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AIRBORNE VISIBLE/INFRARED IMAGING SPECTROMETER (AVIRIS): RECENT IMPROVEMENTS TO THE SENSOR

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1.0 INTRODUCTION

AVIRIS is a NASA-sponsored Earth-looking imaging spectrometer designed, built and operated by the Jet Propulsion Laboratory. Spectral, radiometric and geometric characteristics of the data acquired by AVIRIS are given in Table 1. AVIRIS has been operational since 1989, however in each year since 1989 major improvements have been completed in most of the subsystems of the sensor. As a consequence of these efforts, the capabilities of AVIRIS to acquire and deliver calibrated imaging spectrometer data of high quality have improved significantly over those in 1989. Improvements to AVIRIS prior to 1992 have been described previously (Porter et al., 1990, Chrien et al., 1991, Chrien et al., 1992). In the following sections of this paper we describe recent and planned improvements to AVIRIS in the sensor task.

2.0 SENSOR IMPROVEMENTS

2.1 1992 Engineering and Maintenance Cycle

A planned replacement of the 1985 vintage high density tape recorder (HDTR) was undertaken during this maintenance cycle. Following environmental testing a thermal control system was integrated into the new HDTR to allow operations at the ER-2 aircraft Q-bay temperatures. Incorporation of this recorder into the AVIRIS sensor expanded the data capacity from 6 to 10 gigabytes or from 600 to 1000 linear kilometers of airborne data acquisition per flight. This new recorder also provided an order of magnitude reduction in the per unit cost of recording media. A spare recorder was acquired to allow timely recovery upon HDTR malfunction.

To improve the signal-to-noise performance of AVIRIS, efforts were made to reduce the noise contribution of the pre-amplifier circuitry in each of the AVIRIS spectrometers. This activity resulted in a reduction in noise from approximately 1.8 to 1.1 digitized numbers. Fixed pattern noise was reduced in AVIRIS through increased shielding of the timing and signal chain cables.

To provide improved AVIRIS absolute radiometric calibration, several modifications were made to the onboard calibrator subsystem. Based on failures in 1991, the AVIRIS onboard calibrator bulb was replaced in 1992 with a bulb of longer life and improved stability. An improved color balancing filter was added to provide a more uniform signal across the four AVIRIS spectrometers. Data from the onboard calibrator are recorded with each AVIRIS flight line and provided with all AVIRIS data distributed to investigators.

During the 1992 maintenance cycle a number of the transmissive elements in the AVIRIS sensor were modified. Spectrometer spherical mirrors were recoated to repair accumulated corrosion damage. Anti-reflection coatings were added to the hatch window, the foreoptics window and the foreoptics termination of the fiber harness. These coatings provided incremental improvements in AVIRIS throughput. At this time, the foreoptics window was tilted to minimize the effects of unwanted internal reflections.

Prior to fiber harness installation in 1992, a failure was noted in the primary fiber connecting the C spectrometer to the foreoptics. The spare infrared fiber previously integrated into the fiber harness was installed. Use of the spare fiber introduced an integer shift of three spatial samples in the C spectrometer data. This shift was compensated in the calibrated AVIRIS data prior to distribution to the investigator. The spare infrared fiber performed nominally throughout the seven month flight season.

Following these modifications to the sensor a calibration experiment was held to characterize and validate the performance of AVIRIS. This inflight calibration experiment was held on the 30th of May 1992 at Rogers Dry Lake, California. Surface and atmosphere measurements were acquired at the time of the AVIRIS overflight. The MODTRAN2 (Berk et al., 1989) radiative transfer code was constrained by these in situ measurements to predict the radiance arriving at the AVIRIS aperture. Agreement between the AVIRIS-measured and MODTRAN2-predicted radiance was better than 7 percent. This close agreement demonstrates that AVIRIS performed as expected based on the sensor improvements achieved in this engineering period.

2.2 1993 Engineering and Maintenance Cycle

Optical elements in the AVIRIS sensor were modified and improved during this time period. A set of new fiber harnesses were procured and one of them installed in AVIRIS. The new fiber material was manufactured to have improved strength and resistance to humidity degradation. Problems with both breakage and humidity damage have been encountered with the previous 1986 vintage fiber material. Improvements were made to the spectrometer fiber optic connector to improve repeatability and stability of spectral alignment. The bi-conic surface in the fiber optic connector was found to be critical to the alignment stability of the spectrometers. A poorly machined connector was shown to account for the change in the spectral calibration of the B spectrometer during the 1992 flight season and has since been replaced.

To further improve energy throughput, new spectral order blocking filters were installed in the AVIRIS spectrometers. These filters provided both higher throughput in the band pass and improved blocking of unwanted energy. The improvement in spectrometer B ranges between 20 and 50 percent. In the C spectrometer a 5 to 30 percent increase in throughput was achieved. Better long wavelength energy blocking was achieved in spectrometer D. Reduction in this background energy decreased the noise in the D spectrometer by as much as 30 percent.

