Imaging Spectrometer Science Measurements for Terrestrial Ecology: AVIRIS and New Developments

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Abstract— Contiguous spectral measurements in the image domain made by the NASA Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) have been used to advance a range of Terrestrial Ecology science investigation over the past two decades. Currently there are hundreds of relevant refereed journal articles. The calibrated, high signal-to-noise ratio measurements of AVIRIS are used to investigate terrestrial ecology topics related to: (1) Pattern and Spatial Distribution of Ecosystems and their Components, (2) Ecosystem Function, Physiology and Seasonal Activity, (3) Biogeochemical Cycles, (3) Changes in Disturbance Activity, and (4) Ecosystems and Human Health.

We describe the current status of the AVIRIS instrument and science measurement capability in 2010 to support terrestrial ecology investigations. Selected terrestrial ecology science examples that use AVIRIS measurements are presented as well.

NASA has recently begun development of the Next Generation Airborne Visible/Infrared Imaging Spectrometer (AVIRISng). AVIRISng will exceed the spectral, radiometric and spatial measurement capabilities of AVIRIS-classic and support existing and new terrestrial ecology science. We present the science measurement characteristics of AVIRISng and development status. [1][2]

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1. INTRODUCTION TO IMAGING SPECTROSCOPY

Imaging spectroscopy (also known as hyperspectral imaging) is a field of scientific investigation based upon the measurement and analysis of spectra received as images. Imaging spectrometer instruments measure and record many (typically hundreds) of colors or spectral channels quantitatively for each spatial element in an image. The measured spectra provide the basis for understanding the environment from a remote perspective based in the physics, chemistry and biology revealed by the spectral signatures. See Figure 1 for a set of measured reflectance spectrums corresponding to relevant chemical and biological processes in this spectrum. Approaches other than imaging spectroscopy are unable to provide continuous sampling of the spectrum. For instance, see Figure 2 for a depiction of multi-spectral imaging data for the range from 400nm to 2500nm. It can be readily seen that these discrete measurements are insufficient for determining the chemical and biological processes at work.

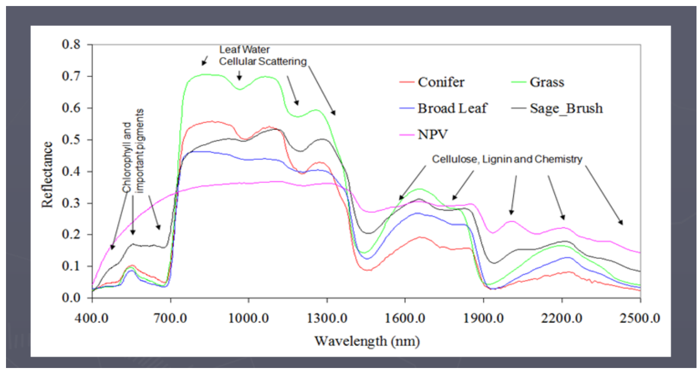

Figure 1 - A limited set of rock forming minerals and vegetation reflectance spectral measured from 400 to 2500 nm in the solar reflected light spectrum. NPV corresponds to non-photosynthetic vegetation. A wide diversity of composition absorption and scattering signatures in nature are illustrated by these materials.

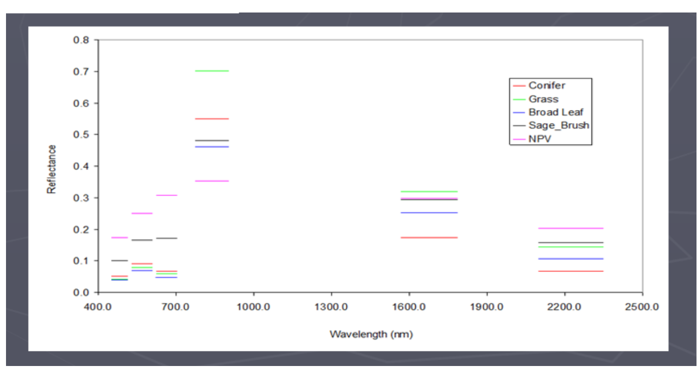

Figure 2 - A depiction of multi-spectral imaging capability across the spectrum from 400 to 2500nm. It

[1] 978-1-4244-7351-9/11/$26.00 ©2011 IEEE.
[2] IEEEAC paper #1112, Version 1, Updated October 26, 2010

can be seen that these discrete measurements are insufficient for de-convolving relevant chemical and biological species.

