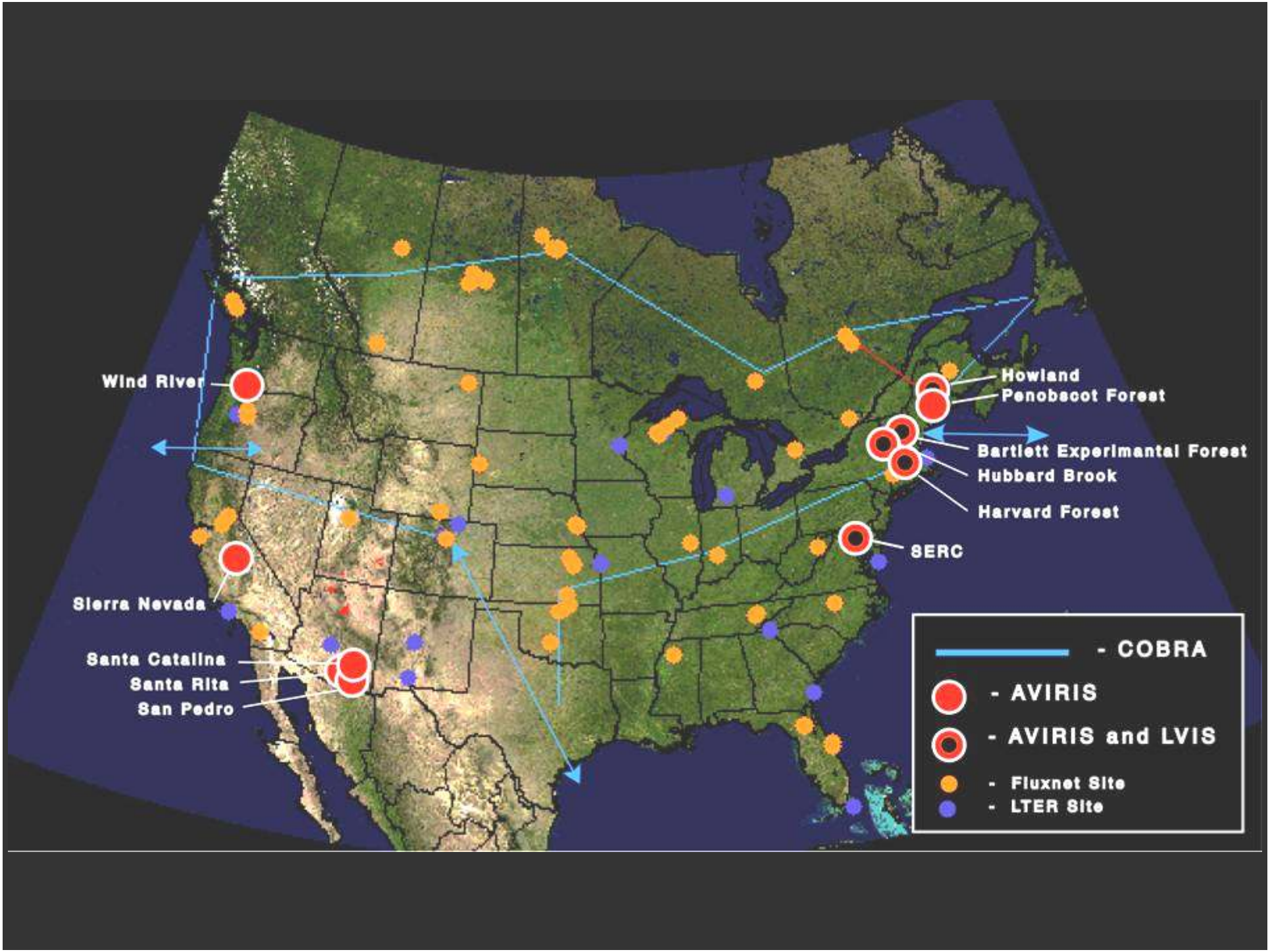
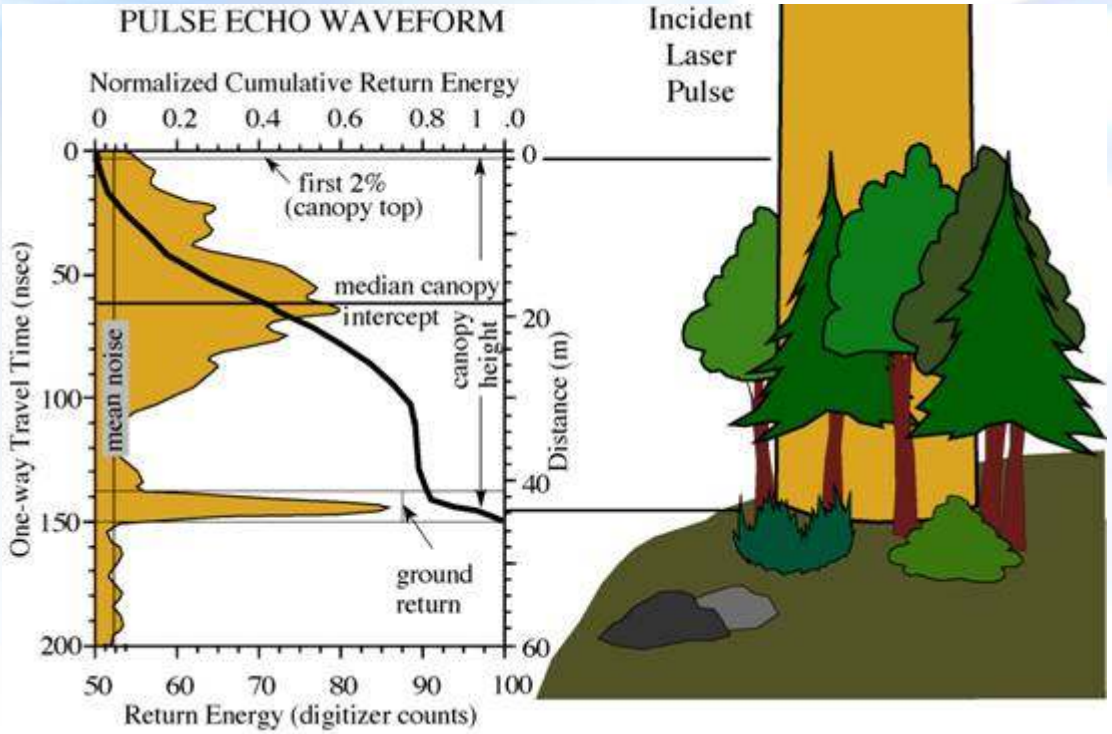

