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

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Understanding Worlds with Imaging Spectroscopy

Airborne Imaging Spectrometer (AIS), Earth-1983

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

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

Time Sequence of Hyperion Images Observing crops over time

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

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
Design Characteristics

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

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

<table>
<thead>
<tr>
<th>Spectral</th>
<th>Radiometric</th>
<th>Spatial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>370 to 2510 nm</td>
<td>0 to Max Lambertian</td>
</tr>
<tr>
<td>Sampling</td>
<td>10 nm</td>
<td>12 bits</td>
</tr>
<tr>
<td>Accuracy</td>
<td>0.5 nm</td>
<td>96 Percent</td>
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</table>

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
Whiskbroom Imaging Spectrometer

Cross Track Sample

- Grid is the Focal Plane
- Dots are IFOV centers
- Colors are Wavelengths
- All Spectra are Directly Intercomparable
Signal-to-Noise Ratio at Reference Radiance

![Graph showing signal-to-noise ratio at reference radiance across different wavelengths.](image)

- **Red line**: 2001
- **Green line**: 1994
- **Blue line**: 1987

The x-axis represents the wavelength (nm) ranging from 400.00 to 2500.00, and the y-axis represents the signal-to-noise ratio ranging from 0 to 1200.00.
AVIRIS 2004 Performance Improvement
Following Completion of Foreoptics Refurbishment

Factor of 2 Throughput Increase in 2004

Throughput Ratio

Wavelength (nm)

Ratio (f040226/f031125)
Baseline
<table>
<thead>
<tr>
<th>Aircraft</th>
<th>1st Year</th>
<th>Altitude</th>
<th>Spatial Resolution</th>
<th>Swath Width</th>
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<td>20 km</td>
<td>20 m</td>
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<td>Low Altitude ER-2</td>
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<td>5.4 km</td>
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<td>Med Altitude ER-2</td>
<td>2002</td>
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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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Commercial Twin Otter
# Aircraft

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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
## Aircraft

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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
AVIRIS vs. HyMap
Current Research and Applications

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

  CLPX Cold Land Processes Field Experiment
  NASA Land Surface Hydrology Program
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)
MEMSCAG Results - SCA

MEMSCAG Results - SCA

MEMSCAG Results - SCA

MEMSCAG Results – grain size

MEMSCAG Results – grain size

Snow Algae Concentration

Chlamydomonas nivalis
Chlorophyll Absorption
Algal Concentration – Study Sites
Current Research and Applications

- Cryosphere 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
AVIRIS – Airborne Visible/Infrared Imaging Spectrometer


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 CO₂ Budget and Regional Airborne Study

Steven C. Wofsey, “North America 2003”
## Associated Field Studies

<table>
<thead>
<tr>
<th>FIELD SITE</th>
<th>AVIRIS</th>
<th>AirMISR</th>
<th>LVIS</th>
<th>COBRA</th>
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</thead>
<tbody>
<tr>
<td>Wind River, WA</td>
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<td>Sierra Nevada, CA</td>
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<tr>
<td>Santa Rita, AZ</td>
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<td>Santa Catalina, AZ</td>
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<td>Smithsonian Env Ctr, MD</td>
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<tr>
<td>Hubbard Brook, NH</td>
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<tr>
<td>Bartlett Forest, NH</td>
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<tr>
<td>Penobscot Forest, ME</td>
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<tr>
<td>Howland, ME</td>
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<tr>
<td>Harvard Forest, MA</td>
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</table>
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
Harvard Forest Canopy Nitrogen

18 m Resolution

Courtesy of Scott Ollinger, Mary Martin, Marie-Louise Smith, and David Hollinger, University of New Hampshire.
Data Fusion
Spectroscopic techniques isolate fractional cover of materials
Spectroscopic techniques isolate fractional cover of materials

Photosynthetic Vegetation

Non-Photosynthetic Vegetation

Bare Substrate

Water

Cellulose/Lignin

OH⁻
Woody Encroachment in Western Pinyon-Juniper Woodlands

(From: Little, 1971)
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.
Asner et al.

RGB color composite where Red = PV, Green = NPV, Blue = bare soil
Woody Encroachment Verified and Validated

\[ R^2 = 0.94 \]
Current Research and Applications

- Cryopsphere Studies
- Terrestrial Carbon Studies
- 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 understanding the polar region?
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...