2. THE AVIRIS INSTRUMENT

Designed at the NASA Jet Propulsion Laboratory as a successor to the Airborne Imaging Spectrometer (AIS) technology demonstrator, the Airborne Visible / Infrared Imaging Spectrometer (AVIRIS) instrument has been in operation since 1989. AVIRIS was designed to measure the complete solar reflected spectrum from 400 to 2500 nm and capture a significant spatial image domain. Several upgrades over time have kept AVIRIS the premier civilian imaging spectrometer in use. Customers work with the NASA Terrestrial Ecology Program Office to schedule flight time with AVIRIS. See Figure 3 for a view of the AVIRIS instrument in the Lab at JPL.

Figure 3 - AVIRIS in the lab at JPL.

AVIRIS measures the total upwelling spectral radiance in the spectral range from 380 to 2510 nm at approximately 10 nm sampling intervals and spectral response function (See Figure 4). These continuous and overlapping spectral channels allow spectral forms to be seen in their entirety across visible and near-IR.

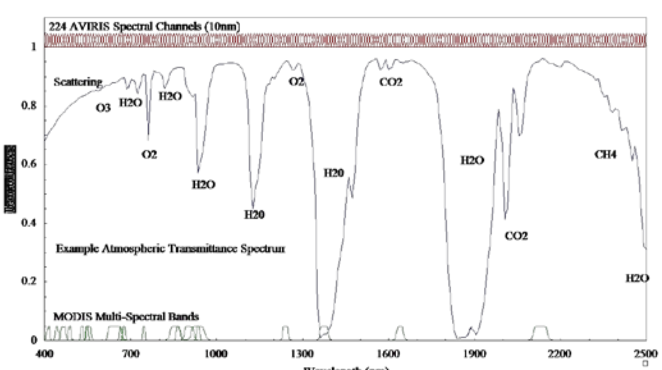

Figure 4 - AVIRIS's 224 channels provide continuous sampling in 10nm bands across the entire spectrum from 400nm to 2500nm.

AVIRIS data is delivered in an image cube format, visible in Figure 5 below. High precision calibration is provided by annual calibration flights over well-characterized sites as well as pre- and post-flight calibrations on each day of operations.

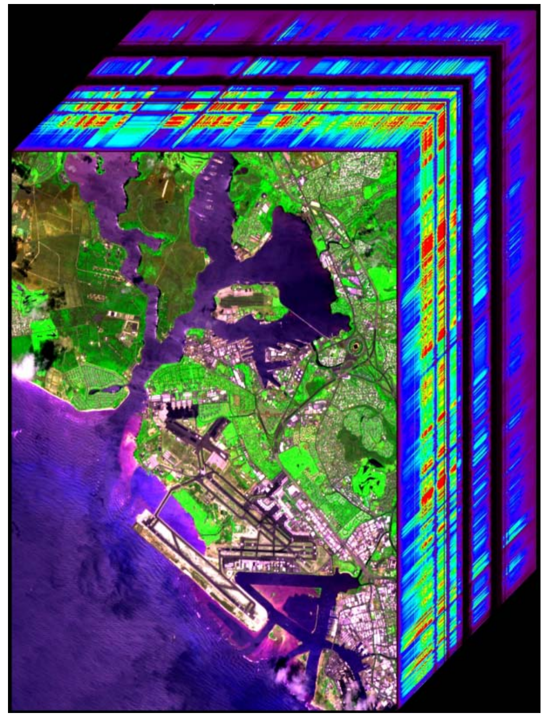

Figure 5 - Example AVIRIS data cube, Pearl Harbor, Hawaii.