Wind River
Howland
Penobscot Forest
Bartlett Experimantal Forest
Hubbard Brook
Harvard Forest
SERC
Sierra Nevada
Santa Catalina
Santa Rita
San Pedro
- COBRA
- AVIRIS
- AVIRIS and LVIS
- Fluxnet Site
- LTER Site

# Associated Field Studies

| | SENSORS & SYSTEMS | | | |
|---|---|---|---|---|
| FIELD SITE | AVIRIS | AirMISR | LVIS | COBRA |
| Wind River, WA | ■ | | | |
| Sierra Nevada, CA | ■ | | | |
| San Pedro, AZ | ■ | | | |
| Santa Rita, AZ | ■ | | | |
| Santa Catalina, AZ | ■ | | | |
| Smithsonian Env Ctr, MD | ■ | ■ | ■ | |
| Hubbard Brook, NH | ■ | ■ | ■ | ■ |
| Bartlett Forest, NH | ■ | ■ | ■ | ■ |
| Penobscot Forest, ME | ■ | | | ■ |
| Howland, ME | ■ | ■ | ■ | ■ |
| Harvard Forest, MA | ■ | ■ | ■ | ■ |

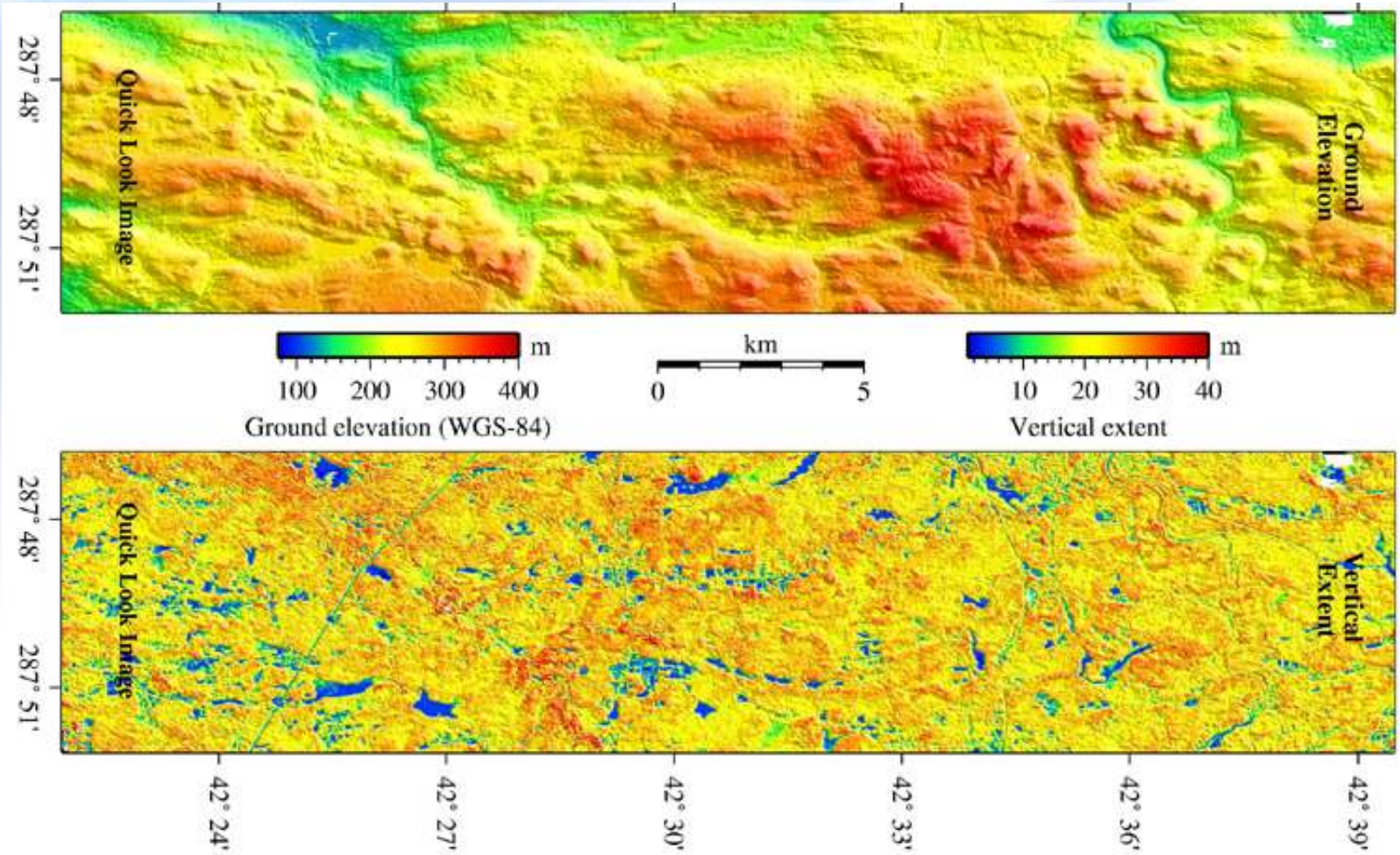
# LVIS – Lidar Forest Canopy Structure




- **Ground elevation(mean elevation of lowest reflection),**
- **Vertical extent/Canopy height (relative to ground reflection),**
- **Height of median energy return (relative to ground reflection),**
- **Ground vs. canopy energy ratios (e.g., canopy cover)**
- **Quadrant heights or deciles (percentiles), complexity, pulse spreading for ground and canopy returns**