During calibration and characterization of AVIRIS in 1993, a nonlinearity in response was discovered for extremely bright targets. The problem was traced to a set of clamping diodes in the pre-amplifiers that are required to compensate for multiplexer switching transients. These diodes have been adjusted to effectively eliminate the nonlinear effects for the imaging of all terrestrial surfaces.

An additional improvement to the onboard calibrator was implemented in this period. In the past, the onboard calibrator signal was reflected into the optical system from one of two sides of a shutter. The side of the shutter measured was an unpredictable function of the flight line acquisition timing. A 3% difference in the reflectance of the two sides of the shutter was measured in 1992. A change was implemented in 1993 to measure both sides of the shutter at the beginning and end of each flight line. This eliminates any ambiguity in the measured onboard calibrator signal.

During this engineering cycle, a new automated spectral calibration capability was implemented for AVIRIS. This allows direct measurement of the spectral response function of each of the 224 AVIRIS channels. During previous years, typically 10 channels of each spectrometer were manually calibrated and the remainder calibrated through interpolation. With this new automated system, a complete set of spectral calibration data is acquired in about 8 hours.

The current inflight determined performance of AVIRIS is discussed in a companion paper (Green et al., 1993).

2.3 Future Engineering and Maintenance Plans

In order to improve reliability and improve AVIRIS performance, a new set of focal planes are planned to be integrated into AVIRIS prior to the 1995 flight season. These focal planes will be based on current detector and multiplexor technology. Improved reliability is expected as well as a significant decrease in focal plane noise with respect to the current 1986 technology focal planes. As a consequence of the decreased noise anticipated in the new focal planes, the AVIRIS digitization will be increased from 10 to 12 bits to fully encode this improved precision.

Improvements are planned for the onboard calibrator including the introduction of an inflight spectral reference that will be used to fully monitor the inflight spectral calibration of AVIRIS. Direct viewing of the downwelling solar irradiance by the AVIRIS spectrometers is also being considered as an additional inflight calibration source. Higher frequency updates of the navigation data via a direct link to the aircraft inertial navigation system and ground positioning system are also being explored.

3.0 CONCLUSION

Since AVIRIS first became operational in 1989 the AVIRIS system has been undergoing incremental improvements. A number of these improvements have occurred in the sensor component of AVIRIS project. In all cases, the driver for these modifications and upgrades has been the quality of data provided to the science investigators. The important modifications in 1992 and 1993 have been described.

Plans are to continue to improve AVIRIS performance in the future. For the AVIRIS sensor, significant improvements may be achieved in the focal planes, onboard calibrator and platform pointing and position telemetry. By pursuing these improvements and upgrades, AVIRIS will continue to have an important role in providing calibrated imaging spectrometer data to researchers across the earth science disciplines.

4.0 ACKNOWLEDGMENTS

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6.0 TABLES

Table 1. AVIRIS Data Characteristics

SPECTRAL	Wavelength range	400 to 2500 nm
	Sampling	<= 10 nm
	Spectral response (fwhm)	10 nm nominal
	Calibration	<= 1 nm
RADIOMETRIC	Radiometric range	0 to maximum lambertian
	Sampling	~ 1 dn noise rms
	Absolute calibration	<= 7 %
	Intraflight calibration	<= 2 %
	Precision/noise	exceeding NEdL/SNR requirement
GEOMETRIC	Field of view (FOV)	30 degrees (11 km)
	Instantaneous FOV	1.0 mrad (20 m)
	Calibration	<= 0.2 mrad
	Flight line length	Up to ten 100 km flight lines

Table 2. AVIRIS Operational Characteristics

SENSOR	Imager type	Whiskbroom scanner
	Cross track samples	614 elements
	Scan rate	12 scans/second
	Dispersion	Four grating spectrometers (A,B,C,D)
	Detectors	224 detectors (32,64,64,64) Si & InSb
	Digitization	10 bits (planned 12 bits in 1994)
	Data rate	17 mbits/second
	Spectrum rate	7300 spectra/second
	Data capacity	>10 gigabytes (>10,000 km^2)
	Onboard calibration	Radiometric and spectral
	Position & pointing	X, Y, Z and roll, pitch, yaw
	Launches	~30 per year
DATA FACILITY	Performance monitoring	48 hours from acquisition
	Archiving	One week from acquisition
	Quick-look distribution	One week from acquisition
	Calibration	Two weeks from request
	Quality monitoring	Prior to distribution
	Distribution	Two weeks from request
	Engineering analysis	High priority as required

Table 3. AVIRIS Data Acquisitions	1991	1992	1993–projected
Months of operations	7	8	7
Aircraft bases	5	4	4
Principal investigators supported	52 (Europe)	32	35
Investigator sites flown	137	172	200
Launches	36	34	35
Inflight calibration experiments	3	3	3
Square kilometers flown	115,000	127,300	140,000
Flight scenes	1150	1273	1400
Gigabytes archived	161	178	196
Data scenes calibrated/distributed	498	847	1000
Approximate data turnaround (months)	5	2.5	1