Key characteristics of the AVIRIS design include 200 µm detectors and F/1 optics. Other features are listed ijn Table 1 below:

Table 1 - AVIRIS Key Measurement Characteristics

Spectral		
	Range	370 to 2500 nm
	Sampling	9.8 nm
	Accuracy	0.5 nm
Radiometric		
	Range	O to Max La,bertian
	Sampling	12 bits
	Accuracy	96 percent
Spatial (ER-2 / Twin Otter aircraft)		
	Swath	11/2.2 km ER-2/TO
	Sampling	20/4 m ER-2/TO
	Accuracy	20/4 m ER-2/TO
Full INU/GPS geo rectification		

The science enabled by this high uniformity and high signal-to-noise ratio imaging spectrometer is well established over the past two decades. To date, AVIRIS data has been referred to in > 600 journal articles in the refereed literature. A broad array of applications regularly utilize AVIRIS data including: mineral mapping, land use trends, inland / coastal waters, environmental hazards / cleanups, disaster responses. See Figures 6, 7, 8, 9 for depictions of relevant data.

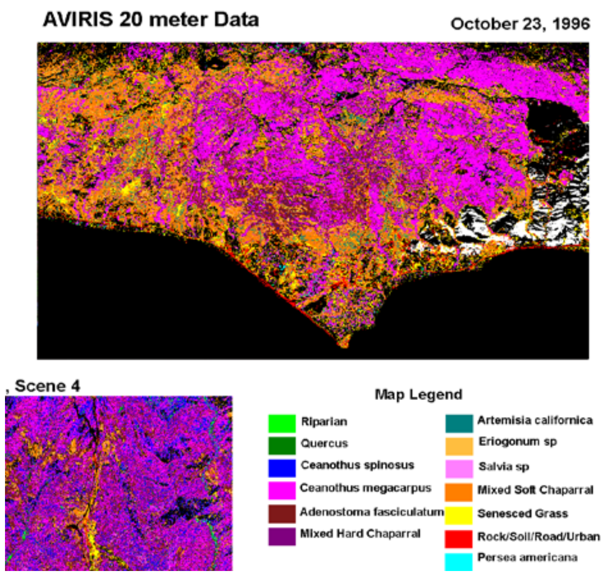

Figure 6 - Data taken in the Santa Monica Mountains to assess wild fire risk [4]

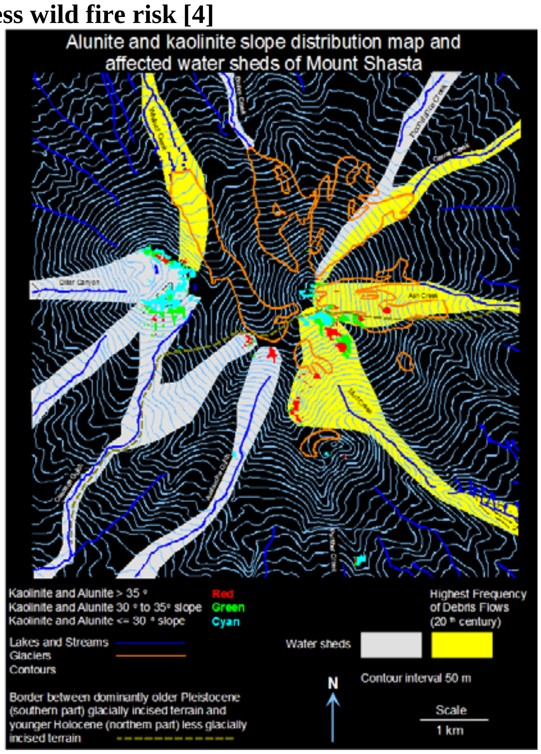

Figure 7 - Data taken to assess volcano debris flow hazard from Mount Shasta in California [3].