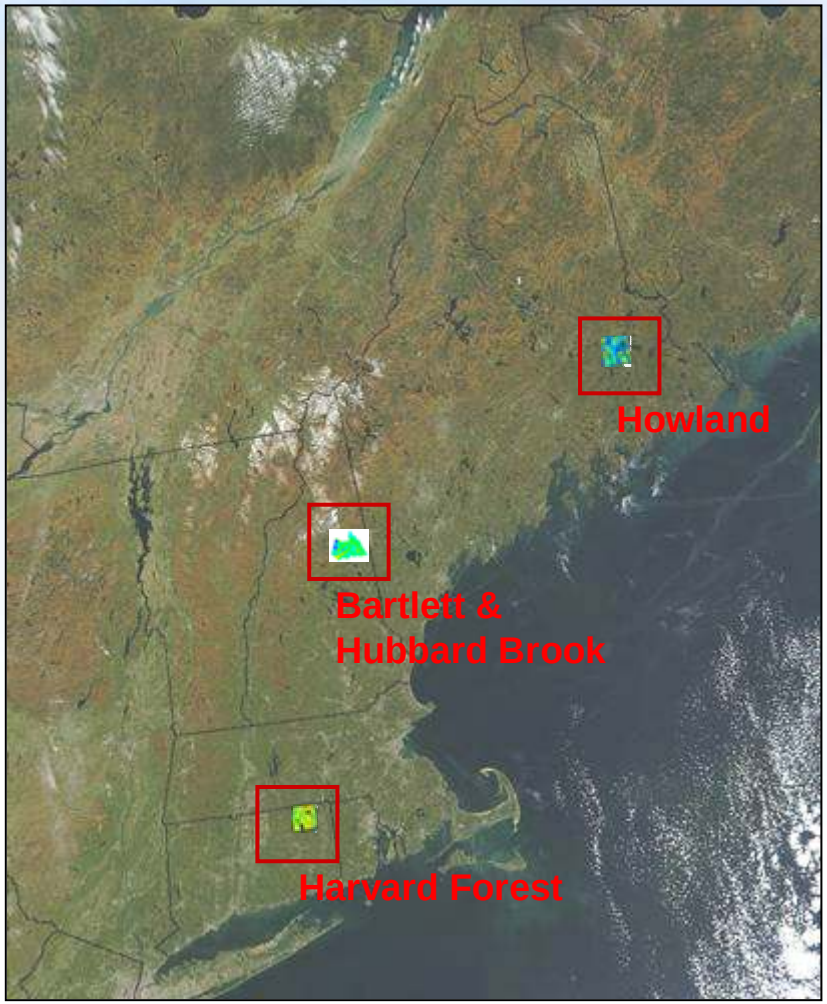
Courtesy of J. Bryan Blair, NASA Goddard Space Flight Center

# LVIS – Harvard Forest Images

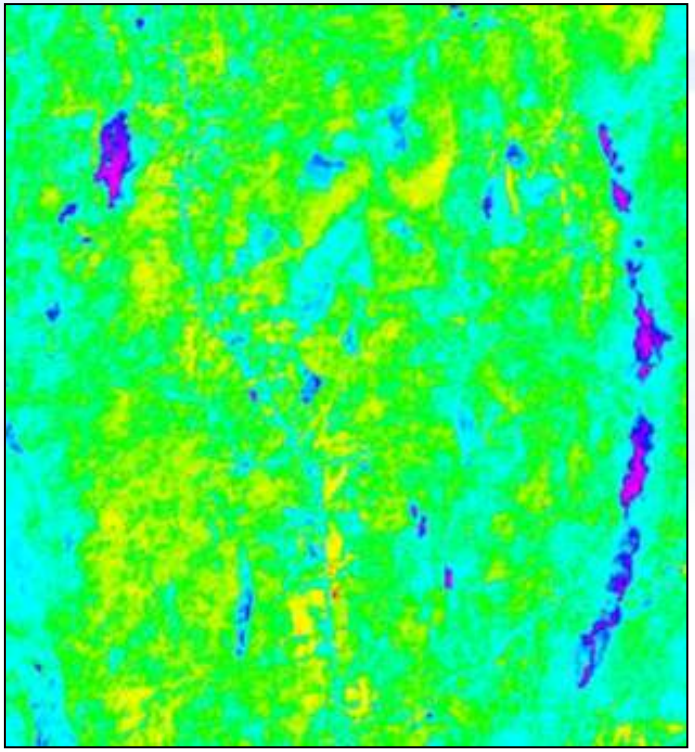


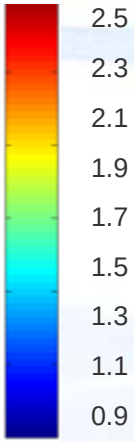

Courtesy of J. Bryan Blair, NASA Goddard Space Flight Center

# AVIRIS – Harvard Forest




## Harvard Forest Canopy Nitrogen



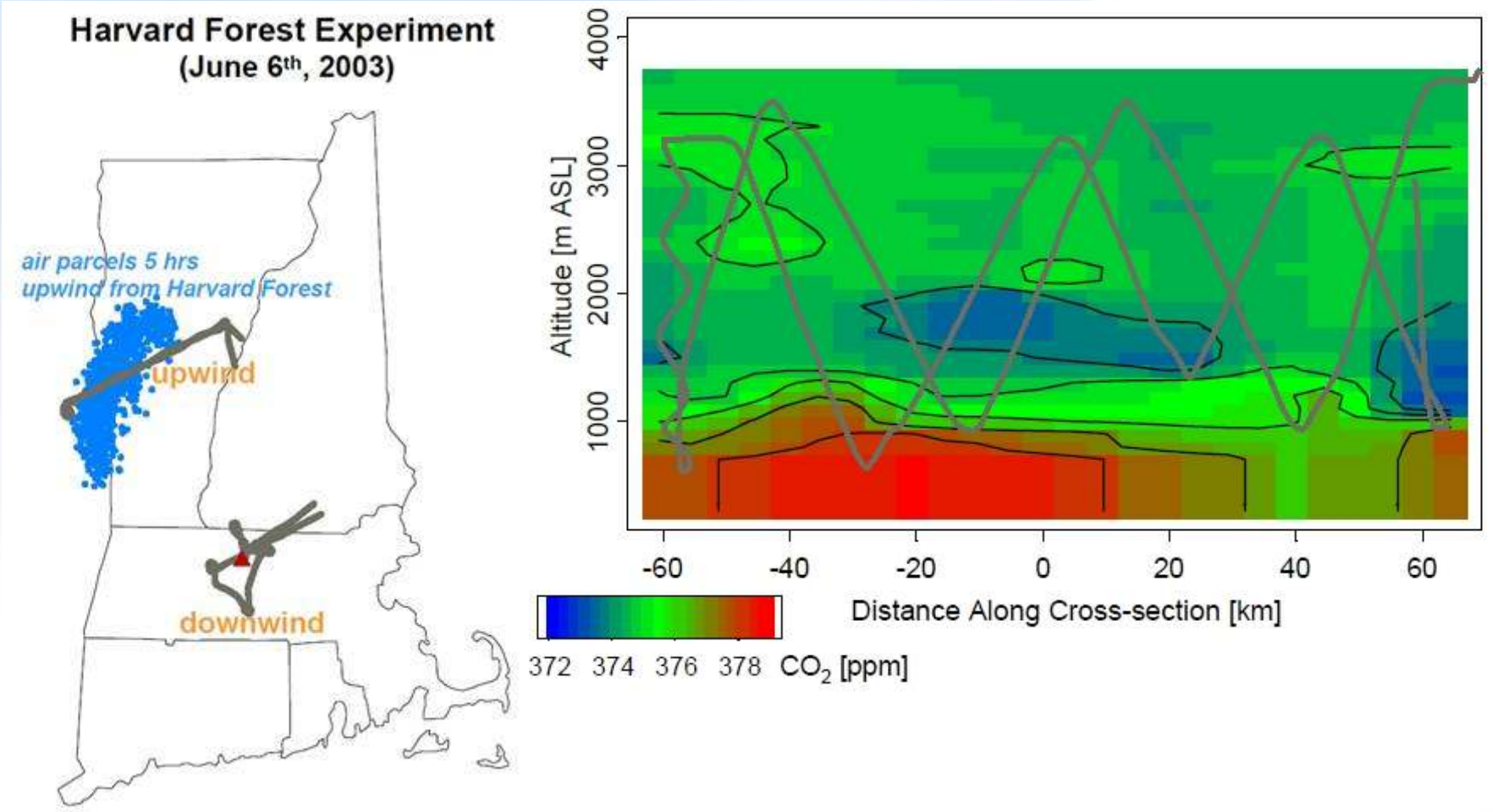



%N

**18 m Resolution**

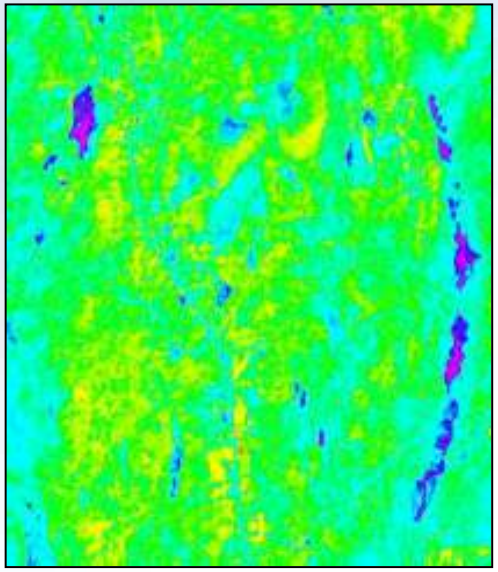
Courtesy of Scott Ollinger, Mary Martin, Marie-Louise Smith, and David Hollinger, University of New Hampshire.