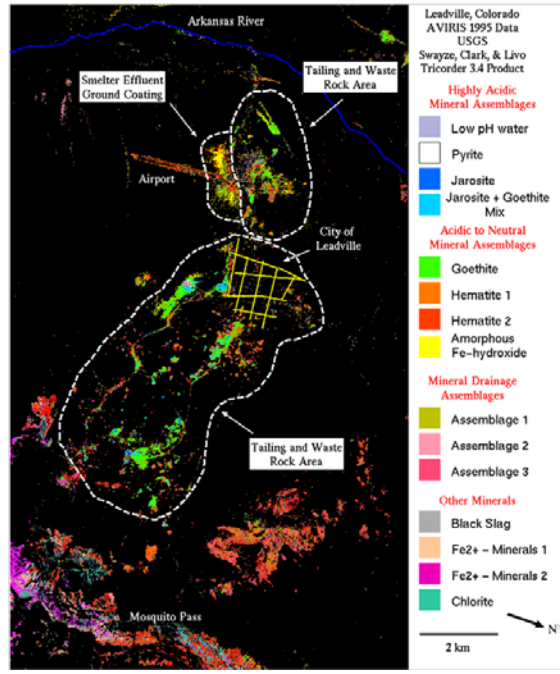

Figure 8 - Data taken to assess and speed remediation of acid and heavy metal hazards in Leadville, CO.

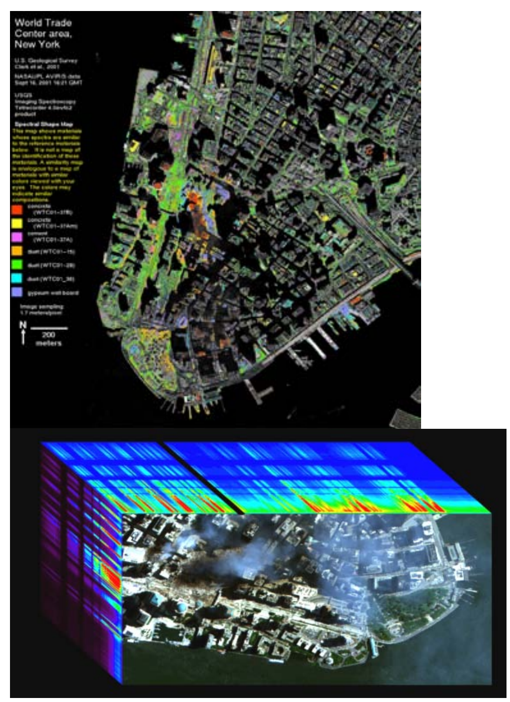

Figure 9 - Data taken to support operations at the World Trade Center disaster site, September 16, 2001.

To date, AVIRIS has made more than 200 flights on four aircraft platforms: NASA's ER-2 jet, the Twin Otter turboprop, Scaled Composites Proteus and NASA's WB-57 (See Figure 10). Missions have been flown across the US, Canada and Europe.

Figure 10 - Aircraft platforms for AVIRIS have included the Twin Otter turboprop, NASA ER-2 jet.

In May 2010, AVIRIS was deployed to the Gulf of Louisiana to play a key role in the oil spill response there. At the time this paper is being written, AVIRIS had 20 days of flight data as part of this campaign with more data lines collected than in a usual year. Improvements in the data pipeline and delivery processes are allowing data delivery to decision makers on the ground in 6 hours, expedited from the usual delivery time of several weeks. AVIRIS data is playing a key role in the mass balance estimate of the amount of oil released by the well. Initial estimates from the AVIRIS data suggest that an equivalent of between 12,000 and 19,000 barrels a day of oil are being released.

3. Design of a Next Generation Imaging Spectrometer

From the Operational experience with the AVIRIS instrument, the JPL team has gained significant confidence in the science and technology of imaging spectroscopy. Specifically, we understand the key measurement characteristics that are needed and we have developed the right set of requirements flowing from the science. All of this experience has guided the movement towards a next generation instrument.

In 2007, the JPL team began to conceptualize the next generation of airborne AVIRIS-like sensors based on input from the research community and potential partners. Internally funded efforts at JPL created progress in the system concepts for such a new sensor.