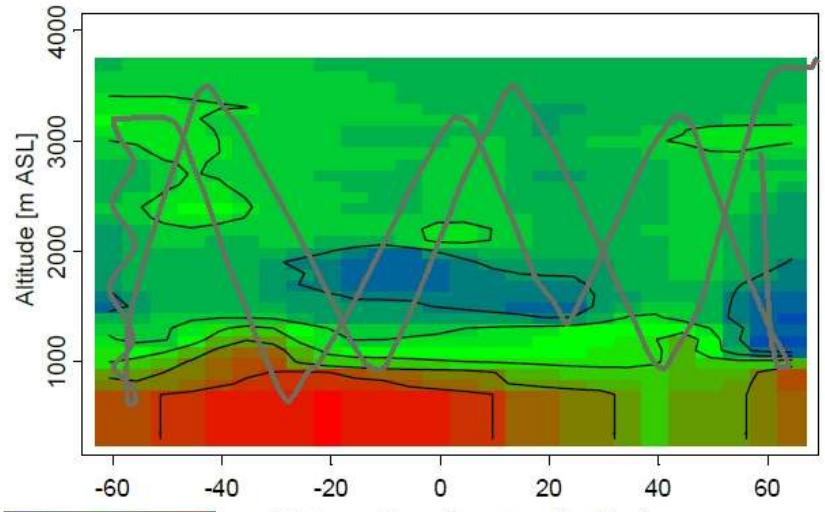
# COBRA – Harvard Forest Experiment

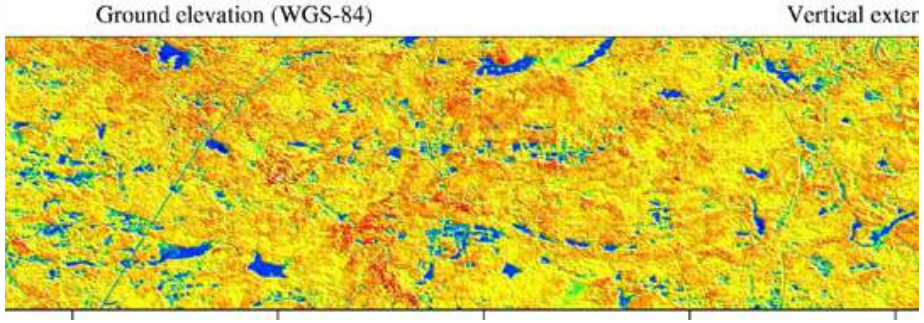



Courtesy of Steven C. Wofsey, Harvard University

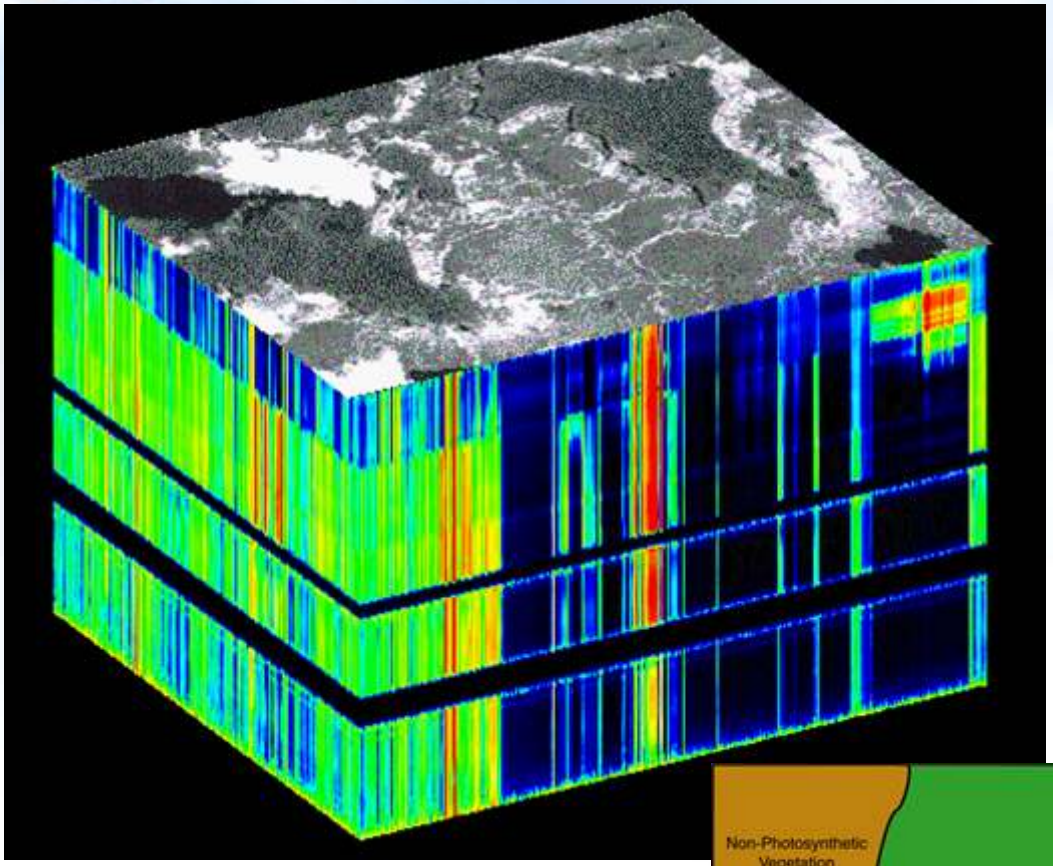
# Data Fusion

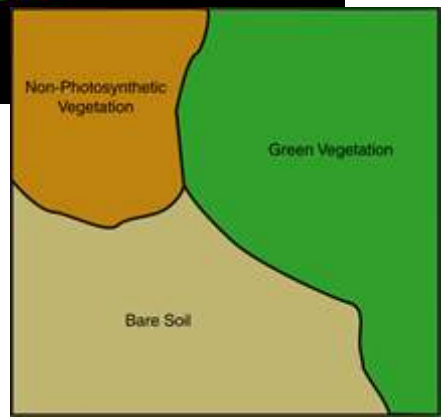


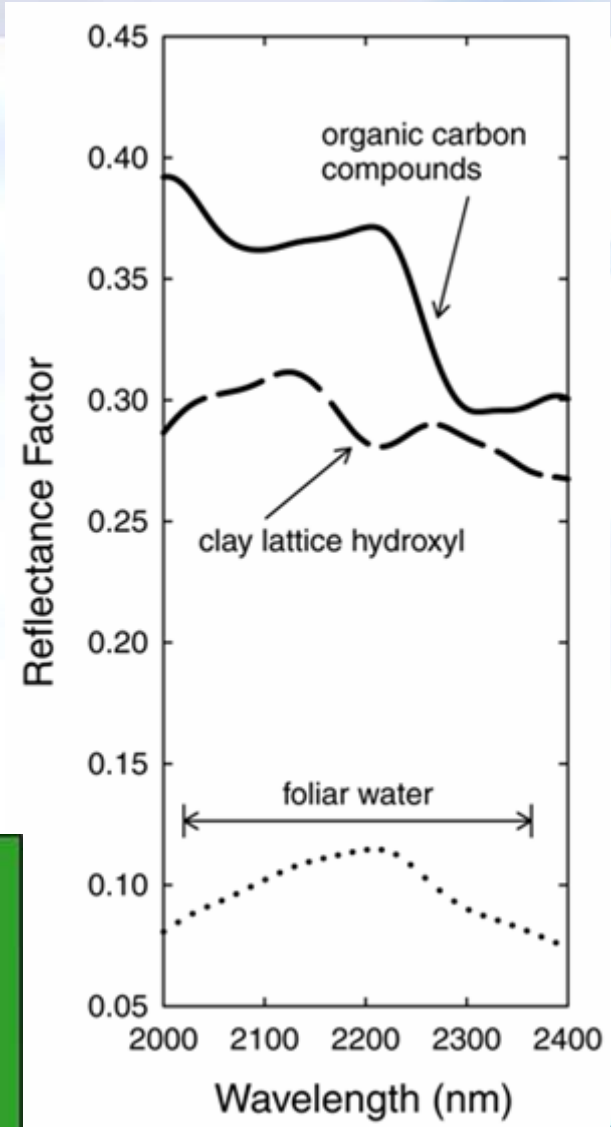

Altitude [m ASL]
1000
2000
3000
4000
-60
-40
-20
0
20
40
60


Ground elevation (WGS-84)
Vertical exter

# Spectroscopic techniques isolate fractional cover of materials





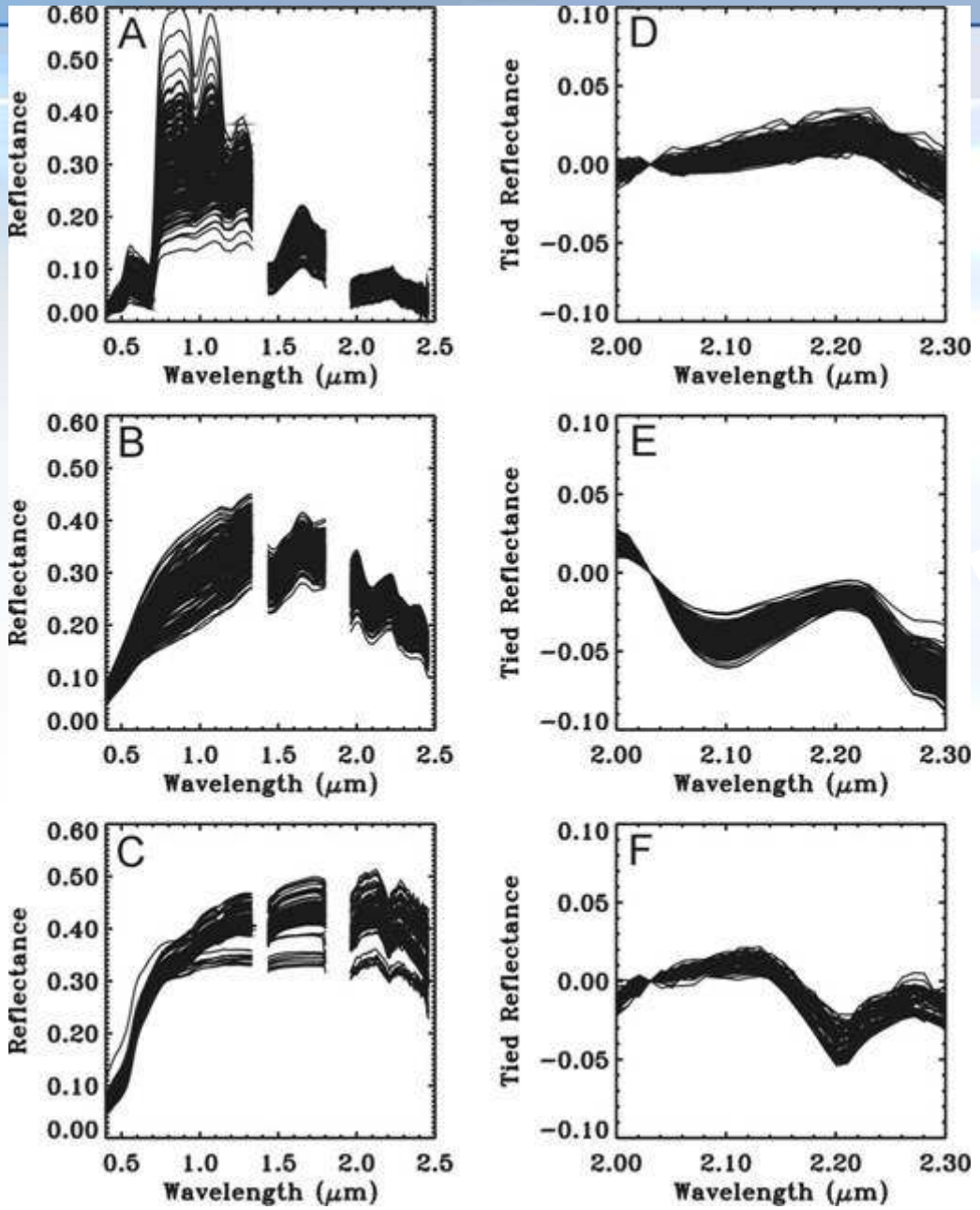

Asner et al.