The Next Generation Imaging Spectrometer (NGIS) design is one outcome of that work. Build of the first NGIS instrument is now underway as an Earth Science Technology Office (ESTO)-funded task. The instrument team has finalized requirements and design work and completed a design review in November 2009. Build of the component parts is now underway and integration of the instrument is scheduled to start July 1, 2010. The target completion date for the completed instrument is July 15, 2011.

The NGIS Instrument is being designed to be compatible with a broad array of possible aircraft platforms. Initial flights will take place in a Twin Otter.

Major components of the flight package (see Figure 11) include the sensor itself, which will be encased in a vacuum enclosure, high precision INS/GPS, focal plane electronics, On-Board Calibrator (OBC) electronics boxes, heaters boxes, and a vibration isolating aircraft mount. Accommodation has been made for companion instruments which may be flown in a co-boresighted configuration at the discretion of the project scientist, but are not part of this development. Companion instruments of value may include an optical camera or LIDAR.

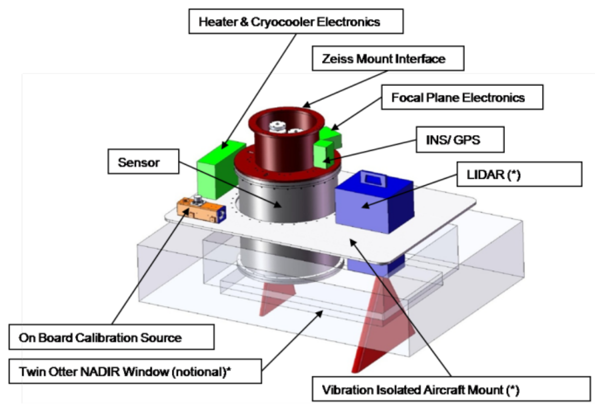

Figure 11 - Major components of the NGIS flight package and optional companion instruments.

The flight package is designed to be easily installed and operated aboard a variety of aircraft platforms. In addition to the sensor and other parts mounted to the aircraft mount, the package includes one electronics rack, mountable to the seat rails and one operator station. Instrument software is designed for autonomous operation including cooldown, data acquisition (once started by operator command) and fault handling. The operator is provided with a simplified view of the data stream to ensure data quality and engineering “health and safety” telemetry.

The sensor itself is approximately 33” tall by 20” in diameter. Major components include the optical telescope and spectrometer benches, the detector, the source for the On Board Calibrator (OBC) and kinematic struts which suspend the assembly from the instrument backplate. The sensor is housed with a vacuum container and three thermal shields and operated at temperatures of down to -40C at the detector. Maintenance of stable temperature across the instrument is vital to minimizing thermal distortions which could affect optical alignment. Operational temperature is maintained by operation of two cyrocoolers. This change to active cooling from the passive cryogen approach used for AVIRIS allows operation for up to 14 days at a time with only minimal maintenance of vacuum. See Figure 12 for a CAD model of the instrument and Table 2 for Key Performance Characteristics.