# Spectroscopic techniques isolate fractional cover of materials

**Photosynthetic Vegetation**

**Non-Photosynthetic Vegetation**

**Bare Substrate**



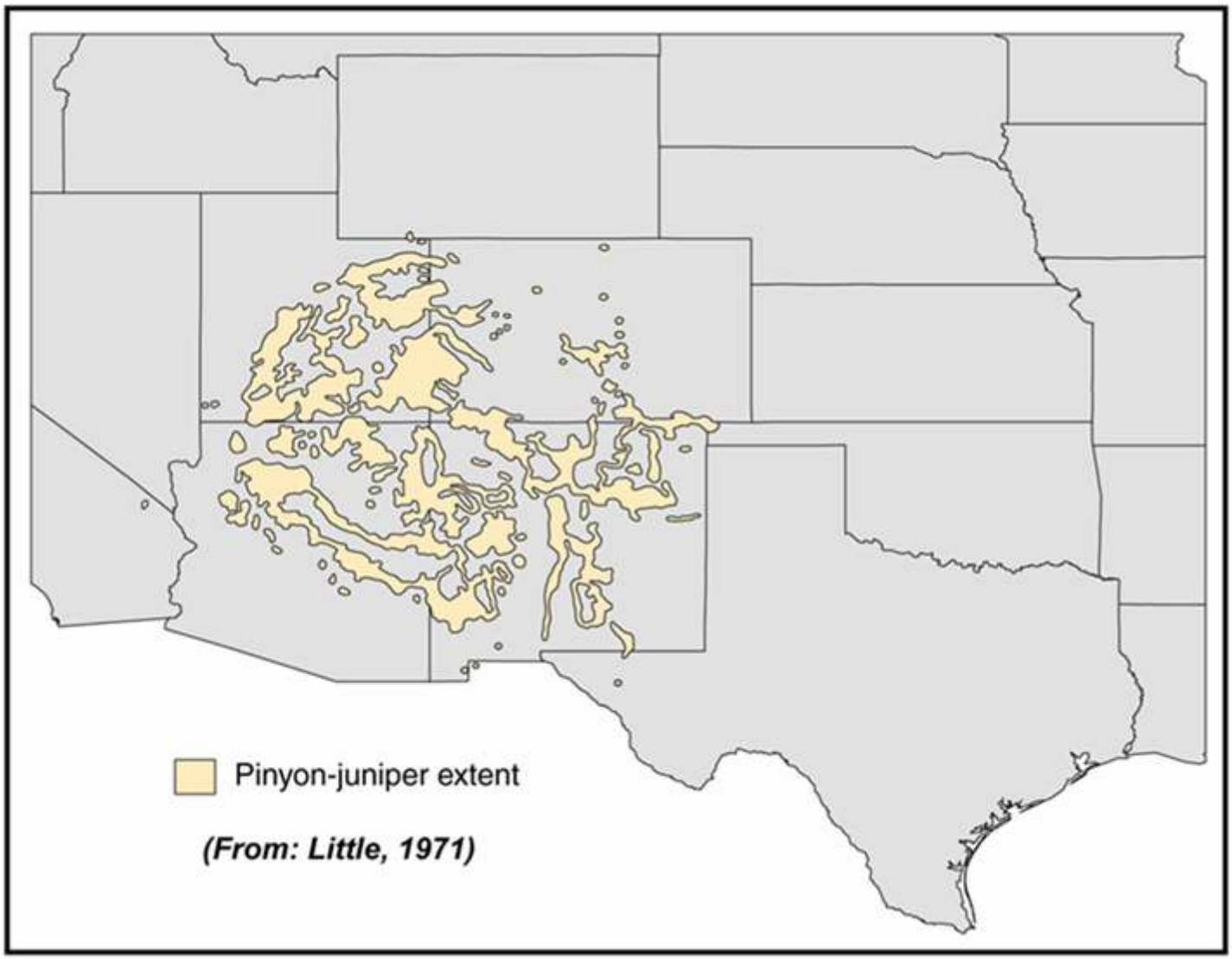

**Water**

**Cellulose/Lignin**

**$OH^-$**

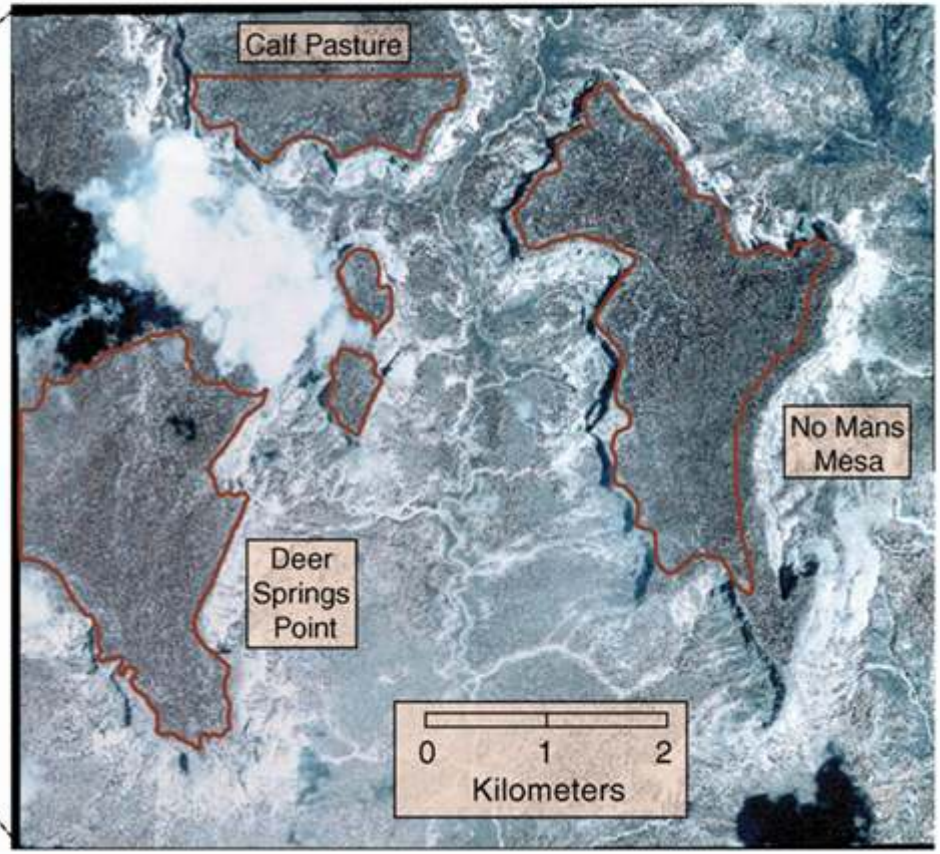
Asner et al.

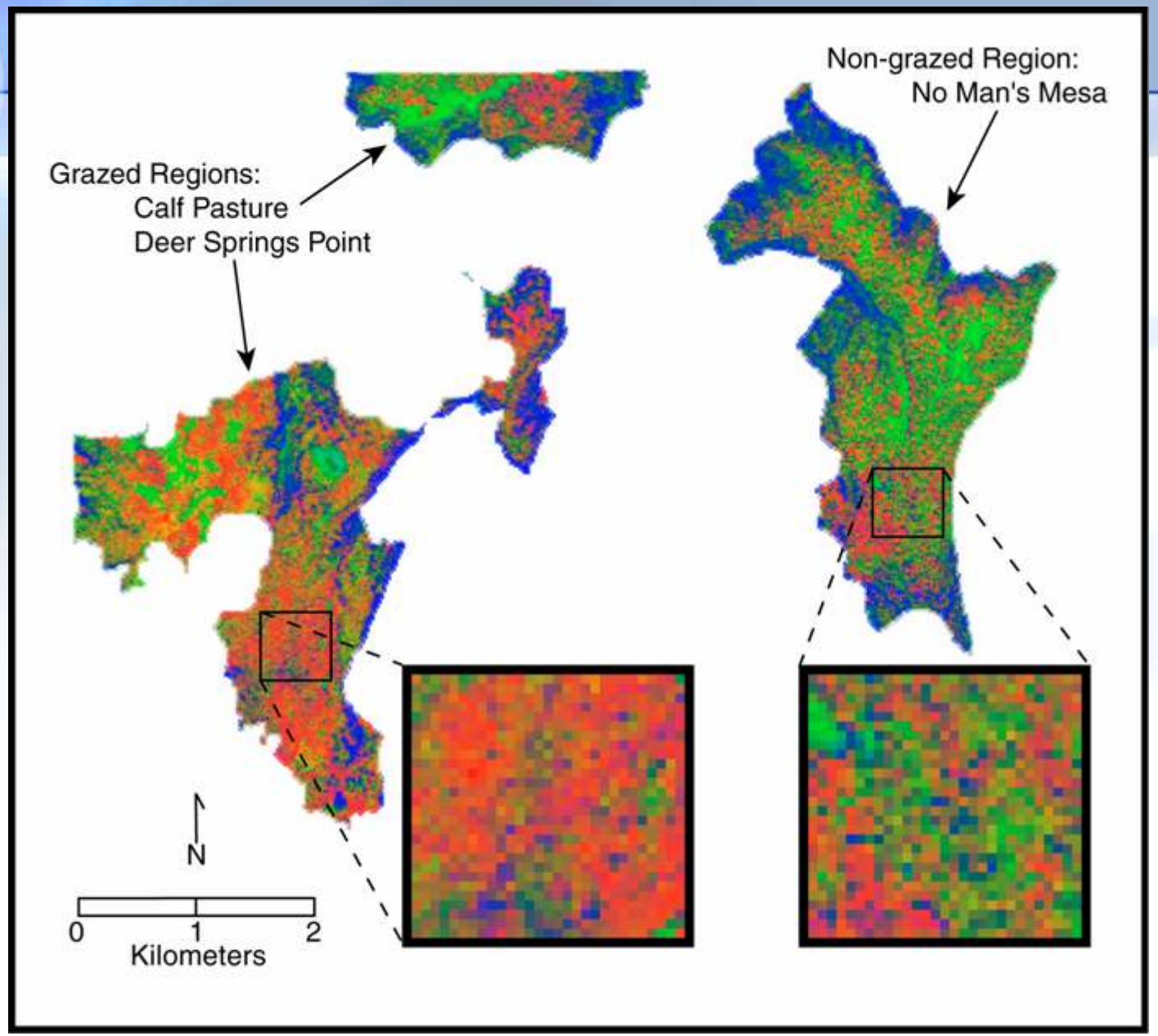
# Woody Encroachment in Western Pinyon-Juniper Woodlands




Asner et al.