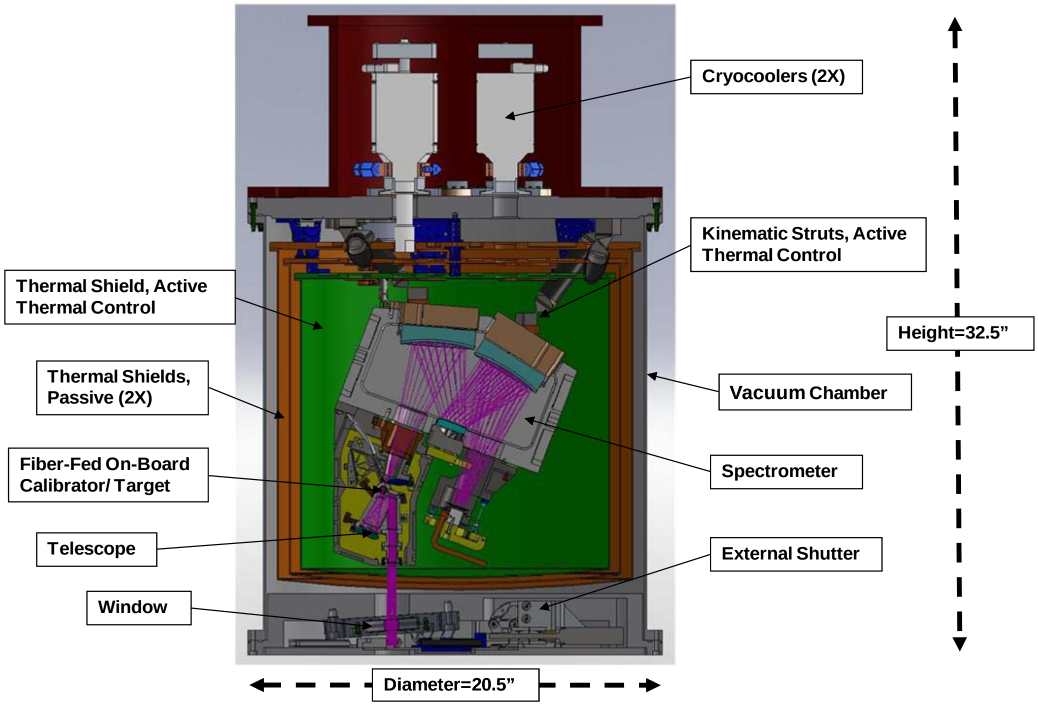

Figure 12 - Major components of the NGIS Instrument

Table 2 - NGIS Key Performance Characteristics

Optical		
	Wavelength Operational Range	380 to 2510 nm
	Spectral Resolution (FWHM, minimum)	5 nm +/- 0.5nm
	Field of View	36 +/- 2 degrees with 600 resolved elements (large enough FOV to encompass LIDAR (4 spots)
	Instantaneous Field of View	1.0 – 1.5 mradians +/- 0.1 mrad
	Spatial Sampling (maximum observed at resolved elements)	1.0 mrad +/- 0.1 mrad
	Spectral Distortion (smile)	uniformity > 97%
	Spatial Distortion (keystone)	uniformity > 97%
Operations & Environment		
	Operational Real Time Display	Waterfall display allows data quality check
	Self-Sufficiency	Safe operation for 24 hours without maintainance or data download
	Ambient Operating Temperature	-40 to +50C
	Maximum Altitude	18,000 m
	Cool down time	<48 hours
	Operational time / mission	14 days

Electronics		
	FPA	480 (spectral direction) x 640 (cross track)
	Frame Rate	10 – 100 frames per sec
	Pixel size	27 micron x 27 micron
	Calibration	On-Board Calibrator
Software		
	Headless Operation	Autonomous Fault Protection responds to health and safety problems
	Data Rate	up to 74 MB/s of throughput
	Data Volume	up to 1.0 Tb of raw data before disk swap
Mechanical		
	Volume of package	83 cm (H) x 57 cm (diameter) plus electronics boxes and racks
	Mass	465 kg
	Vacuum Requirement	10-4 torr
	Data Resolution	Reported as 14 bit
	Vibrational Environment	Maintain instrument calibration and operations when subjected to worst-case aircraft random vibrational loads (defined for Twin Otter)
	Crash Loads	Maintain structural integrity when subjected to 18g forward, 3 g up, 4.5 g side

4. CONCLUSIONS

The AVIRIS instrument is important to data collection across a broad swath of scientific applications, most notably mineralogy and terrestrial ecology investigations.

A team at JPL is currently engaged in building the Next Generation Airborne Visible/Infrared Imaging Spectrometer (AVIRISng). AVIRISng will exceed the spectral, radiometric and spatial measurement capabilities of AVIRIS-classic and support existing and new terrestrial ecology science.

5. ACKNOWLEDGEMENTS

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BIOGRAPHY

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