Figure 1. Location of the study area within Grand Staircase Escalante National Monument. The image of the study area is a color infrared aerial photo acquired at the time of the AVIRIS over-flight. Study area mesas are outlined in red.

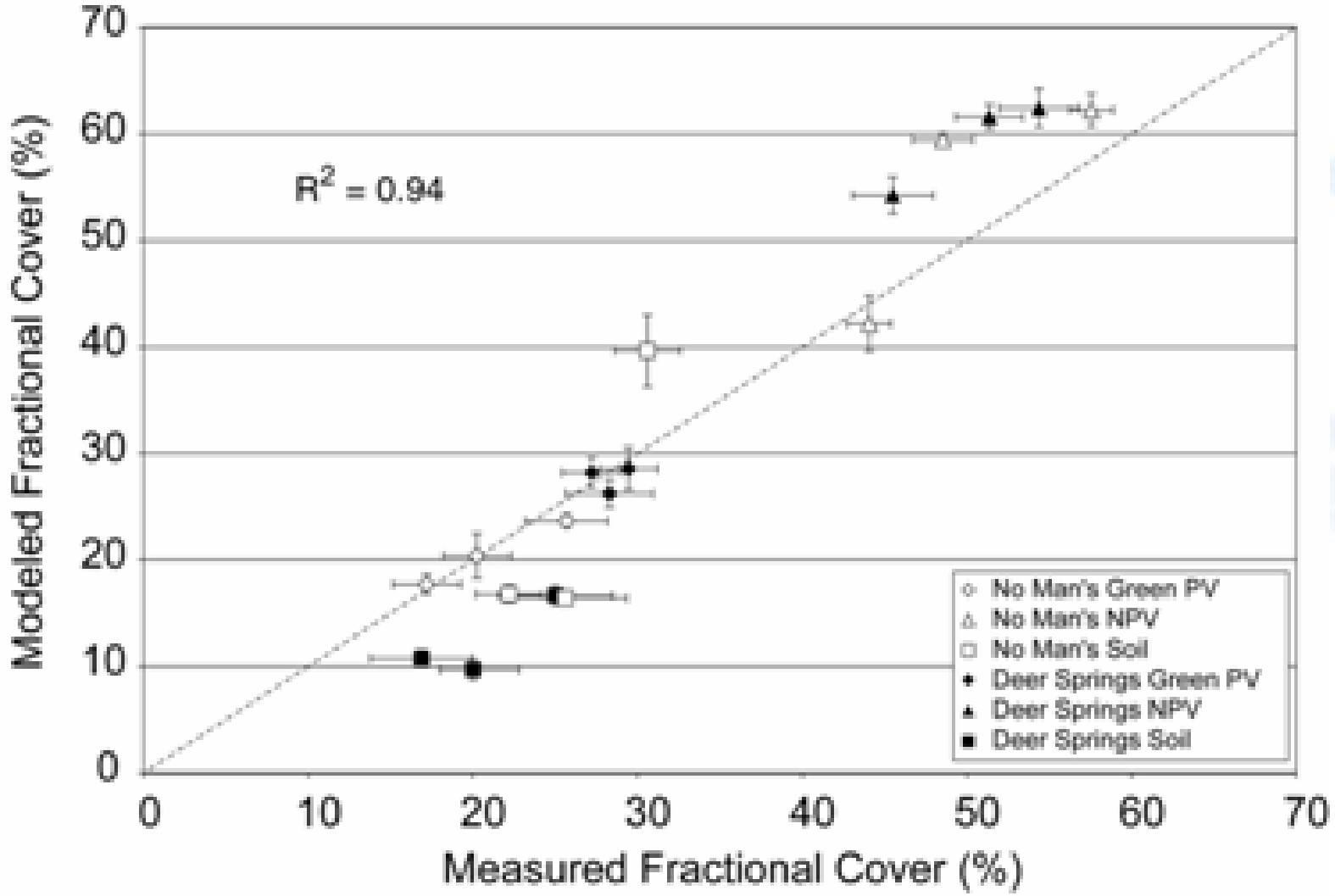





**RGB color composite where Red = PV, Green = NPV, Blue = bare soil**

Asner et al.

# Woody Encroachment Verified and Validated




Asner et al.

# Current Research and Applications

- Cryopsphere Studies
- Terrestrial Carbon Studies
- Space Science

# Space Science

- **NASA Will Perform Earth Science if it supports the Presidents Space Exploration Program……**
- **AVIRIS has been collecting data at sites similar to the Moon and Mars….**
- **Currently working on a Twin Otter mission to the Dry Valleys of Antarctica in 2006 or 2007:**
  - **To support Mars Analog Studies**
  - **To search for life in Extreme Environments**
  - **What about under standing the polar region?**

# AVIRIS Research and Applications

- **Imaging Spectroscopy is relevant to a wide range of Research and applications:**
  - **Atmosphere: water vapor, clouds properties, aerosols, absorbing gases…**
  - **Ecology: chlorophyll, leaf water, lignin, cellulose, pigments, structure, nonphotosynthetic constituents…**
  - **Geology and soils: mineralogy, soil type…**
  - **Coastal and Inland waters: chlorophyll, plankton, dissolved organics, sediments, bottom composition, bathymetry…**
  - **Snow and Ice Hydrology: snow cover fraction, grainsize, impurities, melting…**
  - **Biomass Burning: subpixel temperatures and extent, smoke, combustion products…**
  - **Environmental hazards: contaminants directly and indirectly, geological substrate…**
  - **Calibration: aircraft and satellite sensors, sensor simulation, standard validation..**
  - **Modeling: radiative transfer model validation and constraint…**
  - **Commercial: mineral exploration, agriculture and forest status…**
  - **Algorithms: autonomous atmospheric correction, advance spectra derivation…**
  - **Other: human infrastructure...**

JPL

NASA

# Conclusion